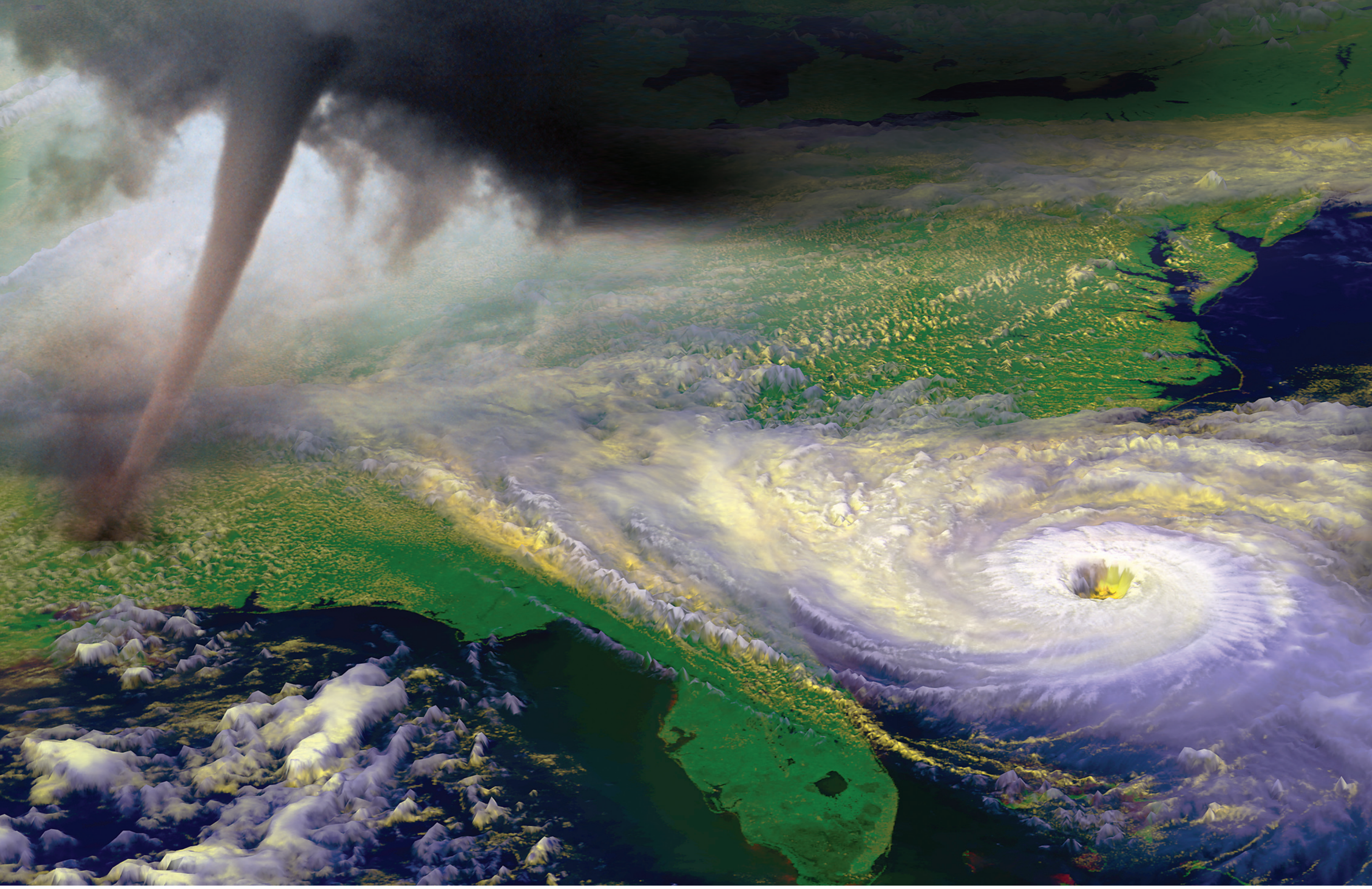


Design and Construction Guidance for Community Safe Rooms

FEMA 361, Second Edition / August 2008

FEMA

3 Design Criteria for Tornado and Hurricane Safe Rooms

This chapter provides the design and performance criteria for the structural systems and envelope systems (including openings and protection systems for openings and windows) for tornado and hurricane safe rooms. The performance criteria includes detailed guidance on debris impact-resistance criteria. Other engineering factors and concepts involved in the design of a safe room are also identified in this chapter, but will be discussed in detail in later chapters. This chapter presents the information in the following order (and each section provides cross-references as to which criteria are the same or different from the criteria presented in the ICC-500 Storm Shelter Standard):

- General approach to the design of safe rooms.
- Load combinations.
- Tornado community safe room wind design and debris impact performance criteria (including the Tornado Safe Room Design Wind Speed Map).
- Hurricane community safe room wind design and debris impact performance criteria (including the Hurricane Safe Room Design Wind Speed Map).
- Residential safe room wind design and debris impact performance criteria.
- Guidance on flood hazard design criteria.
- Guidance on product testing, permitting, code compliance, professional design oversight, peer review, construction documents, signage, labeling, and quality assurance/quality control, and special inspections issues are addressed at the end of the chapter.

3.1 General Approach to the Design of Safe Rooms

The design criteria presented in this chapter are based on the best information available at the time this manual was published and rely heavily on the ICC-500 Storm Shelter Standard. However, FEMA has identified a few design and performance criteria that are consistent with the previous FEMA guidance on safe room design and construction that remain more restrictive than some of the requirements found in the ICC-500. Chapters 5 to 9 of this publication provide a detailed commentary on these criteria and are intended to provide supplemental guidance to the design professional for the safe room criteria set forth in this chapter. The key differences affecting design of the FEMA safe room and the ICC shelter, by hazard and classification, are as follows:

- Tornado community safe rooms per FEMA 361 (see Sections 3.3.1, 3.3.2, and 3.6.1):
  - Should be designed for all cases as partially enclosed buildings, for Exposure C
  - Should be sited out of specific flood hazard areas and designed to the flood design criteria of this chapter
  - Should have life-safety protection elements of the design peer reviewed when safe room occupancy is 50 persons or more
- Hurricane community safe rooms per FEMA 361 (see Sections 3.4.1, 3.4.2, and 3.6.1):
  - Should be designed using Exposure C (may not use Exposure B as with ICC-500)
  - Should be designed as partially enclosed buildings (to account for uncontrolled openings of doors and windows)
  - Should be designed to resist the 9-lb 2x4 wood board missile traveling horizontally at 0.5 x hurricane safe room design wind speed (may not use 0.4 x hurricane safe room design wind speed)
  - Should be sited out of specific flood hazard areas and designed to the flood design criteria of this chapter
  - Should have life-safety protection elements of the design peer reviewed when safe room occupancy is 50 persons or more
- Residential safe rooms per FEMA 361/320 (see Sections 3.5.1, 3.5.2, and 3.6.2):
  - Should be designed using 250 mph as the safe room design wind speed
  - Should be designed to resist the 15-lb 2x4 wood board missile traveling horizontally at 100 mph and vertically at 67 mph
  - Should be sited out of specific flood hazard areas and designed to the flood design criteria of this chapter

The design of a safe room to resist wind loads relies on the approach to wind load determination taken in ASCE 7-05, Chapter 6, Section 6.5, Method 2 – Analytical Procedure. The International Building Code (IBC) 2006 and International Residential Code (IRC) 2006 also reference ASCE 7-05 for determining wind loads. For consistency, the designer may wish to use ASCE 7-05 to determine other loads such as dead, live, seismic, flood, and snow loads that may act on the safe room. Note: The ICC-500 provides rain and

ICC-500 CROSS-REFERENCE

As part of the ICC-500, rain and roof live loads for safe room designs are different and higher than as prescribed by ASCE 7-05 and the IBC and IRC.

roof live loads for safe room design that are above the requirements of ASCE 7-05 and the IBC. Wind loads should be combined with the gravity loads and the code-prescribed loads acting on the safe room in load combinations presented in Sections 3.2.1 and 3.2.2. When wind loads are considered in the design of a building, lateral and uplift loads must be properly applied to the building elements along with all other loads.

The FEMA safe room design and construction criteria are presented in this chapter without detailed discussion or guidance. The remaining chapters of this publication provide both discussion and guidance on the design and construction criteria presented in this chapter. These criteria are based on codes and standards available for adoption by any jurisdiction. Specifically, the criteria are based on the ICC-500, ASCE 7-05 and ACSE 24-05, and the 2006 IBC and IRC unless otherwise noted. For design and construction criteria not provided in this publication, or in the ICC-500, the 2006 IBC and IRC (as appropriate) should be used to determine the required criteria to complete the safe room. Should a designer, builder, or manager have any questions regarding design criteria presented in this standard, the following approach should be taken:

1. When questions arise pertaining to the difference between FEMA 361 criteria and another code or standard (such as the ICC-500), the criteria in FEMA 361 should govern. If not, the safe room cannot be considered to be a FEMA safe room.
2. When questions arise pertaining to design and construction criteria not presented in FEMA 361, but provided in the ICC-500, the criteria of the ICC-500 should be used.
3. Where the purpose of a safe room is to provide life-safety protection from both tornadoes and hurricanes, the entire safe room should be designed and constructed using the most restrictive of the two sets of criteria.
4. When a questions arise pertaining to a criteria or requirements not addressed by this publication or the ICC-500, the 2006 IBC and 2006 IRC (with references to ASCE 7-05 and ASCE 24-05) should be used to provide the necessary design and construction criteria. When these codes or standards provide conflicting criteria, the most conservative criteria should apply.

3.2 Load Combinations

Model building codes and engineering standards are the best available guidance for identifying the basic load combinations that should be used to design buildings. The design professional should determine the loads acting on the safe room using the load combinations and conditions for normal building use as defined in the building code in effect or as presented in Section 2 of ASCE 7-05.

The designer should then calculate the ultimate-wind loads that will act on the safe room using the design coefficients and criteria from this chapter and in the design method from Section 6.5 of ASCE 7-05. For an extreme ("ultimate") wind load (W_x) for a tornado, hurricane, or combined hazard, the designer should use the design parameters presented later in this chapter. However, it is important to remember that the safe room design wind speed selected from this guidance manual is for an extreme-wind event and the load combinations from ASCE 7-05 are based on design level wind events (with velocity, V). Therefore, the wind coefficients in the load combinations from ASCE 7-05 for design level wind events should be modified for the ultimate wind load. The load combinations provided in Sections 3.2.1 and 3.2.2 are for Strength Design (also termed Load and Resistance Factor Design [LRFD]) and Allowable Stress Design (ASD), respectively. These load combinations are the load combinations from ASCE 7-05 for the design level event, except where bolded. The bolded load combinations have been revised to appropriately account for the use of ultimate wind load (W_x) in safe room design that must be calculated using the wind design parameters specified in Sections 3.3.1, 3.4.1, and 3.5.1. The revisions are based on the guidance given in the Commentary of ASCE 7-05 for extreme-wind events and, as such, incorporate different load multipliers (specifically the wind load, W_x) from those used in either the model codes or ASCE 7-05 (Section 2). These load combinations should be used for the safe room design and construction.

Flood hazard design criteria for safe room design are provided in Section 3.6. Note that these criteria define where a safe room may be placed and how to design a safe room if portions of the structure are subject to flood loads. It is possible, and preferred, that there may be no flood loads to consider because a safe room has been sited outside areas subject to flooding.

The load combinations presented in Sections 3.2.1 and 3.2.2 for Strength Design and Allowable Stress Design, respectively, are the same as those presented in the ICC-500. They have been peer reviewed by the Project Team and the Review Committee. It is important to note that these load combinations are different from those presented in the first edition of FEMA 361.

3.2.1 Load Combinations Using Strength Design

For the design of a safe room using Strength Design Methods, the designer should use the load combinations of Section 2.3.2 of ASCE 7-05 to ensure that a complete set of load cases is considered. For the main wind force resisting system (MWFRS), components and cladding (C&C), and foundations of safe rooms designed for extreme- (ultimate-) wind loads, designers should also consider the following load cases (using W_x) so that the design strength equals or exceeds the effects of the factored loads in the following combinations (LRFD):

a) In load combination 3, replace 0.8W with $0.5W_x$.

b) In load combinations 4 and 6, replace 1.6W with $1.0W_x$.

c) Exception 1 from ASCE 7-05, Section 2.3.2 should not apply.

Implementing these modifications of the Strength Design Load Cases from ASCE 7-05 results in the following cases to be used for ultimate wind loads in FEMA 361 (see ASCE 7-05 for definitions of all terms, but note that W_x = ultimate wind load is based on wind speed selected from the appropriate safe room design wind speed map in Sections 3.3 or 3.4):

Load Combination 1: 1.4(D + F)

Load Combination 2: 1.2(D + F + T) + 1.6(L + H) + 0.5(L_r or S or R)

Load Combination 3: 1.2D + 1.6(L_r or S or R) + (L or **0.5 W_x**)

Load Combination 4: 1.2D + **1.0W_x** + L + 0.5(L_r or S or R)

Load Combination 5: 1.2D + 1.0E + L + 0.2S

Load Combination 6: 0.9D + **1.0W_x** + 1.6H

Load Combination 7: 0.9D + 1.0E + 1.6H

Exceptions:

1. N.A.
2. The load factor on H shall be set equal to zero in load combinations 6 and 7 if the structural action due to H counteracts that due to W or E.
3. In combinations 2, 4, and 5, the combination load S shall be taken as either the flat roof snow load or the sloped roof snow load.

The designer should also consider the appropriate seismic load combinations from Section 2.3.2 of ASCE 7-05. Where appropriate, the most unfavorable effects from both wind and seismic loads should be investigated. Wind and seismic loads should not be considered to act simultaneously (refer to Section 9.2 of ASCE 7-05 for the specific definition of earthquake load, E). From the load cases of Section 2.3.2 of ASCE 7-05 and the load cases listed above, the combination that produces the most unfavorable effect in the building, safe room, building component, or foundation should be used.

NOTE

When a safe room is located in a flood zone, the following load combinations in Section 3.2.1 should be considered:

- In V zones and coastal A zones, the 1.0W_x in combinations 4 and 6 should be replaced by 1.0W_x + 2.0F_a.
- In non-coastal A zones, the W_x in combinations 4 and 6 should be replaced by 1.0W_x + 1.0F_a.

3.2.2 Load Combinations Using Allowable Stress Design

For the design of a safe room using Allowable Stress Design Methods, the designer should use the load combinations of Section 2.4.1 of ASCE 7-05 to ensure that a complete set of load cases is considered. For the MWFRS, C&C, and foundations of extreme-wind safe rooms, designers should also consider the following load cases (using W_x) so that the design strength equals or exceeds the effects of the factored loads in the following ASD load combinations:

a) In load combinations 5, 6, and 7, replace W with 0.6W_x.

Implementing these modifications of the Allowable Stress Design Load Cases from ASCE 7-05 results in the following cases to be used for ultimate wind loads in FEMA 361 (see ASCE 7-05 for definitions of all terms, but that W_x = ultimate wind load is based on wind speed selected from the appropriate safe room design wind speed map in Sections 3.3 or 3.4):

Load Combination 1: $D + F$

Load Combination 2: $D + H + F + L + \mathrm{T}$

Load Combination 3: $D + H + F + (L_r \text{ or } S \text{ or } R)$

Load Combination 4: $D + H + F + 0.75(L + T) + 0.75(L_r \text{ or } S \text{ or } R)$

Load Combination 5: $D + H + F + (\mathbf{0.6W_x} \text{ or } 0.7E)$

Load Combination 6: $D + H + F + 0.75(\mathbf{0.6W_x} \text{ or } 0.7E) + 0.75L + 0.75(L_r \text{ or } S \text{ or } R)$

Load Combination 7: $0.6D + \mathbf{0.6Wx} + H$

Load Combination 8: $0.6D + 0.7E + H$

The designer should also consider the appropriate seismic load combinations from Section 2.4.1 of ASCE 7-05. Where appropriate, the most unfavorable effects from both wind and seismic loads should be investigated. Wind and seismic loads should not be considered to act simultaneously (refer to Section 9.2 of ASCE 7-05 for the specific definition of earthquake load, E). From the load cases of Section 2.4.1 of ASCE 7-05 and the load cases listed above, the combination that produces the most unfavorable effect in the building, safe room, building component, or foundation should be used.

NOTE

When a safe room is located in a flood zone, the following load combinations in Section 3.2.2 should be considered:

- In V zones and coastal A zones, $1.5F_a$ should be added to load combinations 5, 6, and 7.
- In non-coastal A zones, $0.75F_a$ should be added to load combinations 5, 6, and 7.

3.2.3 Other Loads and Load Combination Considerations

The ICC-500 provides specific guidance on loads in addition to wind loads. The rain (R) and roof live load (L_r) guidance provided in the ICC-500 applies to the design and construction of safe rooms.

Concrete and masonry design guidance is provided by the American Concrete Institute International (ACI), American Society of Civil Engineers (ASCE), and The Masonry Society (TMS). *Building Code Requirements for Structural Concrete* (ACI 318-08) and *Building Code Requirements and Specifications for Masonry Structures* (ACI 530-08/ASCE 5-08/TMS 402-08, and ACI 530.1-08/ASCE 6-08/TMS 602-08) are the most recent versions of the concrete and masonry design codes. The load combinations for these codes may differ from the load combinations in ASCE 7-05, the IBC, and other model building codes.

When designing a safe room using concrete or masonry, the designer should use load combinations specified in the concrete or masonry codes, except when the safe room design wind speed is taken from Sections 3.3, 3.4, or 3.5 of this manual. For the safe room design wind speed, the ultimate wind load (W_x) should be determined from the wind pressures acting on the building, calculated according to ASCE 7-05 and the provisions and assumptions stated in Sections 3.3, 3.4, or 3.5.

3.3 Tornado Community Safe Room Design Criteria

The first step in designing and constructing a safe room is the identification of the hazard. If there is a need for the design and construction of a safe room to protect lives during a tornado or if tornado hazards have been identified, the following design criteria are recommended. The next step in the design process is to identify the appropriate tornado safe room design wind speed from the map presented in Figure 3-1.

In this map, four zones have corresponding safe room design wind speeds of 250 mph, 200 mph, 160 mph, and 130 mph. These wind speeds should be used to determine the wind forces that act on either the structural frame (i.e., the load-bearing elements – MWFRS) of a building to be used as a safe room, the exterior coverings of the safe room (C&C), and openings or opening protectives (such as doors and windows). Additional discussion on the origin and content of this map is provided in Chapter 6 of this publication.

ICC-500 CROSS-REFERENCE

The tornado community safe room design criteria presented in this section of FEMA 361 are the same as the tornado community shelter design criteria presented in the ICC-500 Storm Shelter Standard unless otherwise noted.

3.3.1 Wind Design Parameters for Tornado Community Safe Rooms

As previously mentioned, the wind loads on the safe room should be calculated using the wind load provisions in Section 6.5 of ASCE 7-05, Method 2 – Analytical Procedure (except when modified by this guidance). The design recommendations for tornado safe rooms do not meet the requirements for using Method 1 – Simplified Procedure. In addition, all doors, windows, and openings should be protected with devices that comply with the design wind pressures as calculated by ASCE 7-05. The safe room provides life-safety protection from wind events and therefore should be capable of resisting ultimate wind loads without failure, although some damage may occur and serviceability of the safe room may be an issue after an event.

The coefficients and parameters used in the ASCE 7-05 pressure calculations in the design of a safe room are different from those listed for regular buildings or even essential facilities. This is because detailed wind characteristics in tornadoes are not well understood and the wind event

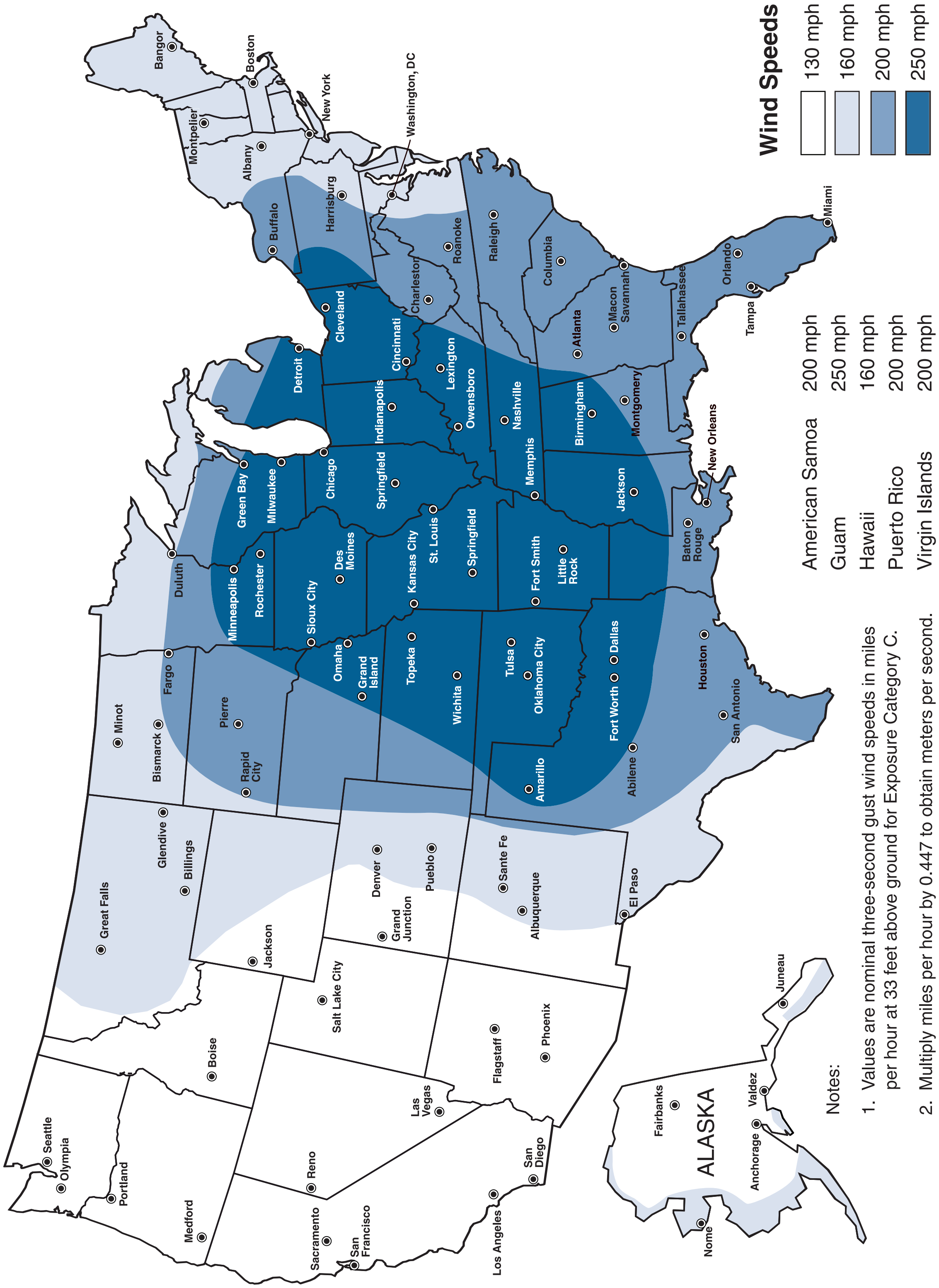


Figure 3-1. Tornado Safe Room Design Wind Speed Map (consistent with ICC-500 Tornado Hazard Map)

should be considered an "ultimate-level" event and not a "design-level" event. After selecting the tornado community safe room design wind speed from Figure 3-1, the following wind design parameters should be used when calculating wind pressures acting on tornado safe rooms:

a) **Select Safe Room Design Wind Speed.** This is the first component of the safe room design process. Select either V_x = 250, 200, 160, 130 mph (3-second gust).

b) **Importance Factor (I)** I = 1.0

c) **Exposure Category** C

d) **Directionality Factor** K_d = 1.0

e) **Topographic Effects** K_{zt} need not exceed 1.0.

f) **Enclosure Classifications.** Enclosure classifications for safe rooms should be determined in accordance with ASCE 7-05, Section 6.2. For determining the enclosure classification for community safe rooms, the largest door or window on a wall that receives positive external pressure should be considered as an opening. As such, the internal pressure coefficient may be appropriate for either an enclosed or partially enclosed building, depending upon the openings in the safe room and whether the atmospheric pressure change (APC) has been calculated or estimated.

g) **Atmospheric Pressure Change.** The potential for APC should be considered in the design of tornado community safe rooms. For tornado community safe rooms, the internal pressure coefficient, GC_{pi}, may be taken as ±0.18 when a venting area of 1 square foot per 1,000 cubic feet of interior safe room volume is provided to account for the effect of APC. The APC venting should consist of openings in the safe room roof having a pitch not greater than 10 degrees from the horizontal or openings divided equally (within 10 percent of one another) on opposite walls. A combination of APC venting meeting the above criteria is permitted (see ICC-500, Section 304.8).

As an alternative to calculating the effects of APC, and designing an appropriate venting system for the safe room, the design may be completed using an internal pressure coefficient of GC_{pi} = ±0.55 as a conservative means to account for the APC.

The design criteria discussed in this chapter pertain to the protection of the safe room space via the structural system, wall and roof assemblies, and doors and windows (and opening protectives). The design of architectural treatments on the exterior of safe room that do not provide protection of occupants within the safe room are not required to meet the design criteria presented in this publication. Should such elements or assemblies be used to improve the aesthetics of the safe room, the loads acting on those elements or assemblies should comply with requirements of the ICC-500 as applicable and, where not addressed by the ICC-500, as identified by model building code in effect or ASCE 7-05. See Chapter 7 for additional information on this topic.

h) **Maximum Safe Room Height.** The height of a safe room is not restricted or limited.

i) **Duration of Protection.** The tornado community safe rooms are designed to provide occupants life-safety protection for storm durations of at least 2 hours.

j) **Ventilation, Sanitation, Power, and Other Non-structural Design Criteria.** Ventilation, sanitation, power, and other recommendations for tornado community safe rooms should be incorporated into the design of the safe room in accordance with ICC-500, Chapter 7. In addition, the safe room should be equipped with an electrical system with an emergency power backup system for lighting and other needs in accordance with ICC-500, Chapter 7. Additional information on these recommendations is also provided in Chapters 4 and 8 of FEMA 361.

k) **Weather Protection.** All exposed components and cladding assemblies and roof coverings of tornado community safe rooms should be designed to resist rainwater penetration during the design windstorm event, and should be designed and installed to meet the wind load requirements as prescribed by ASCE 7-05 for non-safe room wind loads at the site.

l) **Occupancy Classifications for Safe Rooms.** If a safe room is a single-use safe room, the occupancy classification per the IBC should be A-3 for the protected space. If a safe room is a multi-use safe room area, the occupancy classification for the primary use of the protected space (when not in use as a safe room) should be used.

m) **Maximum Allowable Tornado Community Safe Room Population.** From a design and construction standpoint, there is no limitation on the maximum population that a safe room may be designed to protect. However, applicants and sub-applicants who request funding support from FEMA for safe room projects should be aware that limitations do apply to the size of the safe room. Refer to FEMA safe room and benefit-cost analysis tools for guidance and criteria that can be used to define the maximum population. Any group involved in the design and construction of a tornado community safe room should obtain the latest guidance from their FEMA regional office.

n) **Maximum Population Density of a Tornado Community Safe Room.** The minimum recommended safe room floor area per occupant is provided in Table 3-1. The number of standing, seated (wheelchair-bound), or bedridden spaces should be determined based upon the needs of the safe room calculated by the designer and the applicable authority having jurisdiction. However, each community safe room should be sized to accommodate a minimum of one wheelchair space for every 200 occupants. It is also important to note that floor areas within community safe rooms should provide an access route in accordance with ICC/American National Standards Institute (ANSI) A117.1, *Standard on Accessible and Usable Buildings and Facilities*.

Table 3-1. Occupant Density for Tornado Community Safe Rooms

Tornado Safe Room Occupant	Minimum Recommended Usable Floor Area[1] in Square Feet per Safe Room Occupant
Standing or Seated	5
Wheelchair-bound	10
Bedridden	30

[1] See below for recommendations for minimum recommended usable safe room floor area.

o) **Calculation of Usable Floor Area.** The usable safe room floor area should be determined by subtracting the floor area of excluded spaces, partitions and walls, columns, fixed or movable objects, furniture, equipment, or other features that, under probable conditions, cannot be removed, or stored, during use as a safe room from the gross floor area.

An alternative method for determining the usable safe room floor area is to use the following percentages:

1. Reducing the gross floor area of safe rooms with concentrated furnishings or fixed seating by a minimum of 50 percent.
2. Reducing the gross floor area of safe rooms with unconcentrated furnishings and without fixed seating by a minimum of 35 percent.
3. Reducing the gross floor area of safe rooms with open plan furnishings and without fixed seating by a minimum of 15 percent.

p) **Number of Doors.** The number of doors as means of egress from the safe room should be determined based upon the occupant load for the normal occupancy of the space in accordance with the applicable building code. For facilities used solely for safe rooms, the number of doors should be determined in accordance with the applicable building code based upon the occupant load as calculated above in Part n). The direction of the swing of doors should be as required by the applicable building code for the normal occupancy of the space and the egress doors should be operable from the inside without the use of keys or special knowledge or effort.

Where the applicable building code requires only one means of egress door, an emergency escape opening should be provided. The emergency escape opening should be an additional door or an opening that is a minimum of 5.7 square feet in area. Such openings should have a minimum height of 24 inches and a minimum width of 20 inches. The emergency escape opening should be operable from the inside without the use of tools or special knowledge. The emergency escape opening should be located away from the means of egress door by a minimum distance of 1/3 of the length of the maximum overall diagonal dimension of the area to be served.

3.3.2 Debris Impact Criteria for Tornado Community Safe Rooms

The elements of the safe room structure and its components (including windows, doors, and opening protective systems) that separate the individuals therein from the event outside should resist failure from wind pressures and debris impacts. For tornado community safe rooms, the structural elements, the building envelope, and openings in the building envelope should be designed to resist wind-induced loads as well as impacts from debris.

Providing windborne debris protection for safe rooms is different from the debris impact requirements in the IBC, IRC, and ASCE 7-05. All building elements that make up the portion of the safe room that protects the occupants should resist impacts from windborne debris. As mentioned above, these include not only the openings into and out of the safe room, but the walls and roof of the safe room. No portion of the envelope (roof, wall, opening, door, window, etc.) should fail by wind pressure or be breached by the specified windborne debris (at the appropriate debris impact wind speed). The only exceptions are roof or wall coverings that provide code-compliant performance for non-safe room design features, but are not needed for the protection of the occupants within the safe room. In addition, openings for ventilation into and out of the safe room should be hardened to resist both wind loads and debris impact.

For tornado hazards, the debris impact criteria for large missiles vary with the safe room design wind speed. Specifically, the representative missile for the debris impact test for all components of the building envelope of a safe room should be a 15-lb 2x4. The speed of the test missile impacting vertical envelope surfaces varies from 100 mph to 80 mph and the speed of the test missile impacting horizontal surfaces varies from 67 mph down to 53 mph. Table 3-2 presents the missile impact speeds for the different wind speeds applicable for tornado safe room designs. This debris impact test is recommended above any other debris impact criteria that may be applicable in the local jurisdiction in which the safe room is being constructed. If the tornado safe room is located in an area that already requires debris impact protection for openings to minimize damage to buildings and contents, it is important to note that the code mandated requirements for property protection must still be adhered to and that the debris impact protection criteria which provide life-safety protection from tornadoes are additional criteria. A more detailed discussion of the debris impact recommendations is provided in Chapter 7 of this publication.

> Debris impact and extreme winds result from the same storm. However, each debris impact affects the structure for an extremely short duration, probably less than 1 second. For this reason, the highest wind load and the highest impact load are not considered likely to occur at precisely the same time.

Table 3-2. Tornado Missile Impact Criteria

Safe Room Design Wind Speed	Missile Speed (of 15 lb 2x4 board member) and Safe Room Impact Surface
250 mph	Vertical Surfaces: 100 mph Horizontal Surfaces: 67 mph
200 mph	Vertical Surfaces: 90 mph Horizontal Surfaces: 60 mph
160 mph	Vertical Surfaces: 84 mph Horizontal Surfaces: 56 mph
130 mph	Vertical Surfaces: 80 mph Horizontal Surfaces: 53 mph

Note: Walls, doors, and other safe room envelope surfaces inclined 30 degrees or more from the horizontal should be considered vertical surfaces. Surfaces inclined less than 30 degrees from the horizontal should be treated as horizontal surfaces.

To show compliance with the criteria to provide life-safety protection from windborne debris, the following guidance is provided:

a) **Testing for Missile Impacts.** Missile impact resistance of all components of the safe room envelope (including doors and opening protectives) should be tested in accordance with ICC-500, Section 305.

b) **Wall and Roof Assemblies.** All wall assemblies, roof assemblies, window assemblies, door assemblies, and protective devices used to cover openings and penetrations in the wall/roof that are recommended to protect occupants should be tested as identified in Part a) above and ICC-500, Section 306. The testing procedures that are used to comply with these criteria are provided in ICC-500, Section 804.

c) **Openings and Opening Protectives in Tornado Safe Rooms.** The openings in the safe room envelope should be protected by doors complying with ICC-500, Section 306.3.1; windows complying with ICC-500, Section 306.3.2; other opening protectives complying with ICC-500, Section 306.4; or baffled to prevent windborne debris from entering the safe room protected occupant area in accordance with ICC-500, Section 306.5. The testing procedures that are used to show compliance with these criteria are provided in ICC-500, Section 804; this also includes skylight assemblies and other glazed openings. Opening protectives in tornado safe rooms should be permanently affixed, and manually operable from inside the safe room.

   Also, window assemblies (operable and non-operable) and other glazed openings (including skylights, side lights, and transoms) should be tested using the procedures for missile impact resistance in accordance with ICC-500, Section 804; pressure in accordance with ICC-500, Section 805; and cyclic pressures in accordance with ASTM E 1996.

Exceptions:

1. Missile impact testing for the life-safety missile impact criteria is not necessary for window assemblies and other glazed openings where the opening is protected by a device located on the exterior or interior sides of the opening and meeting the criteria of Part a) above.

2. Missile impact and pressure testing for life-safety missile impact criteria is not necessary for window assemblies and other glazed openings where the opening is protected by a device located on the interior side of the opening and meeting the criteria of Part a) above.

d) **Soil-covered Portions of Safe Rooms.** Should all or portions of safe rooms be below ground or covered by soil, missile impact resistance criteria may not need to be addressed. Safe rooms with at least 12 inches of soil cover protecting horizontal surfaces, or with at least 36 inches of soil cover protecting vertical surfaces, do not need to be tested for resistance to missile impact as though the surfaces were exposed. Soil in place around the safe room as specified above can be considered to provide appropriate protection from the representative, tornado safe room missile impact.

e) **Alcove or Baffled Entry Systems.** All protective elements of alcove or baffled entry systems to safe rooms (when used) should be designed to meet the wind load criteria of Section 3.3.1 and the debris impact test criteria of Section 3.3.2 of this publication. Where a door is employed as part of the protection in such an entry system, the door should meet the debris impact test requirements of ICC-500, Section 804.9.7 and the pressure testing requirements of ICC-500, Sections 805 and 806.6. The enclosure classification for safe rooms with alcove or baffled entries should be determined in accordance with Section 3.3.1 of this publication.

f) **Other Debris Hazards.** Lay down, rollover, and collapse hazards (i.e., trees, other structures, rooftop equipment, etc., that have a reasonable chance of adversely impacting the safe room) should be considered by the design professional when determining the location of safe rooms on the site.

g) **Other Hazards.** Fuel tanks, fueling systems, fuel pipes, or any other known hazards near the safe room should be taken into account in the siting and design of the safe room.

3.4 Hurricane Community Safe Room Design Criteria

The first step in designing and constructing a safe room is the identification of the hazard. If there is a need for the design and construction of a safe room to protect lives during a hurricane or from hurricane hazards, the following design criteria are recommended. The next step in the design process is to identify the appropriate hurricane safe room design wind speed from the map presented in Figure 3-2 (including 3-2a through 3-2c).

In these maps, hurricane safe room design wind speeds are not provided by wind zones, but by wind contours and range from 160 mph to 255 mph. These wind speed contours were developed using the same model used to develop the wind speed contours for ASCE 7-05 and represent an "ultimate" design wind speed for the hurricane hazards in these areas. These wind speeds should be used to determine the wind-generated forces that act on either the structural frame (i.e., the load-bearing elements) of a building or shelter to be used as a safe room (MWFRS), the exterior coverings of the safe room (C&C), and openings or opening protectives (such as doors and windows). Additional discussions on the origins and contents of these maps are provided later in Chapters 5 and 6 of this publication.

The difference between the hurricane safe room wind design speed map presented in Figure 3-2 (including 3-2a through 3-2c) and the hurricane shelter design wind speed map in the ICC-500 is the landward limit line for hurricane safe rooms. The FEMA 361 map contains an additional contour line that depicts the inland geographic boundary of the area in which FEMA hurricane community safe room design criteria are deemed appropriate. Should a safe room be constructed landward of this line, the tornado community safe room recommendations presented in Section 3.3 should be used. This inland boundary is defined as the extent of the hurricane-prone region, as mapped by ASCE 7-05.

ICC-500 CROSS-REFERENCE

The hurricane community safe room design criteria presented in this section of FEMA 361 differ from the tornado community safe room design criteria presented in the ICC-500 Storm Shelter Standard in several key areas. These areas are exposure classification, debris impact criteria, and flood protection. Flood design criteria are presented in Section 3.6.

3.4.1 Wind Design Parameters for Hurricane Community Safe Rooms

As previously mentioned, the wind loads on the portions of the safe room that experience wind pressures (including MWFRS, C&C, and openings) should be calculated using the wind load provisions in Section 6.5 of ASCE 7-05, Method 2 – Analytical Procedure (except as modified by this section). The design recommendations for hurricane safe rooms do not meet the requirements for using Method 1 – Simplified Procedure. In addition, all doors, windows, and openings should be protected with devices that comply with the design wind pressures as calculated by ASCE 7-05. The safe room provides life-safety protection from wind events and therefore should be capable of resisting ultimate-wind loads without failure, although some damage may occur and serviceability of the safe room may be an issue after an event.

For additional information on the definition of "hurricane-prone regions," see Chapters 6 and C6 of ASCE 7-05, *Minimum Design Loads for Buildings and Other Structures.*

The coefficients and parameters used in the ASCE 7-05 pressure calculations in the design of a safe room should be different from those listed for regular buildings or even essential facilities because detailed wind characteristics in hurricanes are complex and the wind event should be considered an “ultimate-level” event and not a “design-level” event. Based on the wind speed selected from Figure 3-2, the following wind design parameters should be used when calculating wind pressures acting on hurricane safe rooms:

a) **Select Safe Room Design Wind Speed.** This is the first component of the safe room design process. Select V_x = 255-160 mph (3-second gust).

b) **Importance Factor (I)** I = 1.0

c) **Exposure Category** C

d) **Directionality Factor** K_d = 1.0

e) **Topographic Effects** K_{zt} need not exceed 1.0.

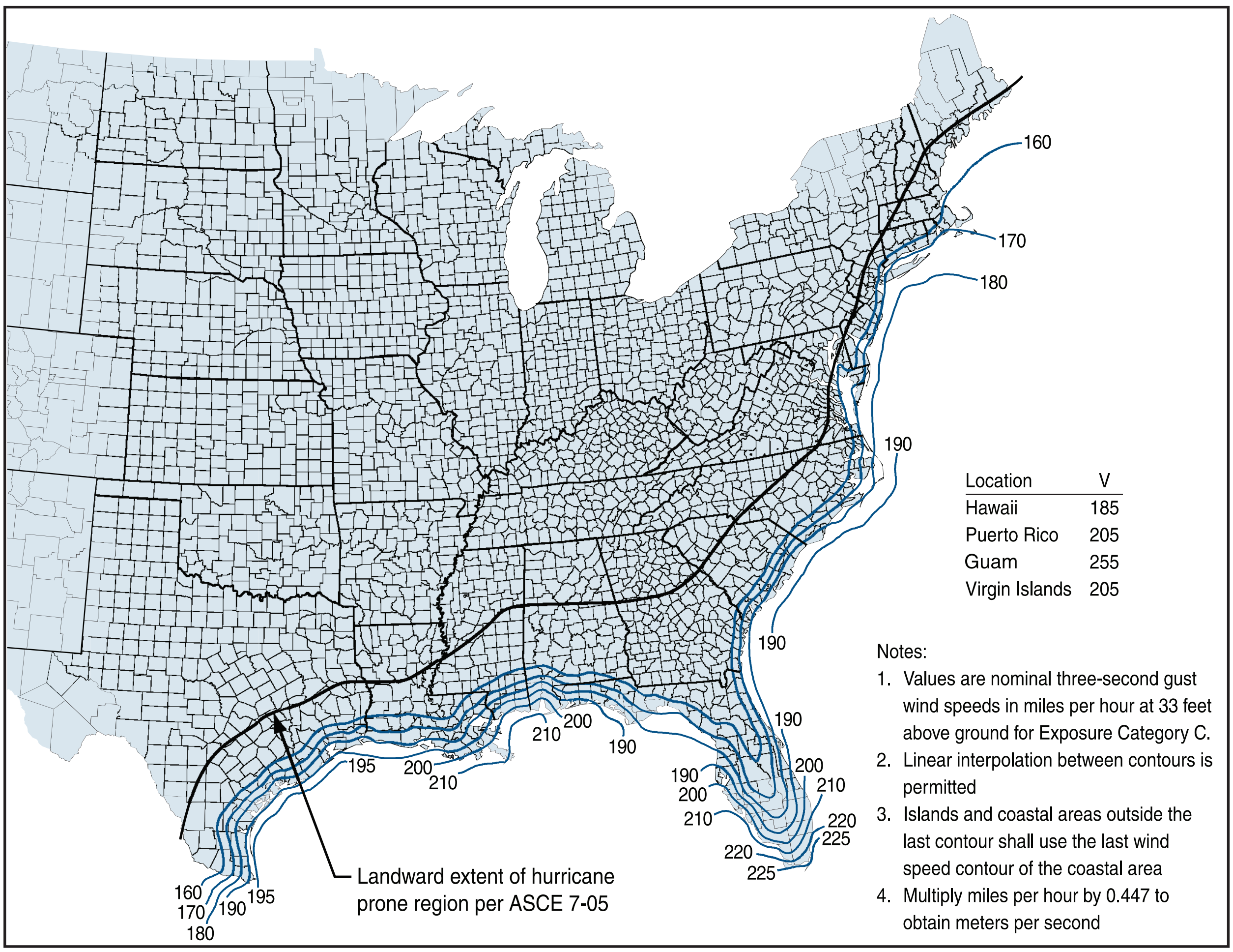


Figure 3-2. Hurricane Safe Room Design Wind Speed Map from the ICC-500

SOURCE: *ICC/NSSA STANDARD FOR THE DESIGN AND CONSTRUCTION OF STORM SHELTERS* (ICC-500).

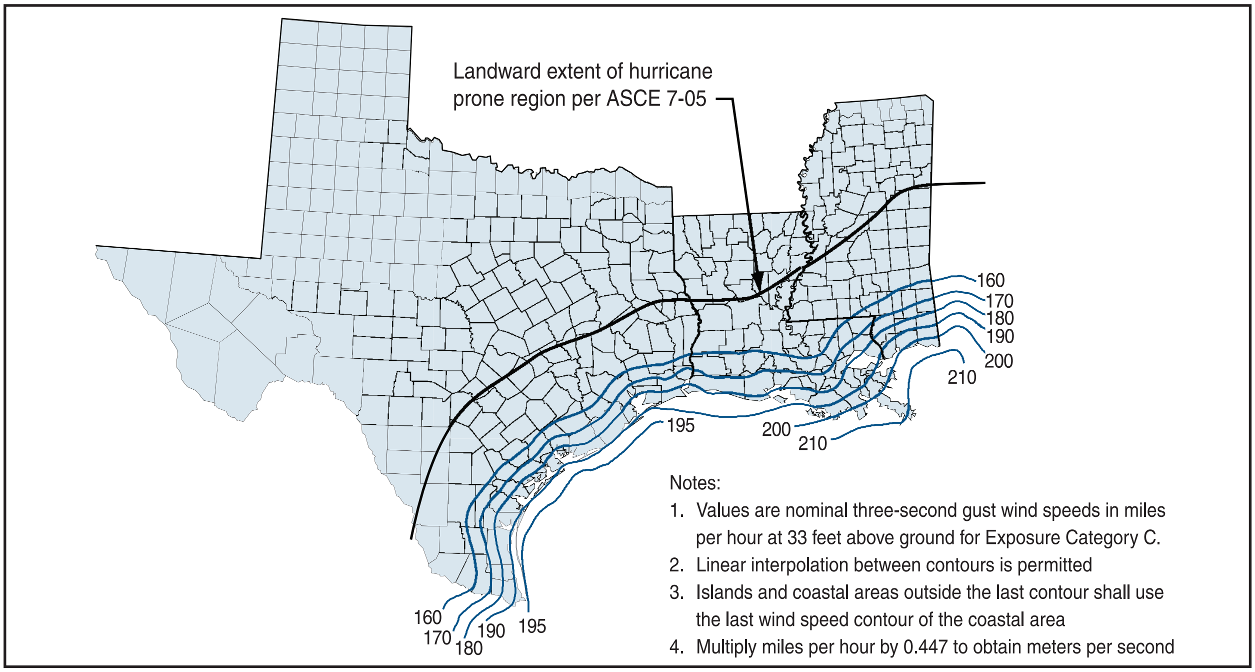


Figure 3-2a. Hurricane Safe Room Design Wind Speed Map from the ICC-500 – Western Gulf of Mexico Detail

SOURCE: *ICC/NSSA STANDARD FOR THE DESIGN AND CONSTRUCTION OF STORM SHELTERS* (ICC-500). WWW.ICCSAFE.ORG < HTTP://WWW.ICCSAFE.ORG >.

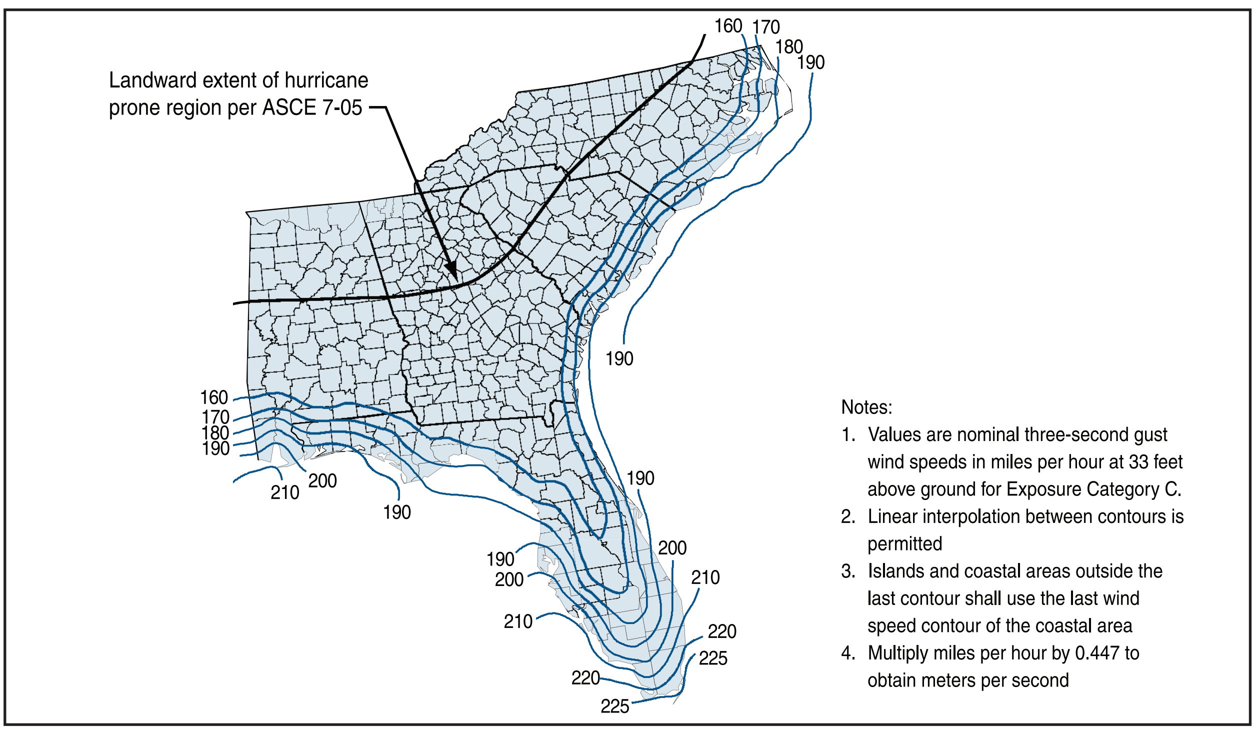


Figure 3-2b. Hurricane Safe Room Design Wind Speed Map from the ICC-500 – Eastern Gulf of Mexico Detail

SOURCE: *ICC/NSSA STANDARD FOR THE DESIGN AND CONSTRUCTION OF STORM SHELTERS* (ICC-500). WWW.ICCSAFE.ORG < HTTP://WWW.ICCSAFE.ORG >.

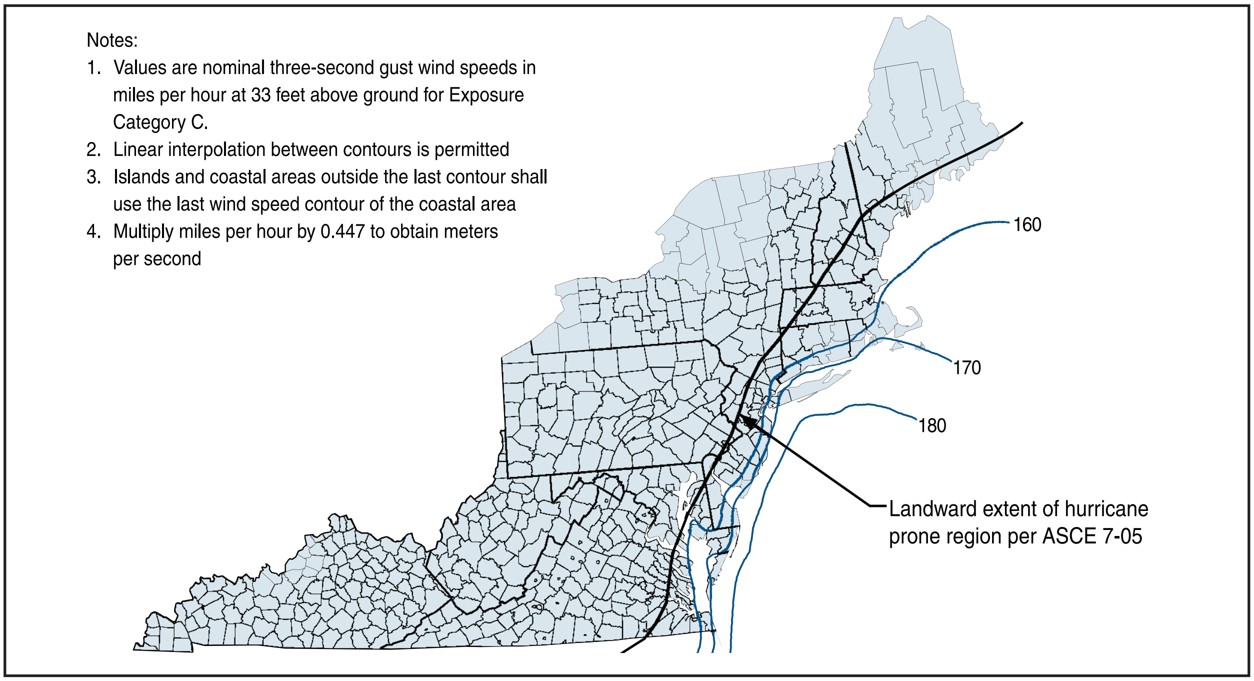


Figure 3-2c. Hurricane Safe Room Design Wind Speed Map from the ICC-500 – Mid-Atlantic and Northeast Detail

SOURCE: *ICC/NSSA STANDARD FOR THE DESIGN AND CONSTRUCTION OF STORM SHELTERS* (ICC-500). COPYRIGHT 2008, WASHINGTON, DC: INTERNATIONAL CODE COUNCIL. REPRODUCED WITH PERMISSION. ALL RIGHTS RESERVED. WWW.ICCSAFE.ORG < HTTP://WWW.ICCSAFE.ORG >.

f) **Enclosure Classifications.** Enclosure classifications for safe rooms should be determined in accordance with ASCE 7-05, Section 6.2. For determining the enclosure classification for hurricane community safe rooms, the largest door or window on a wall that receives positive external pressure should be considered as an opening. As such, the internal pressure coefficient may be appropriately taken for either enclosed or partially enclosed buildings, depending upon the openings in the safe room.

g) **Atmospheric Pressure Change.** The potential for APC is considered negligible for hurricane hazards and therefore need not be considered in the design of hurricane community safe rooms.

h) **Maximum Safe Room Height.** The height of a safe room is not restricted or limited.

i) **Duration of Protection.** The hurricane community safe rooms are designed to provide occupants life-safety protection for storm durations of at least 24 hours.

j) **Ventilation, Sanitation, Power, and Other Non-structural Design Criteria.** Ventilation, sanitation, and other recommendations for hurricane community safe rooms should be incorporated into the design of the safe room in accordance with ICC-500, Chapter 7. In addition, the safe room should be equipped with an electrical system with an emergency power system for lighting and other needs in accordance with ICC-500, Chapter 7.

Emergency lighting recommendations may be met through means other than generators (i.e., flashlights may be used to meet this recommendation). Additional information is also provided in Chapters 4 and 8 of FEMA 361.

k) **Weather Protection.** All exposed C&C assemblies and roof coverings of hurricane safe rooms should be designed to resist rainwater penetration during the design windstorm and should be designed and installed to meet the wind load criteria of Section 3.4.1.

l) **Occupancy Classifications for Safe Rooms.** If a safe room is a single-use safe room, the occupancy classification per the IBC should be A-3 for the protected space. If a safe room is a multi-use safe room area, the occupancy classification for the primary use of the protected space (when not in use as a safe room) should be used.

m) **Maximum Allowable Hurricane Community Safe Room Population.** From a design and construction standpoint, there is no limitation on the maximum population that a safe room may be designed to protect. However, applicants and sub-applicants who request funding support from FEMA for safe room projects should be aware that limitations do apply to the size of the safe room. Refer to FEMA safe room and benefit-cost analysis tools for guidance and criteria that can be used to define the maximum population. Any group involved in the design and construction of a hurricane community safe room should obtain the latest guidance from their FEMA regional office.

n) **Maximum Population Density of a Hurricane Community Safe Room.** The minimum recommended safe room floor area per occupant is provided in Table 3-3. The number of standing, seated, or bedridden spaces should be determined based upon the needs of the safe room determined by the designer and the applicable authority having jurisdiction. However, each community safe room should be sized to accommodate a minimum of one wheelchair space for every 200 occupants or portion thereof. It is also important to note that floor space (areas) within community safe rooms should provide an accessible route in accordance with ICC/ANSI A117.1.

Table 3-3. Occupant Density for Hurricane Community Safe Rooms

Hurricane Safe Room Occupant	Minimum Recommended Usable Floor Area[1] in Square Feet per Safe Room Occupant
Standing or Seated	20
Wheelchair-bound	20
Bedridden	40

[1] See below for recommendations for minimum recommended usable safe room floor area.

o) **Calculation of Usable Floor Area.** The usable safe room floor area should be determined by subtracting the floor area of excluded spaces, partitions and walls, columns, fixed or movable objects, furniture, equipment or other features that under probable conditions can not be removed or stored during use as a safe room from the gross floor area.

An alternative for determining the usable safe room floor area is to use the following percentages:

1. Reducing the gross floor area of safe room areas with concentrated furnishings or fixed seating by a minimum of 50 percent
2. Reducing the gross floor area of safe room areas with unconcentrated furnishings and without fixed seating by a minimum of 35 percent
3. Reducing the gross floor area of safe room areas with open plan furnishings and without fixed seating by a minimum of 15 percent

p) **Number of Doors.** The number of doors as means of egress from the safe room should be determined based upon the occupant load for the normal occupancy of the space in accordance with the applicable building code. For facilities used solely for safe rooms, the number of doors should be determined in accordance with the applicable building code based upon the occupant load as calculated above in Part n). The direction of the swing of doors should be as required by the applicable building code for the normal occupancy of the space and the egress doors should be operable from the inside without the use of keys or special knowledge or effort.

Where the applicable building code requires only one means of egress door, an emergency escape opening should be provided. The emergency escape opening should be an additional door or an opening that is a minimum of 5.7 square feet in area. Such openings should have a minimum height of 24 inches and a minimum width of 20 inches. The emergency escape opening should be operable from the inside without the use of tools or special knowledge. The emergency escape opening should be located away from the means of egress door by a minimum distance of 1/3 of the length of the maximum overall diagonal dimension of the area to be served.

3.4.2 Debris Impact Criteria for Hurricane Community Safe Rooms

The elements of the safe room structure and its components (including windows, doors, and opening protectives) that separate the individuals inside from the event outside should resist failure from wind pressures and debris impacts. For hurricane community safe rooms, the structural elements, the building envelope, and openings in the building envelope should be designed to resist wind-induced loads as well as impacts from debris.

Providing windborne debris protection for safe rooms is different from the debris impact requirements in the IBC, IRC, and ASCE 7-05. All building elements that make up the portion of the safe room that protects the occupants should resist impacts from windborne debris. As mentioned above, these include not only the openings into and out of the safe room, but the walls and roof of the safe room. No portion of the envelope (roof, wall, opening, door, window, etc.) should fail by wind pressure or be breached by the specified windborne debris (at the appropriate debris impact wind speed). The only exceptions are roof or wall coverings that provide code-compliant performance for non-safe room design features, but are not needed for the protection of the occupants within the safe room. In addition, openings for ventilation into and out of the safe room should be hardened to resist both wind loads and debris impact.

For hurricane hazards, the debris impact criteria for large missiles are a function of the hurricane safe room design wind speed. Specifically, the representative missile for the debris impact test for all components of the building envelope of hurricane safe rooms should be a 9-lb 2x4. The speed of the test missile impacting vertical safe room surfaces should be a minimum of 0.50 times the safe room design wind speed. The speed of the test missile impacting horizontal surfaces should be 0.10 times the safe room design wind speed. Table 3-4 presents the missile impact speeds for the different wind speeds applicable for hurricane safe room designs. This debris impact test is recommended above any other debris impact criteria that may be applicable in the local jurisdiction in which the safe room is being constructed. If the hurricane safe room is located in an area that already requires debris impact protection for openings to minimize damage to buildings and contents, it is important to note that life-safety debris impact-resistance criteria identified here should be applied in addition to the code mandated requirements because the protected area must be designed to provide near-absolute protection from hurricanes. A more detailed discussion of the debris impact criteria is provided in Chapter 7 of this publication.

To show compliance with criteria for providing life-safety protection from windborne debris, the following guidance is provided:

a) **Testing for Missile Impacts.** Testing for missile impact resistance of all components of the safe room envelope (including doors and opening protectives) should be in accordance with ICC-500, Section 305, with the exception of the missile impact speed, which should be that specified in Table 3-4.

b) **Wall and Roof Assemblies.** All wall assemblies, roof assemblies, window assemblies, door assemblies, and protective devices used to cover openings and penetrations in the wall/roof that are recommended to protect occupants should be tested as identified in Part a) above and ICC-500, Section 306. The testing procedures that are used to comply with these criteria are provided in ICC-500, Section 804.

ICC-500 CROSS-REFERENCE

The hurricane community safe room missile impact criteria in this section of FEMA 361 differ from the hurricane community shelter design criteria presented in the ICC-500 Storm Shelter Standard. The ICC-500 Standard Committee considered several factors in determining the horizontal missile speed to be used for testing with the 9-lb 2x4 board member. FEMA, however, reviewed the same data, research, and post-storm assessments, but took a position that it is more appropriate to recommend a high impact speed for the representative missile (for the debris impact criteria) when providing near-absolute level of protection of occupants that FEMA has promulgated since the first safe room and shelter guidance in FEMA 320 and FEMA 361.

Table 3-4. Hurricane Missile Impact Criteria

Hurricane Design Missile is a 9-lb 2x4 board member impacting the safe room at the following missile impact speed (as a function of safe room design wind speed [V])				
Hurricane Design Wind Speed (V)	FEMA 361 Horizontal Missile Speed – Hurricane (0.5xV)	FEMA 361 Vertical Missile Speed – Hurricane (0.1xV)	ICC-500 Horizontal Missile Speed – Hurricane (0.4xV)	ICC-500 Vertical Missile Speed – Hurricane (0.1xV)
255 mph	128 mph	26 mph	102 mph	26 mph
250 mph	125 mph	25 mph	100 mph	25 mph
240 mph	120 mph	24 mph	96 mph	24 mph
230 mph	115 mph	23 mph	92 mph	23 mph
220 mph	110 mph	22 mph	88 mph	22 mph
210 mph	105 mph	21 mph	84 mph	21 mph
200 mph	100 mph	20 mph	80 mph	20 mph
190 mph	95 mph	19 mph	76 mph	19 mph
180 mph	90 mph	18 mph	72 mph	18 mph
170 mph	85 mph	17 mph	68 mph	17 mph
160 mph	80 mph	16 mph	64 mph	16 mph

Note: Walls, doors, and other safe room envelope surfaces inclined 30 degrees or more from the horizontal should be considered vertical surfaces. Surfaces inclined less than 30 degrees from the horizontal should be treated as horizontal surfaces.

c) **Openings and Opening Protectives in Tornado Safe Rooms.** The openings in the safe room envelope should be protected by doors complying with ICC-500, Section 306.3.1; windows complying with ICC-500, Section 306.3.2; other opening protectives complying with ICC-500, Section 306.4; or baffled to prevent windborne debris from entering the safe room protected occupant area in accordance with ICC-500, Section 306.5. The testing procedures that are used to show compliance with these criteria are provided in ICC-500, Section 804; this also includes skylight assemblies and other glazed openings. Opening protectives in tornado safe rooms should be permanently affixed, and manually operable from inside the safe room.

Also, window assemblies (operable and non-operable) and other glazed openings (including skylights, side lights, and transoms) should be tested using the procedures for missile impact resistance in accordance with ICC-500, Section 804; pressure in accordance with ICC-500, Section 805; and cyclic pressures in accordance with ASTM E 1996.

Exceptions:

1. Missile impact testing for the life-safety missile impact criteria is not necessary for window assemblies and other glazed openings where the opening is protected by a device that is located on the exterior or interior side of the opening, and meets the criteria of Part a) above.

2. Missile impact and pressure testing for the life-safety wind design criteria are not necessary for window assemblies and other glazed openings where the opening is protected by a device that is located on the interior side of the opening and meets the criteria of Part a) above.

d) **Soil-covered Portions of Safe Rooms.** Should all or portions of safe rooms be below ground or covered by soil, missile impact resistance criteria may not need to be addressed. Safe rooms with at least 12 inches of soil cover protecting safe room horizontal surfaces, or with at least 36 inches of soil cover protecting safe room vertical surfaces, do not need to be tested for resistance to missile impact as though the surfaces were exposed. Soil in place around the safe room as specified above can be considered to provide appropriate protection from the representative hurricane safe room missile impact.

e) **Alcove or Baffled Entry Systems.** All protective elements of alcove or baffled entry systems to safe rooms (when used) should be designed to meet the wind load recommendations of Section 3.4.1 of this publication and the debris impact test recommendations of this section. When a door is employed as part of the protection in such an entry system, the door should meet the debris impact test requirements of ICC-500, Section 804.9.7 and the pressure testing requirements of ICC-500, Sections 805 and 806.6. The enclosure classification for safe rooms with baffled or alcove entries should be determined in accordance with Section 3.4.1 of this publication.

f) **Other Debris Hazards.** Lay down, rollover, and collapse hazards (i.e., trees, other structures, rooftop equipment, etc., that have a reasonable chance of adversely impacting the safe room) should be considered by the design professional when determining the location of safe rooms on the site.

g) **Other Hazards.** Fuel tanks, fueling systems, fuel pipes, or any other known hazards near the safe room should be taken into account in the siting and design of the safe room.

h) **Safe Rooms Meeting Hurricane Impact Test Recommendations.** Safe room envelope components meeting missile impact test recommendations for tornado safe rooms should be considered acceptable for hurricane safe rooms provided they meet structural design load recommendations for hurricane safe rooms.

3.5 Residential Safe Room Design Criteria

This section provides the residential safe room design criteria for both tornado and hurricane safe rooms. FEMA supports the ICC-500 Storm Shelter Standard design and construction requirements for residential tornado and hurricane shelters. However, FEMA safe room guidance on the use of safe rooms in residential applications takes a different approach from the ICC-500. FEMA 320 designs are combination tornado and hurricane safe rooms that meet the most stringent criteria for each hazard. The original FEMA 320, *Taking Shelter From the Storm: Building a Safe Room Inside Your House* (1998, and revised in 1999) provided prescriptive solutions for homeowners for below- and above-ground safe rooms that could provide "near-absolute protection" without the need to obtain and hire professional design services, provided the design plans in the publication are used properly. Therefore, the intent of FEMA in the original publication, and in any revisions to FEMA 320, remains the same, to continue to provide the prescriptive solutions for sheltering from extreme-wind events for life-safety protection. As such, the FEMA 320 designs provide FEMA's interpretation of how to implement the combined tornado and hurricane residential safe room criteria based on the design criteria included in this section.

Along with these revisions and updates to FEMA 361, FEMA has updated and expanded the guidance provided in FEMA 320. The updated FEMA 320 guidance and prescriptive design plans comply not only with the residential shelter requirements of the ICC-500, but also with the community shelter requirements for small shelters (less than 16 occupants) to support the use of these safe rooms in buildings other than residences. Since FEMA 320 does not present detailed design information, this section of FEMA 361 provides designers with the criteria used for the development of the revised, prescriptive safe room plans in FEMA 320. Therefore, the revised FEMA 320, *Taking Shelter From the Storm: Building a Safe Room for Your Home or Small Business* publication (August 2008) presents simple and conservative prescriptive approaches to safe room designs that are considered compliant with both FEMA 361 criteria and the ICC-500 requirements for the design and construction of combined, residential tornado and hurricane safe rooms.

ICC-500 CROSS-REFERENCE

The residential safe room design criteria presented in FEMA 361 meet the design criteria presented in the ICC-500 for combined, residential tornado and hurricane shelters. The FEMA safe room criteria presented here also meet the requirements for combined, small tornado and hurricane community safe rooms (with maximum occupancies of 16 persons or less). The criteria presented here are the basis for the safe room designs presented in FEMA 320, *Taking Shelter From the Storm: Building a Safe Room For Your Home or Small Business*.

3.5.1 Wind Design Parameters for Residential Safe Rooms

Calculate the wind loads on the residential safe room for all sections that experience wind pressures (including MWFRS and C&C) using the wind load provisions in Section 6.5 of ASCE 7-05, Method 2 – Analytical Procedure (except as modified by this section). The design recommendations for residential safe rooms do not meet the requirements for using Method 1 – Simplified Procedure. In addition, all doors, windows, and openings should be protected with devices that comply with the design wind pressures as calculated by ASCE 7-05. The safe room provides life-safety protection from wind events and therefore should be capable of resisting ultimate wind loads without failure, although some damage may occur and serviceability of the safe room may be an issue after an event. The following wind design parameters should be used when calculating wind pressures acting on residential safe rooms:

a) **Select Safe Room Design Wind Speed.** The design wind speed for residential safe rooms should be taken as V_x = 250 mph (3-second gust).

b) **Importance Factor (I)** I = 1.0

c) **Exposure Category** C

d) **Directionality Factor** $K_d = 1.0$

e) **Topographic Effects** K_{zt} need not exceed 1.0.

f) **Enclosure Classifications.** Enclosure classifications for small community safe rooms should be that used for a partially enclosed building as defined by ASCE 7-05, Section 6.2. For residential safe rooms serving one- and two-family dwellings only, the partially enclosed building classification is recommended, but the enclosed building classification may be used for the design of the safe room.

g) **Atmospheric Pressure Change (APC).** When the safe room is being designed as a partially enclosed building, it meets the alternative design criteria for considering APC in the design of the safe room. Therefore, the designer should use $GC_{pi} = \pm 0.55$.

h) **Maximum Safe Room Height.** The height of the residential safe room is restricted to 8 feet of vertical wall.

i) **Duration of Protection.** The residential safe rooms are designed to provide occupants life-safety protection for storm durations of at least 24 hours.

j) **Ventilation, Sanitation, Power and Other Non-structural Design Criteria.** Ventilation, sanitation, power, and other services for tornado community safe rooms should be incorporated into the design of the safe room in accordance with ICC-500, Chapter 7. In addition, the safe room should be equipped with an electrical system with an emergency power backup system for lighting and other needs in accordance with ICC-500, Chapter 7. Emergency lighting recommendations may be met through means other than generators (i.e., flashlights may be used to meet this recommendation). Additional information is also provided in Chapters 4 and 8 of FEMA 361.

k) **Weather Protection.** All exposed C&C assemblies and roof coverings of hurricane safe rooms should be designed to resist rainwater penetration during the design windstorm and should be designed and installed to meet the wind load recommendations of Section 3.3.1.

l) **Occupancy Classifications for Safe Rooms.** A safe room serves occupants of dwelling units as defined in Section 310 of the IBC and having an occupant load not exceeding 16 persons.

m) **Maximum Allowable Residential Safe Room Population.** The maximum allowable population for the prescriptive designs provided is 16 persons (only when the design selected provides at least 80 square feet of net, usable floor space within the safe room).

n) **Maximum Population Density of a Residential Safe Room.** The minimum safe room floor area per occupant in a residential safe room is provided in Table 3-5.

Table 3-5. Occupant Density for Residential Safe Rooms

Type of Safe Room	Minimum Recommended Usable Safe Room Floor Area in Square Feet Per Occupant
Tornado	
One- and Two-Family Dwelling	3
Other Residential	5
Hurricane	
One- and Two- Family Dwelling	7
Other Residential	10

For this table, the usable tornado safe room floor area should be the gross floor area, minus the area of sanitary facilities, if any, and should include the protected occupant area between the safe room walls at the level of fixed seating, where fixed seating exists.

o) **Number of Doors.** The number of doors as means of egress from the safe room should be determined based upon the occupant load for the normal occupancy of the space in accordance with the applicable building code. A minimum of one door is recommended and an emergency escape opening, in addition to the egress door is not required.

It is important to note that use and occupancy of a residential safe room is at the discretion of the safe room occupant. Compliance with FEMA residential safe room design recommendations should not be seen as a waiver or variance from the Federal Government of disregard or to not comply with a mandatory evacuation order issued by local emergency management officials or the authority having jurisdiction (AHJ).

3.5.2 Debris Impact Criteria for Residential Safe Rooms

The entire safe room structure, and especially the components that separate the individuals inside from the event outside, should resist failure from wind pressures and debris impacts. For residential safe rooms, the structural elements and the building envelope should be designed to resist wind-induced loads as well as impacts from debris.

Providing windborne debris protection for safe rooms is different from the debris impact requirements in the IBC, IRC, and ASCE 7-05. All building elements that make up the portion of the safe room that protects the occupants should resist impacts from windborne debris. As mentioned above, these include not only the openings into and out of the safe room, but the walls and roof of the safe room. No portion of the envelope (roof, wall, opening, door, window, etc.) should fail by wind pressure or be breached by the specified windborne debris (at the appropriate debris impact wind speed). The only exceptions are roof or wall coverings that provide code-compliant performance for non-safe room design features, but are not needed for the protection of the occupants within the safe room. In addition, openings for ventilation into and out of the safe room should be hardened to resist both wind loads and debris impact.

For the residential safe room, the representative missile for the debris impact test for all components of the safe room envelope should be a 15-lb 2x4. The speeds of the test missile impacting vertical and horizontal safe room surfaces are presented in Table 3-6. This debris impact test is recommended above and beyond any other debris impact criteria that may be applicable in the local jurisdiction in which the safe room is being constructed. If the residential safe room is located in an area that already requires debris impact protection for openings to minimize damage to buildings and contents, it is important to note that the code mandated requirements for property protection must still be adhered to and that the debris impact protection criteria that provide life-safety protection from tornadoes and hurricanes are the additional criteria. A more detailed discussion of the debris impact criteria is provided in Chapter 7 of this publication.

Table 3-6. Residential Safe Room Missile Impact Criteria

Safe Room Design Wind Speed	Missile Speed (of 15-lb 2x4 board member) and Safe Room Impact Surface
250 mph	Vertical Surfaces: 100 mph Horizontal Surfaces: 67 mph

Note: Walls, doors, and other safe room envelope surfaces inclined 30 degrees or more from the horizontal should be considered vertical surfaces. Surfaces inclined less than 30 degrees from the horizontal should be treated as horizontal surfaces.

To show compliance with criteria pertaining to life-safety protection from windborne debris, the following guidance is provided:

a) **Testing for Missile Impacts.** Testing for missile impact resistance of all components of the safe room envelope (including doors and opening protectives) should be in accordance with ICC-500, Section 305, with the exception of the missile impact speed, which should be that specified in Table 3-6.

b) **Wall and Roof Assemblies.** All wall assemblies, roof assemblies, window assemblies, door assemblies, and protective devices used to cover openings and penetrations in the wall/roof that are recommended to protect occupants should be tested as identified in Part a) above and ICC-500, Section 306. The testing procedures that are used to comply with these criteria are provided in ICC-500, Section 804.

c) **Openings and Opening Protectives in Tornado Safe Rooms.** The openings in the safe room envelope should be protected by doors complying with ICC-500, Section 306.3.1; windows complying with ICC-500, Section 306.3.2; other opening protectives complying with ICC-500, Section 306.4; or baffled to prevent windborne debris from entering the safe room protected occupant area in accordance with ICC-500, Section 306.5. The testing procedures that are used to show compliance with these criteria are provided in ICC-500, Section 804; this also includes skylight assemblies and other glazed openings. Opening protectives in residential safe rooms should be permanently affixed and manually operable from inside the safe room.

Also, window assemblies (operable and non-operable) and other glazed openings (including skylights, side lights, and transoms) should be tested using the procedures for missile impact resistance in accordance with ICC-500, Section 804; pressure in accordance with ICC-500, Section 805; and cyclic pressures in accordance with ASTM E 1996.

Exceptions:

1. Missile impact testing for the life-safety missile impact criteria is not necessary for window assemblies and other glazed openings where the opening is protected by a device located on the exterior or interior sides of the opening and meeting the criteria of Part a) above.
2. Missile impact testing and pressure testing for the life-safety missile impact criteria are not necessary for window assemblies and other glazed openings where the opening is protected by a device located on the interior side of the opening and meeting the criteria of Part a) above.

d) **Soil-covered Portions of Safe Rooms.** Should all or portions of a safe room be below ground or covered by soil, missile impact resistance criteria may not be to be addressed. Safe rooms with at least 12 inches of soil cover protecting horizontal surfaces, or with at least 36 inches of soil cover protecting vertical surfaces, do not need to be tested for resistance to missile impact as though the surfaces were exposed. Soil in place around the safe room as specified above can be considered to provide appropriate protection from the representative residential safe room missile impact.

e) **Alcove or Baffled Entry Systems.** All protective elements of alcove or baffled entry systems to safe rooms (when used) should be designed to meet the wind load recommendations of Section 3.5.1 of this publication and the debris impact test recommendations of Section 3.5.2 of this publication. Where a door is employed as part of the protection in such an entry system, the door should meet the debris impact test requirements of ICC-500, Section 804.9.7 and the pressure testing requirements of ICC-500, Sections 805 and 806.6. The enclosure classification for safe rooms with alcove or baffled entries should be determined in accordance with Section 3.5.1 of this publication.

f) **Other Debris Hazards.** Lay down, rollover, and collapse hazards (i.e., trees, other structures, equipment, etc., that have a reasonable chance of adversely impacting the safe room) should be considered by the design professional when determining the location of safe rooms on the site.

3.6 Flood Hazard Design Criteria for Safe Rooms

The design of safe rooms to resist wind forces and wind loads was identified in the previous section. It is also important to address the flood hazards that may exist at a safe room site. This section outlines the flood design criteria for community and residential safe rooms. This process, like the wind design, can be accomplished and completed by a design professional using the processes presented in ASCE 7-05 as modified in this publication for the flood hazard (if it exists). If the flood hazard does not exist at the site, a statement identifying that there is not a flood hazard should be included on the project plans.

SAFE ROOMS AND TSUNAMI HAZARDS

Tsunami hazards may exist in some jurisdictions where safe rooms are designed and constructed to provide protection from hurricanes. Flood Insurance Rate Maps (FIRMs) will exist for these areas, but tsunami inundation maps may or may not.

The tsunami hazard in the U.S. is the greatest along the coasts in Washington, Oregon, California, Alaska, and Hawaii, and along the coasts of the U.S. territories in the Caribbean. Most areas considered to have a high tsunami risk have been studied, and tsunami inundation areas associated with the credible worst-case scenario have been mapped. These maps were prepared as part of the National Tsunami Hazard Mitigation Program (NTHMP) in cooperation with affected states and communities. FEMA has also recently started to evaluate tsunami hazards through its Map Modernization Program, by performing Probabilistic Tsunami Hazard Assessments (PTHAs). Currently, FEMA's Tsunami Pilot Study Working Group is developing a methodology that identifies relevant tsunami events and then maps the corresponding 500-year inundation area and tsunami elevations.

Until a unified set of tsunami hazard maps is available, FEMA recommends that the existing maps be used to identify the extents of the tsunami hazard in a given jurisdiction. Once a tsunami hazard has been identified to exist, FEMA recommends that both community and residential safe rooms be constructed outside of tsunami inundation areas. This is similar to the approach used for the flood design criteria in this Section 3.6, which recommends that safe rooms not be sited in Velocity (V) Zones shown on FIRMs or in storm surge inundation zones shown on Sea, Lake, and Overland Surges from Hurricanes (SLOSH) maps.

For additional information on the mapping of tsunami inundation zones, see the NTHMP web site at http://nthmp.tsunami.gov/. For additional information on the design and construction of structures in tsunami inundation areas, see FEMA P646, *Guidelines for the Design of Structures for Vertical Evacuation from Tsunamis* (June 2008), available at http://www.atcouncil.org/atc64.shtml.

3.6.1 Flood Design Criteria for Community Safe Rooms

Flood hazards should be considered when designing a community safe room. Flood loads acting on a structure containing a safe room will be strongly influenced by the location of the structure relative to the flood source. It is for this reason that safe rooms should be located <u>outside</u> of the following high-risk flood hazard areas:

a. The Coastal High Hazard Area (VE zones) or other areas known to be subject to high-velocity wave action; or

b. Areas seaward of the Limit of Moderate Wave Action (LiMWA) where mapped, also referred to as the Coastal A Zone in ASCE 24-05; or

c. Floodways.

Structures containing community safe rooms should be located in areas at low risk to flooding and mapped as unshaded Zone X or Zone C (outside the 500-year [0.2 percent annual change] floodplain) wherever possible. Where not possible, the structures should be located in the least hazardous portion of the area subject to flooding during the 0.2 percent annual chance flood (shaded Zone X or Zone B), or if that is not possible, then in the least hazardous portions of the 1 percent annual chance floodplain (i.e., within SFHA, Zones AO or AH, or Zones AE or A1-30). Siting of structures containing safe rooms in SFHAs is not a desirable option, and should be avoided except in special circumstances where consultation with local and state emergency management officials and with FEMA concludes there is no other feasible option.

For the purposes of this guidance, the lowest floor used for safe room space and/or safe room support areas should be elevated to the higher of the following elevations, which should be used as the design flood elevation (DFE) for flood load calculations:

1. Two feet above the base flood elevation (BFE), i.e., 2 feet above the flood elevation having a 1 percent annual chance of being equaled or exceeded in any given year (100-year event); or
2. The stillwater flood elevation associated with the 0.2 percent annual chance of being equaled or exceed in any given year (500-year event); or
3. The lowest floor elevation required by the community's floodplain ordinance, if such ordinance exists; or
4. Two feet above the highest recorded flood elevation in an area, if the area is designated as Zone D on a FIRM or Flood Hazard Boundary Map, or if the area has not been evaluated as part of a NFIP flood study (or equivalent flood study); or
5. If the community safe room is in an area subject to coastal storm surge inundation:

    a. The maximum stillwater inundation elevation associated with a Category 5 hurricane

    b. The wave crest elevation having a 0.2 percent annual chance of being equaled or exceeded in any given year.

> In areas where Category 5 storm surges are not mapped, references in this document to "Category 5" storm surge inundation area should be taken to mean the area inundated by the highest storm surge category mapped. See Chapter 10, References, for a list of some web sites that provide state-specific storm surge inundation maps.

DEFINITION

In this publication, the term **storm surge** means an abnormal rise in sea level accompanying a hurricane or other intense storm, and whose height is the difference between the observed level of the sea surface and the level that would have occurred in the absence of the cyclone. Storm surge (see Figure 3-3) is usually estimated by subtracting the normal or astronomic high tide from the observed storm tide.

Safe rooms subject to flooding, including any foundation or building component supporting the safe room, should be designed in accordance with the provisions of this chapter, ASCE 7-05, Section 5, and ASCE 24-05.

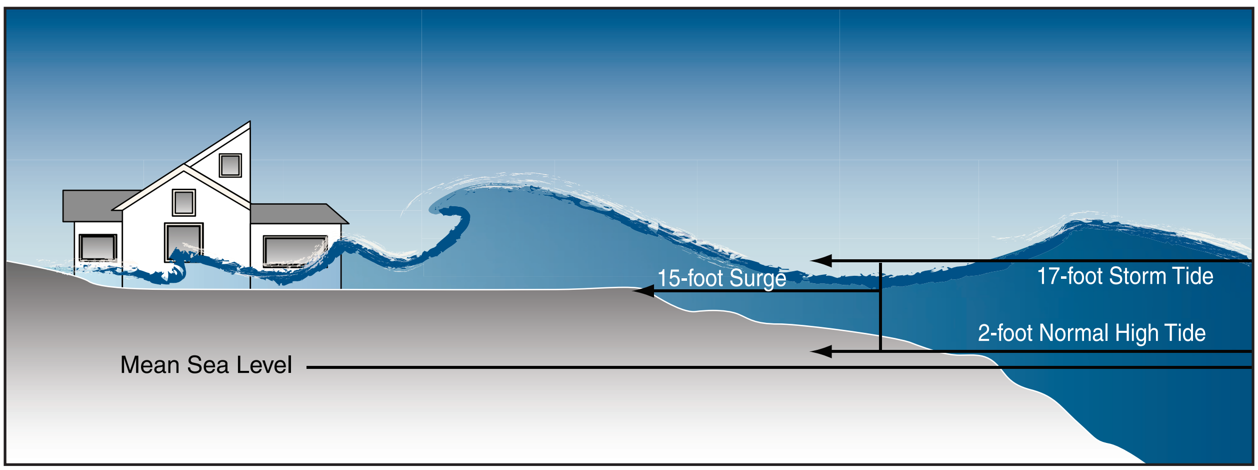


Figure 3-3. Storm surge

When at all possible, a community safe room should be located outside the influence of coastal storm surge and outside of any areas subject to flooding. When a safe room is installed in a Special Flood Hazard Area (SFHA) or other flood-prone area, the top of lowest floor for the safe room should be elevated at or above the highest flood elevation defined in Section 3.6.1.

3.6.2 Flood Design Criteria for Residential Safe Rooms

Flood hazards should be considered when designing and constructing a residential safe room. A tornado or hurricane residential safe room should be located outside of the high-risk flood hazard areas listed in this section. If the safe room needs to be located within the SFHA, the lowest floor of the safe room should be elevated to the highest of flood hazard elevations identified in this section.

Flood loads and conditions acting on a structure containing a safe room will be strongly influenced by the location of the structure relative to the flood source. It is for this reason that residential safe rooms should be located outside of the following high-risk flood hazard areas:

a. The Coastal High Hazard Area (VE zones) or other areas known to be subject to high-velocity wave action; or

b. Areas seaward of the LiMWA where mapped, also referred to as the Coastal A Zone in ASCE 24-05; or

c. Floodways; or

d. Areas subject to coastal storm surge inundation associated with a Category 5 hurricane (where applicable, these areas should be mapped areas studied by the U.S. Army Corps of Engineers [USACE], NOAA, or other qualified source).

> In areas where Category 5 storm surges are not mapped, references in this document to "Category 5" storm surge inundation area should be taken to mean the area inundated by the highest storm surge category mapped. See Chapter 10, References, for a list of some web sites that provide state-specific storm surge inundation maps.

A residential safe room, as prescribed in FEMA 320 or designed to the criteria presented in Section 3.5.2, should not be located within the SFHA if at all possible. If it is not possible to install or place a residential safe room outside the SFHA, the residential safe room should be placed outside of the high hazard areas identified above and the top of the elevated floor of the safe room should be design and constructed to the highest of the elevations specified below based on the Flood Insurance Study (FIS) or FIRM. It is important to note, if the residential safe room plans from FEMA 320 are used, the designs are restricted by a maximum allowable height above grade as specified on the drawing sheets; for a maximum elevation above existing grade of 3 to 5 feet. The elevations that should be considered when designing the safe room are the highest of:

1. The minimum elevation of the lowest floor required by the floodplain ordinance of the community (if such ordinance exists); or

2. Two feet above the BFE, (i.e., 2 feet above the flood elevation having a 1 percent annual chance of being equaled or exceeded in any given year [100-year event]); or

3. The stillwater flood elevation associated with the 0.2 percent annual chance of being equaled or exceed in any given year (500-year event).

   Residential Tornado Safe Room Exception: Where a residential tornado safe room is located outside of the hurricane-prone region as identified on Figure 3-2, and the community participates in the NFIP, the safe room need only be elevated to the minimum lowest floor elevation identified by the floodplain ordinance of the community.

Note, when installing a residential safe room in an area that has not been mapped or studied as part of a NFIP flood study (or equivalent flood study), the top of the safe room floor should be elevated such that it is 2 feet above the flood elevation corresponding to the highest recorded flood elevation in the area that has not been evaluated. Should no historical flood elevation data be available for the area, the elevation of the safe room floor should be set at the elevation identified by the local authority having jurisdiction.

3.7 Product Testing

The design of safe rooms to resist wind forces and wind loads can be accomplished and completed by a design professional using the processes presented in ASCE 7-05 as modified in this publication or approved through laboratory testing. However, to show that the safe room provides life-safety protection against flying debris, all wall and roof assemblies, window and door assemblies, and exterior cladding (envelope) systems should successfully pass the debris impact-resistance product testing. In addition, since all openings in the safe room envelope should be protected by doors, windows, opening protective devices complying with wind pressure and debris impact-resistant criteria described in Sections 3.3, 3.4, and 3.5, these systems should also be tested and approved. Alternatively, baffles or walls to prevent windborne debris from entering the protected occupant area of the safe room complying with the design criteria of Sections 3.3, 3.4, and 3.5 should also be considered acceptable if testing shows they meet the design criteria specified in this document.

ICC-500 CROSS-REFERENCE

The safe room performance criteria for debris impact-resistance and product testing presented in this section of FEMA 361 are the same as the shelter design criteria presented in the ICC-500 Storm Shelter Standard Sections 305, 306, and Chapter 8, Test Method for Impact and Pressure Testing.

All safe rooms and components that protect the occupants from wind and windborne debris should be designed and tested to resist wind pressures and a breach from debris impact in accordance with the Test Method for Impact and Pressure Testing in Chapter 8 of the ICC-500. The hazard criteria specified for the impact and pressure testing of safe room components have been described in the tornado community safe room debris impact criteria of Section 3.3.2, the hurricane community safe room debris impact criteria of Section 3.4.2, and the residential safe room debris impact criteria of Section 3.5.2.

Once testing has been completed, documentation should be maintained and provided to the AHJ where the safe room is being constructed. It is important to note that DHS and FEMA are not product testing agencies and do not “certify” or lend their authority to any group to produce or provide “FEMA approved” or “FEMA certified” products. The means by which product testing and compliance with the FEMA criteria is documented and presented will be addressed later in this chapter. FEMA supports the statement in Section 306.1 of ICC-500 not to require additional testing of assemblies and products for different levels of debris impact, if the most stringent criteria of missile size and speed are met. The ICC-500 states:

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.*

3.8 Permitting, Code Compliance, Professional Design Oversight, and Peer Review

This section clarifies the permitting, compliance, and involvement of the design professional in the safe room permitting design process. Where safe rooms are designated areas normally occupied for other purposes, the requirements of the applicable construction codes for the occupancy of the building should apply unless otherwise stated in this publication.

However, where a facility is designed to be occupied solely as a safe room, the designated occupancy should be Assembly 3 (A-3) as defined by the IBC for purposes of determination of applicable requirements that are not included in this publication or the ICC-500. Where the construction of a safe room is to take place in jurisdictions where no applicable codes exist, the provisions of the International Code Council *2006 International Building Code* should apply.

ICC-500 CROSS-REFERENCE

The safe room recommendations for permitting, code compliance, and design oversight presented in this section of FEMA 361 are the same as the requirements for permitting, code compliance, and design oversight presented in the ICC-500 Storm Shelter Standard.

3.8.1 Permitting and Code Compliance

Before construction begins, all necessary state and local building and other permits should be obtained. The design professional should meet with the local code official to discuss any concerns the building official may have regarding the design of the safe room. This meeting will help ensure that the safe room is properly designed and constructed to local ordinances or codes. As of 2008, no model building codes address the design of a tornado or hurricane safe room. The only way the design and construction of safe rooms or shelters is addressed is if the AHJ has adopted FEMA 361 or the ICC-500 as a design standard for shelters. This will change if jurisdictions adopt the 2009 Editions of the IBC and IRC that will incorporate the ICC-500 standard by reference, unless the AHJ explicitly removes the referencing text from the code language during the code adoption process.

Complete detailed plans and specifications should be provided to the building official for each safe room design. The design parameters used in the structural design of the safe room, as well as all life-safety, Americans with Disabilities Act (ADA), mechanical, electrical, and plumbing recommendations that were addressed, should be presented on the project plans and in the project specifications (see Section 3.8 for additional information on documentation of safe room information on project plans).

> The reader should be aware of descriptors and modifiers in the text of both this publication and the ICC-500 that state the code and standard requirements are applicable to the design of community safe rooms meeting FEMA's design criteria. The omission of the residential safe room is not an oversight but rather an exception to these requirements such that these items are not required for the residential safe room or the construction documents associated with the residential safe room.

Egress recommendations should be based on the maximum occupancy of the safe room as defined by Sections 3.3.1, 3.4.1, and 3.5.1, depending upon the hazard and use of the safe room. This will likely occur when the designer calculates the occupancy load based on the 5 square feet or 10 square feet per person recommended in Sections 3.3.1 and 3.4.1 for tornado and hurricane safe rooms, respectively. For multi-use safe rooms, reaching the maximum occupancy may be a rare event. For life-safety considerations, egress points for the safe room area should be designed to the maximum possible occupancy until the criteria in this publication or in the ICC-500 governing the design of safe rooms or shelters have been adopted to govern safe room design in that particular jurisdiction. As a result, the design professional will likely have difficulty providing doors and egress points with hardware (specifically latching mechanisms) that comply with code and resist the design missile impact criteria presented earlier in this chapter. Design professionals who are limited to door hardware that is acceptable to the building official but that does not meet the impact-resistance criteria should refer to Table 7-2 and also Section 7.4 for guidance on the use of missile-resistant barriers to protect doors from debris impact.

Regarding code requirements not related to life-safety or structural requirements (typically those for mechanical, electrical, and plumbing systems), the designer should design for the normal use of a multi-use safe room unless otherwise directed by the AHJ. It would not be reasonable to consider the additional cost of and need for providing additional mechanical, electrical, and plumbing equipment and facilities for the high-occupancy load that would occur only when the safe room is providing protection from a tornado or hurricane. Safe rooms designed to the criteria in this manual are for short-duration use, and the probability of their use at maximum occupancy is low.

3.8.2 Professional Design Oversight

The building owner should employ a registered design professional during the construction of a community safe room. The task for the design professional, is to conduct visual observations of the construction of the structural system for general conformance to the approved construction documents at significant construction stages and at completion of the construction of the structural system. Structural observation should not obviate the need for other inspections or testing as specified by this publication, the ICC-500, or the applicable building code.

Deficiencies should be reported in writing to the owner and to the authority having jurisdiction. At the conclusion of the work, the registered design professional who made the structural observations should submit to the AHJ a written statement that the site visits have been made and identify any reported deficiencies that, to the best of the structural observer's knowledge, have not been resolved.

> **ICC-500 CROSS-REFERENCE**
>
> The safe room criteria for Peer Review of Safe Room Designs in this section of FEMA 361 are more stringent than the Peer Review criteria presented in the ICC-500 Storm Shelter Standard Sections 305, 306, and Chapter 8, Test Method for Impact and Pressure Testing.

3.8.3 Peer Review

Construction documents for community safe rooms designed for more than 50 occupants should undergo a peer review by an independent registered design professional for conformance with the design criteria of this chapter. This peer review should focus on the structural and non-structural design of elements that provide life-safety protection for the occupants of the safe room. The design professional performing the peer review may be the same design professional who provides design oversight as recommended in Section 3.8.2.

3.9 Construction Documents, Signage Criteria, and Labeling

This section provides the criteria that should be adhered to when documenting the design criteria on project plans or within the safe room itself. The location of the safe room, the design criteria for the safe room, the product testing information, and similar information should be clearly identified on the project plans or construction documents. In addition, all safe rooms should have a label clearly identifying it as a safe room designed to provide life-safety protection to its occupants at a specified performance level; this is referred to as signage.

> **ICC-500 CROSS-REFERENCE**
>
> The safe room recommendations for construction documents, signage, and labeling presented in this section of FEMA 361 are the same as the construction documents, signage, and labeling presented in the ICC-500 Storm Shelter Standard.

3.9.1 Construction Documents

Although not all jurisdictions require detailed construction documents, compliance with the FEMA criteria presented in this publication requires that construction documents should be prepared and maintained. Such documents should contain information as required by the applicable building code, the authority having jurisdiction, and this section.

The following information applicable to construction and operation of the safe room should be supplied on the construction documents:

a) **Safe Room Design Information.** The area being designated for use as a safe room should be clearly identified on the construction documents. In addition, the following information should be provided for these areas, as part of the construction documentation:

   1. A floor plan drawing or image representing the entire facility indicating the location of the safe room on a site or within a building or facility.
   2. A statement that the wind design conforms to the provisions of the FEMA 361, *Design and Construction Guidance for Community Safe Rooms*, with the edition year specified.
   3. The safe room design wind speed, mph.
   4. The importance factor, I.
   5. The wind exposure *category (indicate all if more than one is used)*.
   6. The internal pressure coefficient, GC_{pi}.
   7. The topographic factor K_{zt}.
   8. The directionality factor K_d.
   9. A statement that the safe room has/has not been constructed within an area susceptible to flooding in accordance with Chapter 3 of this publication.
   10. Documentation showing that components of the safe room envelope will meet the missile impact and pressure test recommendations identified in Chapter 3 of this publication and Chapter 8 of the ICC-500 Storm Shelter Standard.
   11. The occupancy load of the safe room.
   12. The usable safe room floor area.
   13. Venting area (sq. in.) provided locations in the safe room.
   14. If applicable, the designer should document the flood hazard at the site and the design elevation used for the safe room (per Section 3.6).
   15. The lowest floor elevation (and corresponding datum) of the structure containing the safe room, the lowest floor elevation of the safe room floor, and the lowest floor or a room or space that houses any mechanical, electrical, or support equipment that is needed for the operation of the safe room.

b) **Enclosure.** When a safe room is to be constructed as a portion of a host building, the walls and floors enclosing the safe room should be clearly indicated on the drawings.

c) **Signage.** The type and location of signs recommendations by this publication should be indicated on the floor plans.

d) **Inspections.** Where any special details are utilized in the design of the structure, or where any special investigations are recommended that are in addition to those required by the applicable building code, the construction documents should contain a schedule of the inspections recommended and the criteria for the special installation.

e) **Special Details.** The construction documents should provide any special manufacturer's details or installation instructions for systems or equipment designed for the safe room.

f) **Special Instructions.** The construction documents should contain details of special instructions recommended for the specified functional operation of the safe room, such as:

1. Type and location of equipment and amenities provided within the safe room, including water supply, sanitary facilities, fire extinguishers, batteries, flashlights, special emergency lighting equipment, or any other equipment recommended to be installed in the safe room.
2. Specifications for any alarm system to be installed.
3. Instructions for the installation or deployment of any special protection equipment, such as shutters, screens, special latching of doors or windows, any equipment or switching for mechanical, electrical and plumbing equipment.

3.9.2 Signage Criteria and Labeling

All safe rooms should have a sign outside or inside the safe room with the name of the manufacturer or builder of the safe room, its purpose (i.e., the storm type), and safe room design wind speed. The sign should remain legible and visible. Further, any products, materials, or systems specified for occupant protection should be labeled by the agency that approved them when called for by the applicable publication (such as this document), standard (such as the ICC-500), or the local building code.

3.10 Quality Assurance/Quality Control and Special Inspections

Because a tornado or hurricane safe room should perform well during extreme conditions, quality assurance and quality control (QA/QC) for the design and construction of the safe room should be at a level above that for normal building construction. Design calculations and shop drawings should be thoroughly scrutinized for accuracy. When the design team is satisfied that the design of the safe room is acceptable, a registered design professional should prepare the quality assurance plan for the construction of the safe room. The construction documents for any tornado or hurricane community safe room should contain a quality assurance plan as defined in Sections 3.10.1 through 3.10.3.

3.10.1 Detailed Quality Assurance/Quality Control Recommendations

The quality assurance plan should be based on the Special Inspection Requirements listed in Sections 1704, 1705, and 1706 of the IBC; however, because of the design wind speeds involved, exceptions that waive the need for quality assurance when elements are prefabricated should not be allowed. The IBC recommends using these special inspections and quality assurance program when the design wind speeds are in excess of 110 to 120 mph (3-second gust), depending on exposure or if the building is in a high seismic hazard area. Sufficient information to ensure that the safe room is built in accordance with the design and performance criteria of this manual should be provided by the design professional. The quality of both construction materials and methods should be ensured through the development and application of a quality control program.

A quality assurance plan should be provided for the following:

a) Roof cladding and roof framing connections

b) Wall connections to roof and floor diaphragms and framing

c) Roof and floor diaphragm systems, including connectors, drag struts, and boundary elements

d) Main wind force resisting systems, including braced frames, moment frames, and shear walls

e) Main wind force resisting system connections to the foundation

f) Fabrication and installation of components and assemblies of the safe room envelope recommended to meet missile impact test recommendations of this chapter

g) Recommendations for components and cladding, including soffits

h) Corrosion resistance or protection of metal connectors exposed to the elements that provide load path continuity

i) Recommendations for critical support systems connections and debris impact-protection of the components and connections

3.10.2 Quality Assurance Plan Preparation

The design of each main wind force resisting system and each wind-resisting component should include a quality assurance plan prepared by a registered design professional. The quality assurance plan should identify the following:

a) The main wind force resisting systems and wind-resisting components

b) The special inspections and testing to be required in accordance with Section 106.2 of the ICC-500

c) The type and frequency of testing to be performed

d) The type and frequency of special inspections to be performed

e) The structural observations to be performed in accordance with Section 106.4 of the ICC-500

f) The distribution, type, and frequency of reports of test, inspections, and structural observations to be prepared and maintained

3.10.3 Contractor's Responsibility

Each contractor responsible for the construction of a MWFRS or any component listed in the quality assurance plan should submit a written statement of responsibility to the authority having jurisdiction, the responsible design professional, and owner prior to the commencement of work on the system or component. The contractor's statement of responsibility should contain:

a) Acknowledgement of awareness of the special criteria contained in the quality assurance plan

b) Acknowledgement that control will be exercised to obtain conformance with the construction documents

c) Procedures for exercising control within the contractor's organization, and the method and frequency of reporting and the distribution of reports

d) Identification and qualifications of the person(s) exercising such control and their position(s) in the organization

Exception: Prefabricated or panelized safe room components that have been inspected and labeled by an approved agency meeting the requirements of the applicable building code.

3.10.4 Special Inspections and Acceptance

The construction of safe rooms and installation of all equipment should be subject to inspections in accordance with the applicable building code. Special inspections should be provided for construction and installation of materials as required by the applicable building code, and when the proposed work comprises:

a) Construction materials and systems that are alternatives to traditional materials and systems prescribed by the applicable code

b) Unusual design and construction applications

In addition, where fabrication of structural load-bearing and debris impact-resistant components and assemblies is being performed on the premises of a fabricator, a special inspection of the fabricator's shop should be performed. However, this inspection may be waived if the prefabricated or panelized safe room components have been inspected and labeled by an approved agency that meets the requirements of the applicable building code.

4 Characteristics of Tornadoes and Hurricanes

This chapter provides basic information about tornadoes and hurricanes and their effects on the built environment. This information will help the reader better understand both how extreme winds damage buildings and the specific guidance provided in Chapter 3.

4.1 General Wind Effects on Buildings

Building failures occur when winds produce forces on buildings that they were not designed or constructed to withstand. Failures also occur when the breaching of a window or door creates a relatively large opening in the building envelope. These openings allow wind to enter buildings, where it again produces forces that the buildings were not designed to withstand. Other failures may be attributed to poor construction, inadequate structural systems, older building codes that provided little to no hazard-resistance provisions, and poor selection of building materials.

Past history and post-disaster investigations have shown that, to a large extent, (1) wind-induced structural damage to both residential and non-residential buildings can be minimized and (2) wind- and debris-induced damage to the building exterior (envelope) can be reduced. Experience shows that mitigation opportunities for building protection exist for properties that may be exposed to wind hazards along the periphery of strong and violent tornadoes, in the path of the vortex of weak tornadoes, and within the wind fields of most hurricanes. In these areas, damage to property was investigated to determine whether losses could have been minimized through compliance with up-to-date model building codes and engineering standards, and whether construction techniques proven to minimize damage in other wind-prone areas were used. Buildings designed and constructed above basic code requirements (i.e., “hardened” buildings), and newer structures designed and constructed to modern, hazard-resistant codes have been found to be able to resist the wind load forces from weak tornadoes

NOTE

If a standard-size window is broken by windborne debris on the wall of a typical single-story home, an opening in the building envelope can be formed that is large enough (4 to 5 percent of the wall area) that the building may experience internal pressurization. In addition to exposing the interior of the building to wind-driven rain, an increase in wind loads may result in a partial or complete structural failure.

(EF1 or weaker). Furthermore, during stronger tornado strikes, not all damage is from the rotating vortex of the tornado. Much of the damage is from straight-line winds rushing toward and being pulled into the tornado itself. Many newer homes designed and constructed to modern codes, such as the *International Residential Codes* (IRC 2000 Edition and newer), with a continuous load path to resist extreme-wind forces may survive without structural failure. The primary damage to these newer homes is to the building envelope (i.e., cladding and other exterior systems: roof covering, roof deck, exterior walls, and windows). Even this type of damage may be reduced on buildings that are designed and constructed according to the IRC 2000 (or newer) when the building experiences weaker tornadoes and the outermost winds from stronger tornadoes. This is an important consideration for building owners who are contemplating mitigation because these are the most frequent wind hazards. Based on NOAA tornado data from 1997 to 2006, EF0, EF1, and EF2 tornadoes account for approximately 80 to 95 percent of reported tornadoes in any given year.

However, for tornadoes classified EF3 and larger (see Table 4-1), larger buildings and large areas of buildings cannot be economically strengthened to resist the wind loads and debris impacts. If the building cannot resist the wind loads acting on it, it will fail. However, if the occupants of the building have retreated to a safe, specially designed and constructed safe room area, injuries and deaths will be avoided. Safe rooms designed and constructed according to the principles in this publication provide a near-absolute level of protection for their occupants.

4.2 Wind-Induced Forces – Tornadoes and Hurricanes

Tornadoes and hurricanes are complex wind events that cause damage ranging from minimal or minor to extensive devastation. It is not the intent of this section to provide a complete and thorough explanation or definition of tornadoes, hurricanes, and the damage associated with each event. Rather, this section defines basic concepts concerning tornadoes, hurricanes, and their associated damages.

4.2.1 Tornadoes

Tornadoes are one of nature's most violent storms. According to the *Glossary of Meteorology* (AMS 2000), a tornado is "a violently rotating column of air, pendant from a cumuliform cloud or underneath a cumuliform cloud, and often (but not always) visible as a funnel cloud." From 1997 to 2006, in an average year, approximately 1,300 tornadoes have been reported across the United States, resulting in 67 deaths and over 1,100 injuries annually. The most violent tornadoes, with wind speeds of 250 mph or more, are capable of tremendous destruction. Damage paths can be more than 1 mile wide and up to 50 miles long. Tornadoes can occur anywhere in the United States. The states along the Atlantic and Gulf coasts have some of the highest occurrence rates of smaller tornadoes (EF0-EF2), while the Great Plains region of the country (which includes parts of Texas, Oklahoma, Kansas, and Nebraska) consistently has the highest occurrence rates of larger tornadoes (EF3-EF5). Tornadoes are responsible for the greatest number of wind-related deaths each year in the United States.

Tornadoes come in all shapes and sizes. In the southern states, peak tornado season is March through May; peak months in the northern states are during the summer. Tornadoes can also occur in thunderstorms that develop in warm, moist air masses in advance of eastward-moving cold fronts. These thunderstorms often produce large hail and strong winds, in addition to tornadoes. During the spring in the central plains, thunderstorms frequently develop along a “dryline,” which separates warm, moist air to the east from hot, dry air to the west. Tornado-producing thunderstorms may form as the dryline moves east during the afternoon hours. Along the front range of the Rocky Mountains, in the Texas panhandle, and in the southern high plains, thunderstorms frequently form as air near the ground flows “upslope” toward higher terrain. If other favorable conditions exist, these thunderstorms can produce tornadoes. Tornadoes occasionally accompany tropical storms and hurricanes that move over land. They are most common to the right and ahead of the path (in the right front quadrant) of the storm center as it comes onshore.

In a simplified tornado “model,” there are three regions of tornadic winds:

- Near the surface, close to the core or vortex of the tornado. In this region, the winds are complicated and include the peak at-ground wind speeds, but are dominated by the tornado’s strong rotation. It is in this region that strong upward motions occur that carry debris upward, as well as around the tornado.
- Near the surface, away from the tornado’s vortex. In this region, the flow is a combination of the tornado’s rotation, inflow into the tornado, and the background wind. The importance of the rotational winds as compared to the inflow winds decreases with distance from the tornado’s vortex. The flow in this region is extremely complicated. The strongest winds are typically concentrated into relatively narrow swaths of strong spiraling inflow rather than a uniform flow into the tornado’s vortex circulation.
- Above the surface, typically above the tops of most buildings. In this region, the flow tends to become nearly circular.

In a tornado, the diameter of the core or vortex circulation can change with time, so it is impossible to say precisely where one region of the tornado’s flow ends and another begins. Also, the visible funnel cloud associated with and typically labeled the vortex of a tornado is not always the edge of the strong, high winds. Rather, the visible funnel cloud boundary is determined by the temperature and moisture content of the tornado’s inflowing air. The highest wind speeds in a tornado occur at a radius measured from the tornado vortex center that can be larger than the edge of the visible funnel cloud’s radius. It is important to remember that a tornado’s wind speeds cannot be determined solely from its appearance.

From 1971 until February 2007, tornadoes were typically categorized according to the Fujita Scale (F Scale), which was created by the late Dr. Tetsuya Theodore Fujita, University of Chicago. The Fujita Scale[1] categorized tornado severity by damage observed, not by recorded

[1] The text describing the Fujita Scale and the Enhanced Fujita Scale was primarily taken from the report titled: *A Recommendation for an Enhanced Fujita Scale (EF-Scale)*, October 17, 2006, by the Wind Science and Engineering Research Center, Texas Tech University.

wind speeds. Ranges of wind speeds have been associated with the damage descriptions of the Fujita Scale, but their accuracy has been called into question by both the wind engineering and meteorological communities, especially the ranges for the higher end (F4 and F5) of the scale. The wind speeds were estimates intended to represent the observed damage. They were not calibrated, nor did they account for variability in the design and construction of buildings.

As a result, the Wind Science and Engineering (WISE) Research Center at TTU and other researchers from the wind engineering and meteorological communities worked together to revise and update the Fujita Scale over the past several years. The resulting tornado classification scale is called the Enhanced Fujita Scale (EF Scale). The primary limitations of the Fujita Scale were a lack of damage indicators, no account of construction quality and variability, and no definitive correlation between damage and wind speed. These limitations have led to inconsistent ratings of tornadoes.

NOTE

Dr. Fujita's group at the University of Chicago and personnel at the National Severe Storms Forecast Center (NSSFC) independently assigned Fujita Scale ratings to tornadoes in the historical records based on written descriptions of the damage. However, the primary recordkeeper of the NSSFC data became the Storm Prediction Center (SPC), which maintained the tornado track data through 1995. Tornado records since that time are kept at the National Climatic Data Center (NCDC) in Asheville, North Carolina.

Based on its vast experience in tornado damage and investigation, the TTU team assigned to the project proposed 28 damage indicators that consisted of buildings, structures, and trees. For each damage indicator (DI), several degrees of damage (DODs) are identified. The DODs are sequenced so each one requires a higher expected wind speed than the previous one. Damage ranges from the initiation of visible damage to complete destruction of the particular DI.

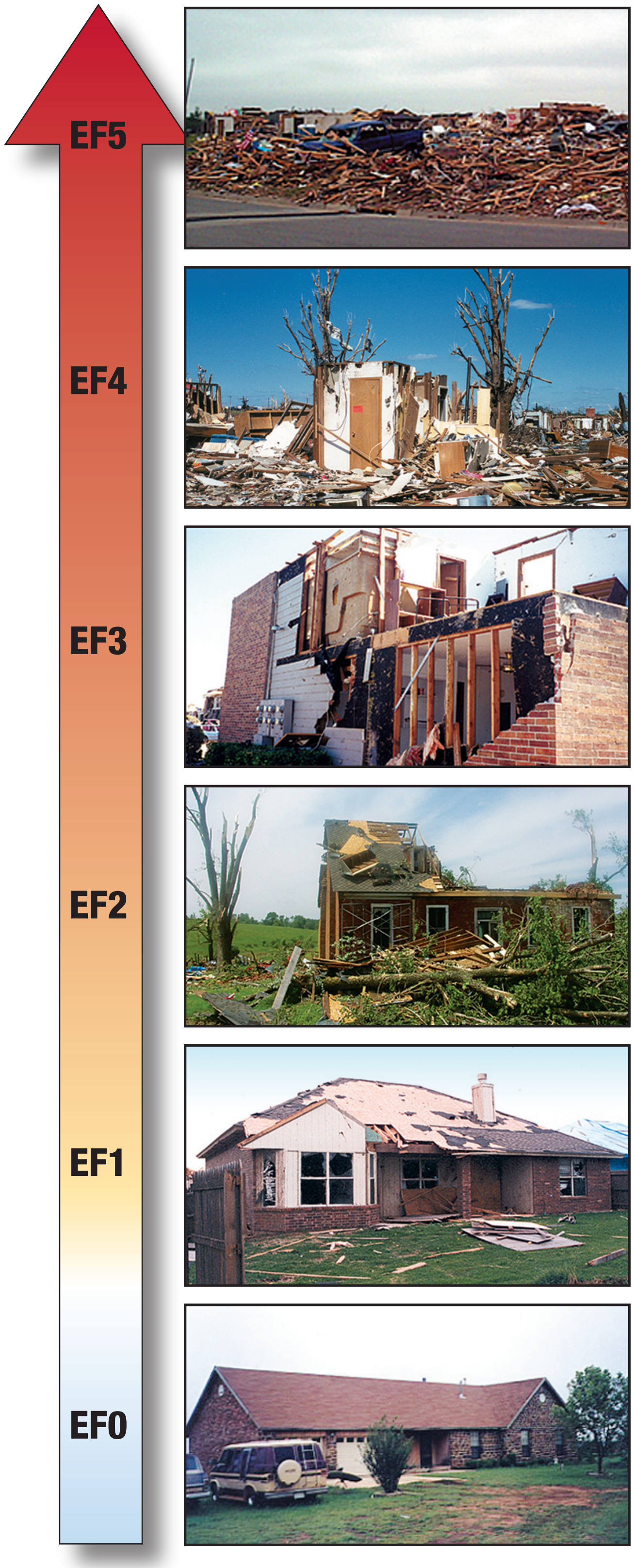
The strategy of damage indicators requires that an expected, upper and lower bound wind speed be defined for each DOD. The range of wind speed defined by the upper and lower bound wind speeds accounts for circumstances that cause the actual wind speed associated with the damage to deviate from the expected value. The expected value of wind speed to cause a given DOD is based on a set of "normal" conditions. A weak link is a discontinuity in the load path, which runs from the building surface through the structural system to the foundation.

The EF scale addresses the major limitations of the original Fujita Scale. Additional DIs are proposed along with DODs. Through an expert elicitation process, wind speeds corresponding to the described damage for each DOD are estimated. The estimated wind speed then determines the EF Scale category appropriate for the observed damage. The categories range from EF0 to EF5. The wind speed ranges in each category are related to Fujita Scale ranges by a correlation function (see the 2006 WISE paper) and are shown in Table 4-1. This correlation between Fujita Scale and EF Scale wind speeds provides a link between the two scales and thus makes it possible to express a Fujita Scale rating in terms of an EF Scale rating. The only difference is the wind speed ranges in each scale. Thus, the historical tornado database is preserved and can be easily converted to the criteria of the EF Scale. Figure 4-1 presents a description of the damage states of the EF Scale and provides photos to assist with understanding.

Table 4-1. Comparison Table for the Fujita and Enhanced Fujita Scales

Fujita Scale		EF Scale	
Fujita Scale	**3-Second Gust Speed (mph)**	**EF Scale**	**3-Second Gust Speed (mph)**
F0	45-78	EF0	65-85
F1	79-117	EF1	86-109
F2	118-161	EF2	110-137
F3	162-209	EF3	138-167
F4	210-261	EF4	168-199
F5	262-317	EF5	200-234

The Fujita Scale categorizes tornado severity based on observed damage. The six-step scale ranges from F0 (light damage) to F5 (incredible damage). Since February 2007, the National Weather Service has used the Enhanced Fujita Scale (EF Scale). This new scale ranges from EF0 to EF5. See http://www.spc.noaa.gov/efscale for further information on the EF Scale.



Incredible: Strong frame houses are lifted from foundations, reinforced concrete structures are damaged, automobile-sized missiles become airborne, trees are completely debarked.

Devastating: Well-constructed houses are destroyed, some structures are lifted from foundations and blown some distance, cars are blown some distance, large debris becomes airborne.

Severe: Roofs and some walls are torn from structures, some small buildings are destroyed, non-reinforced masonry buildings are destroyed, most trees in forest are uprooted.

Considerable: Roof structures are damaged, mobile homes are destroyed, debris becomes airborne (missiles are generated), large trees are snapped or uprooted.

Moderate: Roof surfaces are peeled off, windows are broken, some tree trunks are snapped, unanchored mobile homes are overturned, attached garages may be destroyed.

Light: Chimneys are damaged, tree branches are broken, shallow-rooted trees are toppled.

Figure 4-1. Typical tornado damage

4.2.2 Hurricanes and Typhoons

A hurricane, as defined by NOAA, is a tropical cyclone in which the maximum sustained surface wind (using the U.S. 1-minute average) is 74 mph or greater. The term hurricane is used for Northern Hemisphere tropical cyclones east of the International Dateline to the Greenwich Meridian. Tropical cyclones are classified as follows:

- Tropical Depression – An organized system of clouds and thunderstorms with a defined circulation and maximum sustained winds of 38 mph or less.
- Tropical Storm – An organized system of strong thunderstorms with a defined circulation and maximum sustained winds of 39 to 73 mph.
- Hurricane – An intense tropical weather system with a well-defined circulation and sustained winds of 74 mph or higher. In the western Pacific, hurricanes are called "typhoons," and similar storms in the Indian Ocean are called "cyclones."

Hurricanes that affect the U.S. mainland are products of the Tropical Ocean (Atlantic Ocean, Caribbean Sea, or Gulf of Mexico) and the atmosphere. Powered by heat from the sea, they are steered by the easterly trade winds and the temperate westerly trade winds, as well as by their own intense energy. Around their core, winds grow with great velocity, generating violent seas. Moving ashore, they sweep the ocean inward (storm surge) while spawning tornadoes, downbursts, and straight-line winds, and producing torrential rains and floods. A comparison of the sustained wind speed measure of the Saffir-Simpson Hurricane Scale and the 3-second gust measure now used by ASCE 7-05, the ICC-500, and this publication for their respective wind speed maps is presented in Table 4-2.

Table 4-2. The Saffir-Simpson Hurricane Scale Wind Speeds and Pressures

Strength	Sustained Wind Speed (mph)*	Gust Wind Speed (mph)**	Pressure (millibars)
Category 1	74-95	89-116	>980
Category 2	96-110	117-134	965-979
Category 3	111-130	135-159	945-964
Category 4	131-155	160-189	920-944
Category 5	>155	>189	<920

* 1-minute sustained over open water

** 3-second gust over open water

Hurricanes are categorized according to the Saffir-Simpson Hurricane Scale (see Table 4-2 and Figure 4-2), which is used by the National Weather Service (NWS) to estimate the potential property damage and flooding expected along the coast from a hurricane landfall. The scale is a 1 to 5 rating based on the hurricane's intensity. Wind speed and barometric pressure are the determining factors in the scale. Storm surge is not a determining factor, because storm surge values are highly dependent on the slope of the continental shelf in the landfall region.

Recently, there has been an increased recognition of the fact that wind speed, storm surge, and inland rainfall are not necessarily related. There is growing interest in classifying hurricanes by separate scales according to the risks associated with each of these threats.

In terms of wind interaction with buildings, hurricanes create both positive and negative (i.e., suction) pressures. A particular building should have sufficient strength to resist both the applied wind loads and windborne missile impact loads in order to prevent wind-induced building failure or damage. The magnitude of the pressure is a function of many factors, such as the wind speed, exposure, topography, and building height and shape.

Typhoons affect the Pacific Islands (e.g., Guam and American Samoa) and, like hurricanes, can generate high winds, flooding, high-velocity flows, damaging waves, significant erosion, and heavy rainfall. Historically, typhoons have been classified according to strength as either typhoons (storms with less than 150 mph winds) or super typhoons (storms with wind speeds of 150 mph or greater) rather than by the Saffir-Simpson Hurricane Scale. For the purposes of this publication, the guidance provided for hurricanes applies to areas threatened by typhoons.

4.3 Effects of Extreme-Wind Forces

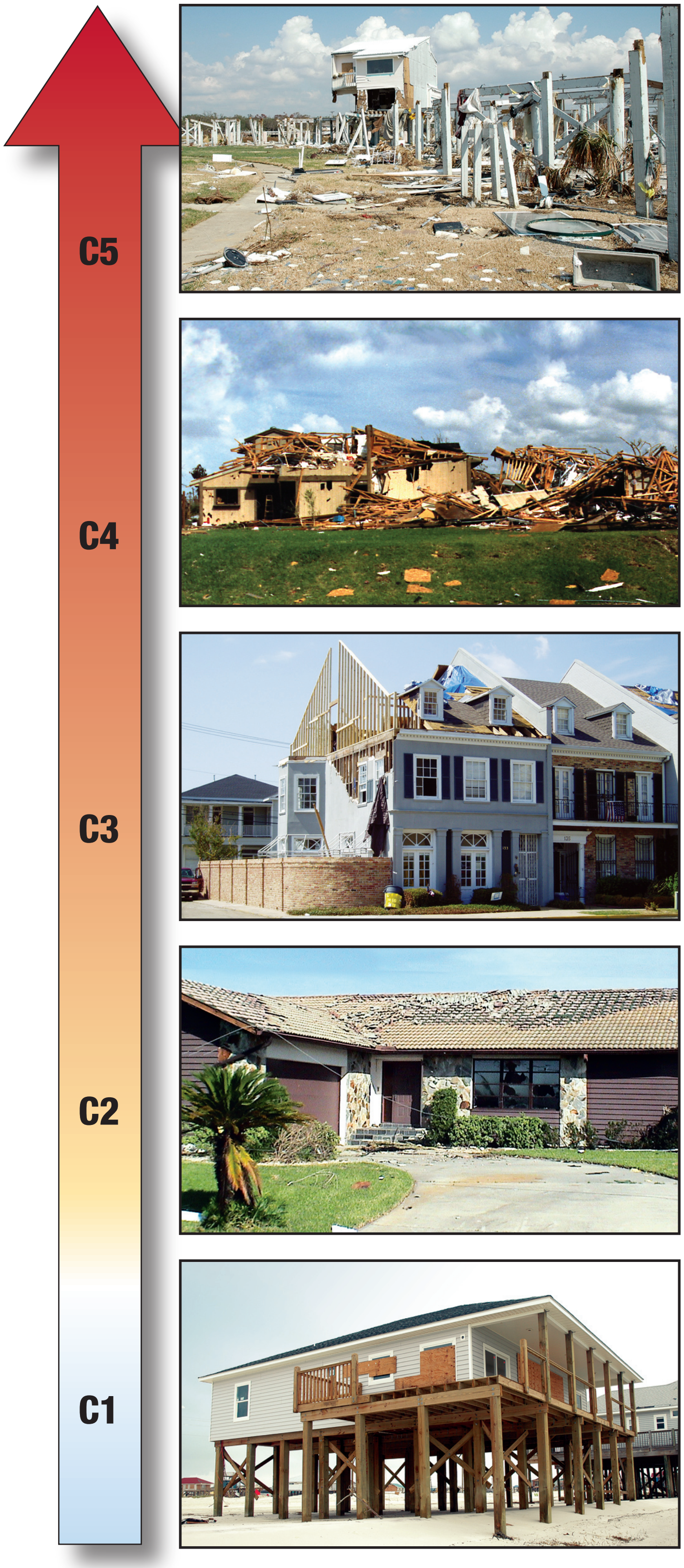
Wind-induced damage to residential and commercial buildings indicates that extreme winds moving around buildings generate loads on building surfaces that can lead to the total failure of a building, especially if that building was not designed to modern, hazard-resistant building codes. In addition, internal pressurization due to a sudden breach of the building envelope (the failure of the building exterior) is also a major contributor to poor building performance under ultimate-wind loading conditions. These loads should be transferred in an identifiable path from the building exterior or, in case of envelope breach, interior surfaces to the structural system and through the foundations into the ground. If a building is constructed with such a path (called a continuous load path), the building's ability to survive during a design event will be improved, even if a portion of the building envelope fails. This section discusses topics related to wind and wind pressures acting on buildings. The importance of a continuous load path within a building or structure is discussed in Chapter 6.

CROSS-REFERENCE

Section 6.6 presents detailed information about continuous load paths. A continuous load path is required in a safe room in order for it to resist the wind and wind pressures described in this section.

CROSS-REFERENCE

The design wind speed for a safe room designed to the criteria set forth in this publication is selected from either Figure 3-1 or Figure 3-2, depending upon the hazard or combined hazards. If the safe room is being designed as a combined hazard safe room, the highest wind speed should be selected for the proposed location on each map.



Catastrophic: Roof damage is considerable and widespread, window and door damage is severe, there are extensive glass failures, some complete buildings fail.

Extreme: Extensive damage is done to roofs, windows, and doors; roof systems on small buildings completely fail; some curtain walls fail.

Extensive: Large trees are toppled, some structural damage is done to roofs, mobile homes are destroyed, structural damage is done to small homes and utility buildings.

Moderate: Some trees are toppled, some roof coverings are damaged, major damage is done to mobile homes.

Minimal: Damage is done primarily to shrubbery and trees, unanchored mobile homes are damaged, some signs are damaged, no real damage is done to structures.

Figure 4-2. Typical hurricane damage

4.3.1 Effects of Tornado and Hurricane Wind Forces

Damage to buildings from tornadoes and hurricanes can occur as a result of three types of forces:

- Forces induced by changes in atmospheric pressure (for tornadoes only)
- Wind-induced forces
- Forces induced by debris impact

The atmospheric pressure in the center of the tornado vortex is lower than the ambient atmospheric pressure. When a tornado vortex passes over a building, the outside pressure is lower than the ambient pressure inside the building. This atmospheric pressure change (APC) in a tornado may cause outward-acting pressures on all surfaces of the building. If there are sufficient openings in the building, air flowing through the openings will equalize the inside and outside atmospheric pressures, and the APC-induced forces will not be a problem. However, it should be noted that openings in the building envelope also allow wind to enter the building and cause internal pressures in addition to wind-induced aerodynamic external pressures (see Section 6.3.1).

Maximum APC occurs in the center of a tornado vortex where winds are assumed to be zero. A simple tornado vortex model suggests that, at the radius of the maximum winds, APC is one-half of the maximum value. Thus, for tornado loadings, two situations of the state of the building should be considered: (1) sealed building or (2) vented building (i.e., a building with openings). For a sealed building, the maximum design pressure occurs when wind-induced aerodynamic pressure is combined with one-half APC-induced pressure. For a vented building, the maximum design pressure occurs when wind-induced aerodynamic pressure is combined with wind-induced internal pressure. See Chapter 6 for design guidance regarding the effects of APC.

Forces from tornadic and hurricane winds are discussed in the next few sections and guidance on the calculation of these forces is provided in Chapter 6. Forces due to debris impact are discussed later in this chapter and guidance on the evaluation of how to address these forces is provided in Chapter 7.

4.3.2 Forces Generated by the Safe Room Design Wind Speed

The design wind speed for construction of a community safe room should be determined from Figures 3-1 or 3-2 for tornado and hurricane hazards, respectively. When calculating the wind pressures based on the safe room design wind speed, the designer should not consider the effects of the other parts of the building that may normally reduce wind pressures on the safe room. The designer should also consider that the collapse of the non-safe room parts of the building may or may not impart additional loads on the safe room and verify that the safe room is designed for these additional loads.

The design wind speed is used to predict forces on both the main wind force resisting system and on the exterior surfaces of the buildings – components and cladding. The MWFRS is the structural system of the building or safe room that works to transfer wind loads to the ground and includes structural members such as roof systems (including diaphragms), frames, cross bracing, and load-bearing walls. C&C elements include wall and roof members (e.g., joists, purlins, studs), windows, doors, fascia, fasteners, siding, soffits, parapets, chimneys, and roof overhangs. C&C elements receive wind loads directly and transfer the loads to other components or to the MWFRS.

The effects of wind on buildings can be summarized as follows:

- Inward-acting, or positive, pressures act on windward walls and windward surfaces of steep-sloped roofs.
- Outward-acting, or negative pressures act on leeward walls, side walls, leeward surfaces of steep-sloped roofs, and all roof surfaces for low-sloped roofs or steep-sloped roofs when winds are parallel to the ridge.
- Airflow separates from building surfaces at sharp building edges and at points where the building geometry changes.
- Localized suction or negative pressures at eaves, ridges, edges, and the corners of roofs and walls are caused by turbulence and flow separation. These pressures affect loads on C&C.
- Windows, doors, and other openings are subjected to wind pressures and the impact of windborne debris (missiles). If these openings fail (are breached) either because of wind pressure or windborne debris impact, the entire structure becomes subject to wind pressures that can be twice as great as those that would result if the building remained fully enclosed. Further, some or all of the occupants within the safe room would become exposed to wind and windborne debris impact hazards.

Extreme winds associated with tornadoes and hurricanes are capable of imposing large lateral (horizontal) and uplift (vertical) forces on buildings. The strength of the building's structural frame, connections, and envelope determines the ability of the building to withstand the effects of these forces.

Wind loads are influenced by the location of the building site (the general roughness of the surrounding terrain, including open, built-up, and forested areas, can affect wind speed), height of the building (wind pressures increase with height above ground, or the building may be higher than surrounding vegetation and structures and, therefore, more exposed), surrounding topography (abrupt changes in land surface elevations can create a wind speedup effect), and the configuration of the building (roof geometry and building shape).

Roof shape plays a significant role in roof performance, both structurally and with respect to the magnitude of the wind loads. Compared to other types of roofs, hip roofs generally perform better in extreme winds because they have fewer sharp corners and their construction makes them inherently more structurally stable. Gable-end roofs require extensive detailing to properly transfer lateral loads acting against the gable-end wall into the structure. Steeply pitched roofs

(roofs angled to the horizontal at 30 degrees or more) usually perform better than flat roofs because uplift on the windward roof slopes is either reduced or eliminated.

Figure 4-3 illustrates the effects of roof geometry on wind loads. Notice that the roof with the 3-foot parapet around the edges does not have elevated roof pressures at the corners. By comparison, the flat roof without parapet has corner roof wind loads more than 1.5 times the edge pressures of the roof with parapet. Also, the gable-end and hip roofs with a roof pitch of greater than 30 degrees produces the lowest leeward and corner pressures. The highest roof pitches tested are 45 degrees (12 on 12 pitch) because few roofs have steeper pitches than 45 degrees and few data are available for higher slopes.

Wind loads and the impact of windborne debris are both capable of damaging a building envelope. Post-disaster investigations of wind-damaged buildings have shown that many building failures begin because a component or a segment of cladding is blown off, allowing wind and rain to rapidly enter the building. An opening on the windward face of the building can also lead to a failure by allowing positive pressures to build up inside, which, in conjunction with negative external pressures, can "blow the building apart." Figure 4-4 depicts the forces that act on a structure when an opening exists in the windward wall.

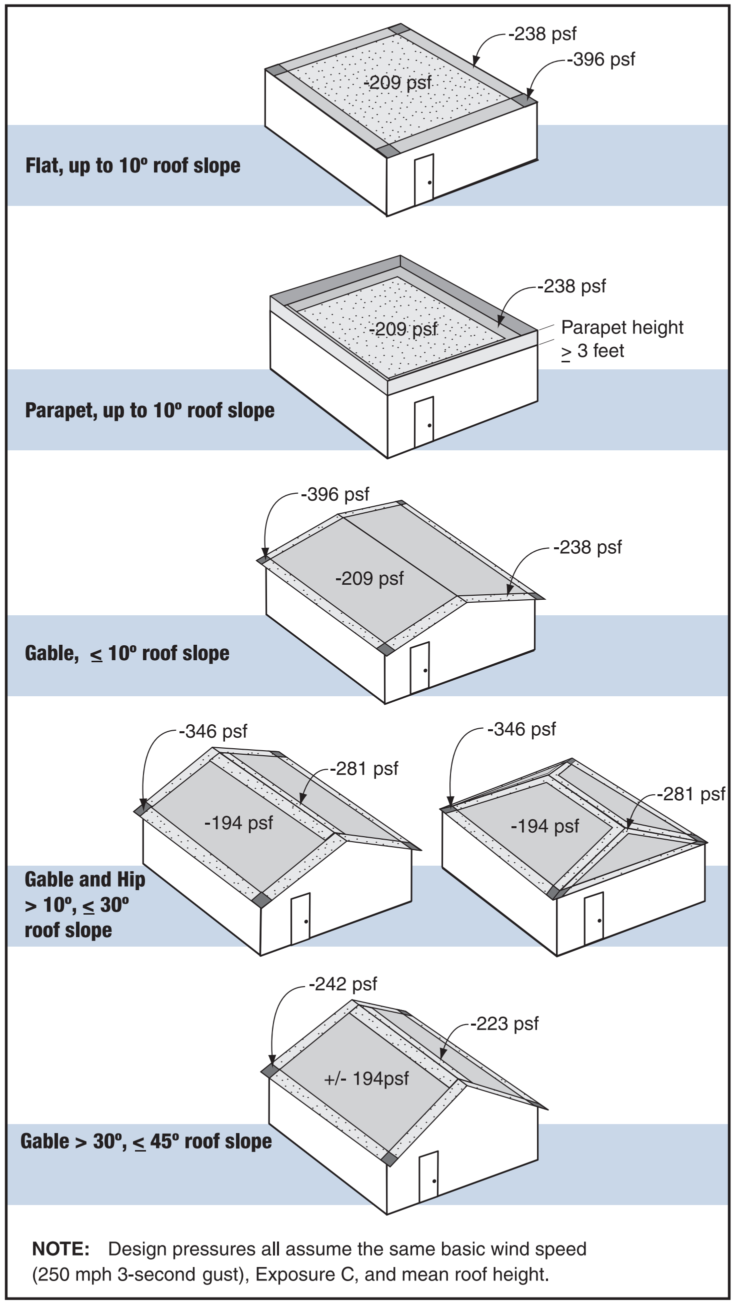


Figure 4-3. Calculated pressures (based on ASCE 7-05 C&C equations) acting on a typical safe room. This figure illustrates the different roof pressures that result for the same building and wind speed as the roof shape is varied. For the calculation of the loads from these pressures, the safe room was assumed to be a 50-foot x 75-foot rectangular building with a constant mean roof height of 12 feet. Note: These loads do not include any additional loads from internal pressurization resulting from either a vented or breached building envelope.

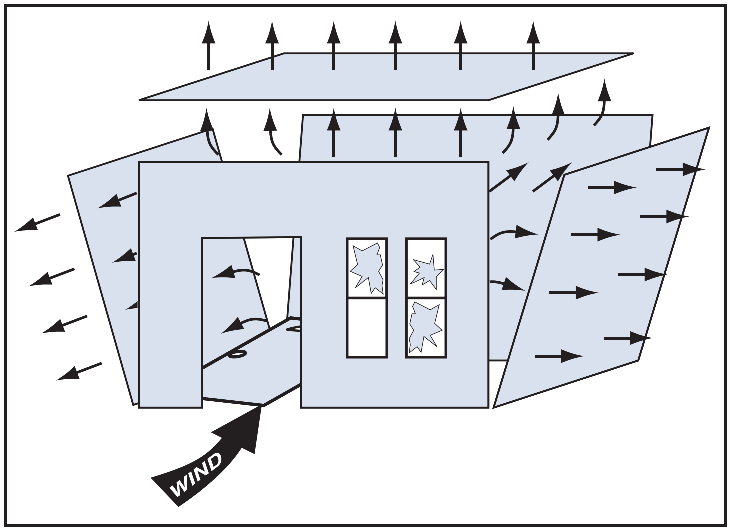


Figure 4-4. Internal pressurization and resulting building failure due to design winds entering an opening in the windward wall

The magnitude of internal pressures depends on whether the building is "enclosed," "partially enclosed," or "open" as defined by ASCE 7-05. The internal pressures in a building are increased when a building changes from an "enclosed" to a "partially enclosed" building (e.g., when a building envelope is breached). The design criteria presented in Chapter 3 (and discussed in detail in Chapters 5, 6, and 7) state that safe room designs to provide occupants with life-safety protection be based on the partially enclosed internal pressures or on enclosure classifications outlined in the ICC-500, Chapter 3. The walls and the roof of the safe room and connections between the components should be designed for the largest possible combination of internal and external pressures. This design concept is in keeping with a conservative approach because of the life-safety issues involved in safe room design.

4.3.3 Building Failure Modes – Elements, Connections, and Materials

The wind forces described in the previous section will act on a building as both inward-acting and outward-acting forces. The direction and magnitude of the forces are governed by the direction of the wind, location of the building, height and shape of the building, and other conditions that are based on the terrain surrounding the building. Chapter 6 of this publication and Section 6 of ASCE 7-05 provide information on calculating the direction and magnitude of the wind forces acting on a building once the design wind speed and types of openings in the building envelope have been determined.

Building failures can be independently categorized by one or a combination of the four failure modes illustrated in Figure 4-5. Winds moving around a building or structure may cause sliding, overturning, racking, and component failures. A sliding failure occurs when wind forces move a building laterally off its foundation. An overturning failure occurs when a combination of the lateral and vertical wind forces cause the entire building to rotate about one of its sides. A racking failure occurs when the building's structural system fails laterally, but the building typically remains connected to the foundation system. A component failure, the most common failure seen during extreme-wind events (and typically a contributing factor to the first three failure modes listed), may be caused by wind pressures or windborne debris (missile) impacts. Component failures may be either full-system failures or individual element failures.

Most buildings are designed as enclosed structures with no large or dominant openings that allow the inside of the building to experience internal pressurization from a wind event. The beginning of this chapter identified the concept that, under extreme-wind conditions, a breach in the building envelope due to broken windows, failed entry doors, or failed large overhead doors may cause a significant increase in the net wind loads acting on building components such as walls and the roof structure. In such cases, the increase in wind loads may cause a partial failure or propagate into a total failure of the primary structural system. Uplift or downward forces (depending on roof pitch and wind direction) may act upon the roof of the building and cause overturning, racking, or failure of components.

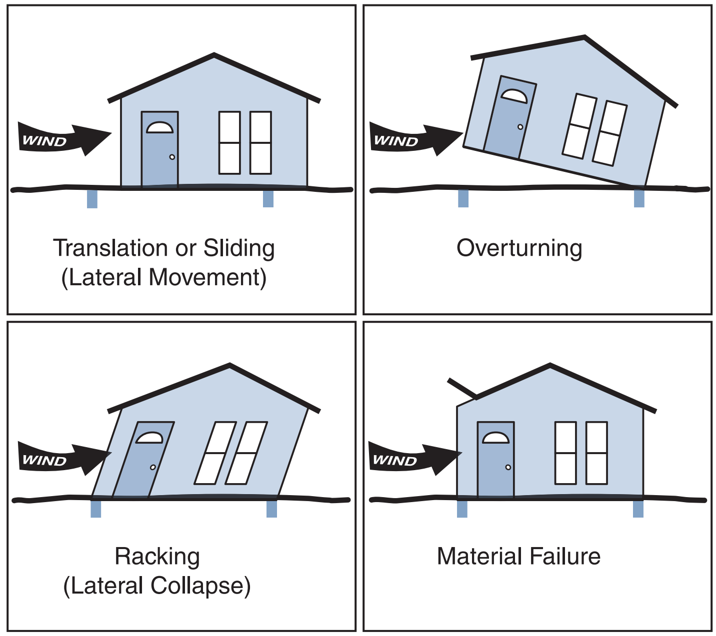


Figure 4-5. Forces on a building due to wind moving around the structure

4.3.4 Cyclic Loading

Both tornadoes and hurricanes have unsteady wind patterns within their circular wind fields. These effects cause cyclic loading on buildings. Tornadoes, however, generally pass over a site in a very short time. Wind experts believe that the cyclic periods of wind loads in tornadoes are short and less frequent than those in hurricanes. Thus, designing tornado safe rooms for cyclic loads is not required.

Hurricane winds typically affect a site for a much longer period of time, which can result in many repetitive cycles close to the peak loads. Failures in the roof system itself and of roof-to-wall, wall-to-wall, wall-to-floor, and wall/floor to foundation connections are precipitated under such repetitive loads. Cyclic loads become particularly important when either the structure or a component is flexible or when the fastening system receives repetitive loading. When cyclic loads are to be considered, designers are advised to review loading cycles given in the ICC-500, Chapter 8 (Protocols for Testing) for shelters and ASTM Standard E 1996, or to use allowable stresses below the endurance limit of materials or connections. Structural connections of heavy steel and reinforced concrete and masonry construction, where the structural system is rigid, are more likely to resist hurricane cyclic loads.

4.3.5 Windborne Debris and the Selection of the Representative Missile

Tornadoes and hurricanes produce large amounts of debris that become airborne. This windborne debris (missiles) may kill or injure persons unable to take refuge and may also perforate the envelope and other components of any conventional building in the path of the debris. The actual size, mass, and speed of missiles in tornadoes or hurricanes vary widely by storm type and event. Only a few direct measurements of debris velocity have been made; such measurements require the use of photogrammetric techniques to analyze videos of tornadoes that contain identifiable debris. For this reason, the choice of the missile, the impact of which a safe room should withstand, is somewhat subjective and relies upon the selection of a "representative" missile traveling at an assumed speed related to the safe room design wind speed. Tornadic winds tend to lift and accelerate debris (missiles) consisting of roof gravel, sheet metal, tree branches, broken building components, and other items. Large debris, such as cars, tends to tumble along the ground. The impact of this debris can cause significant damage to wall and roof components. The speed at which the representative missile travels is a function of the shelter design wind speed and was presented in Section 3.3.2.

2x6 missile penetrating a refrigerator, Midwest tornadoes of May 3, 1999

A plywood missile lodged in a palm tree, Hurricane Andrew

From over 38 years of post-disaster investigations after tornadoes and hurricanes, the WISE Research Center at TTU concluded that the missile most likely to perforate building components during a hurricane event is a 2x4 wood member, weighing up to 15 pounds. Other, larger airborne missiles do occur; for example, cars can be moved across the ground or, in extreme winds, they can be tumbled, but they are less likely than smaller missiles to perforate building elements. Following the Oklahoma and Kansas tornado outbreaks of May 3, 1999, both FEMA and TTU investigated tornado damage and debris fields and concluded that resistance to the impact of a 15-lb 2x4 missile was a reasonable criterion for tornado safe room design.

The ICC-500 Shelter Standard Committee worked to define the appropriate representative missile and speed for hurricane hazards although the data and research on windborne debris associated with both hurricanes and tornadoes are limited at best. As a result, little data are available from the field, wind tunnel tests, or empirical studies to discuss this topic in detail. The committee concluded that, based on construction in coastal areas, it was appropriate that the representative, large missile need not be larger than the 9-lb 2x4 board member. However, a notable point is that the FEMA safe room publications review committee examined the ICC-500 proposed debris impact criteria and testing methods and supporting data, and ended with a different determination as to the appropriate speed at which the representative missile travels during a hurricane. As a result, the FEMA criteria will utilize the same 9-lb 2x4 board member as the large, representative missile, but will test the impact resistance of a safe room at a higher speed than the ICC-500. The speed at which the representative missile travels is a function of the shelter design wind speed and was presented in Section 3.3.2. More detail on this topic is provided in Chapter 7.

CROSS-REFERENCE

Chapter 7 presents additional information about cyclic loading for missile impact protection and for code compliance in specific regions of the country.

4.4 Multi-Hazard Considerations

Most safe rooms are built with a single purpose in mind: to protect the local population against the dangers inherent to extreme-wind events. This singular objective, however, should not divert the designers' and local decision-makers' attention from the all too real presence of other hazards, both natural and manmade. For this reason, designers and local officials alike should adopt a multi-hazard approach from the very beginning of their safe room deliberations. Multi-hazard approach to building design has gained prominence and the support of FEMA and other government agencies and professional associations that have long promoted this approach. This is not only because a multi-hazard approach ensures a comprehensive risk analysis and appropriate mitigation responses, but because it is able to optimize building design and produce the most cost-effective design solutions over a life-cycle of a building.

4.4.1 Multi-Hazard Risk Assessment

Once it is established that extreme winds represent a sufficient threat to the community, it is recommended that a multi-hazard approach be used in assessing the multitude of risks. The potential adverse effects of other hazards on the functionality of safe rooms should be identified, evaluated, and documented. The final risk analysis should include these multi-hazard considerations in order to produce as comprehensive a list of design requirements as possible.

4.4.2 Multi-Hazard Design

Multi-hazard design (i.e., the design of buildings that may be exposed to more than one hazard) can be both an advantage and a disadvantage for the designer. This is because, on the one hand, two or more hazards may pose design requirements that reinforce each other, thus reducing costs and improving protection. On the other hand, design requirements for some hazards may be conflicting, thereby making them extremely difficult to reconcile. Many recommended features of wind-resistant design, for example, are detrimental for earthquake-resistant design and vice versa. In such circumstances, it is extremely important to conduct a careful risk analysis and identify all design constraints and prioritize all design parameters.

4.4.3 Flood Hazards

The designer should investigate all sources of flooding that could affect the use of the safe room. It should be remembered that the functionality of the safe room can be affected by flooding in many different ways. The building itself may be under water or surrounded by water, but it can also be affected indirectly when access to the safe room is disrupted or blocked as a result of flooding in the area.

The sources of flooding include floods up to and including the 500-year flood, any flood of record, flooding from storm surge (in coastal areas), and flooding from local drainage. If it is not possible to locate a community safe room on a site outside an area subject to the flooding defined in the hazard design criteria provided in Chapter 3, special precautions should be taken to ensure the safety and well-being of anyone using the safe room. The lowest floor of the safe room should be elevated above the flood elevation from any of the flooding sources described. All utilities or services provided to the safe room should be protected from flooding as well. Additionally, the planning and design of the proposed safe room should be conducted according to the 8-step process mandated by the Executive Order 11988, Floodplain Management.

A safe room in a flood-prone area should be properly equipped to meet any emergency medical, food, and sanitation needs during the time the occupants could be isolated by flooding. Access to the safe room should be maintained during flooding conditions. If access is not possible by ground transportation during flooding, alternative access should be provided. An example of how alternative access can be achieved is the installation of a helicopter pad that is above the flood levels. In all cases, both the designer and the owner will need to work with local and state emergency managers to ensure that these special requirements are met, both in the safe room design and construction and in emergency operation procedures.

For residential safe rooms, the design criteria are more stringent than for the community safe rooms (and also when compared to the ICC-500). Residential safe rooms cannot be placed in any area that may be affected or inundated by coastal storm surge for any category hurricane. Potential safe room owners should be aware that flood design criteria for residential safe rooms is provided to guide the appropriate design and construction of safe rooms that may be exposed to these hazards.

Whether constructing a community or residential safe room, the safe room developer should remember that FEMA provides policy statements and guidance separate from the design criteria in this publication for both wind and flood hazards associated with extreme-wind shelter projects. The FEMA HMA Safe Room Policy, and associated guidance, should be consulted for the latest information from FEMA regarding implementation of safe room design criteria and how much of the design criteria may be eligible for federal funding.

4.4.4 Seismic Hazards

When a safe room is in a seismically active area as defined by the IBC, ASCE 7-05, or FEMA's National Earthquake Hazards Reduction Program (NEHRP) provisions, a seismic risk assessment of the structure should be conducted. New facilities will also require the assessment of risks for the selected site conditions. Seismic design requirements should be reviewed for compatibility with other design parameters and prioritized according to the design program.

As mentioned earlier, wind and earthquake (seismic) loads differ in the mechanics of loading (i.e., the way the load is applied). In a wind event, the load is applied to the exterior of the envelope of the structure. Typically, internal building elements that are not part of the MWFRS of the building will not receive loads unless there is a breach of the building envelope. Earthquakes induce loads based on force acceleration relationships. These relationships require that all objects of mass develop loads. Therefore, all structural elements and all non-structural components within, and attached to, the structure will be loaded. As a result, seismic loading requires both exterior building elements and internal building elements (including non-load-bearing elements and fixtures) to be designed for the seismically-induced forces.

Another important seismic consideration for the designer is the assumed response of the structure during an event. Buildings are designed to remain elastic during a wind event – elastic in the sense that no permanent deformation of any of the structural members will occur. For earthquakes, this is not the case. Design for earthquakes is based on a two-earthquake scenario. The first earthquake is the common earthquake that can occur many times in the life of a structure and the second is the larger, rare earthquake. The design process requires that the structure remain elastic for the common earthquake. But, for the rare earthquake, permanent deformation is allowed as long as it does not result in structural collapse of the building. Building elements that can "stretch and bend" give a structure the ability to withstand a large earthquake without the economic penalty of having to accommodate the rare earthquake without any permanent deformation.

Design Methods

After earthquakes in the 1920s and 1930s in California, engineers began to recognize the need to account for the lateral seismic-induced loads on structures. The first seismic codes calculated lateral seismic-induced loads using a percentage of the weight of the structure. This allowed common analysis procedures to be used. This method has been retained and is seen in today's building codes. It is commonly called the equivalent static force method. Over the years, this percentage coefficient has been refined and put on a more rational basis derived from the dynamic analysis of structures.

There are cases in which a more complicated dynamic analysis procedure is required. This dynamic analysis is common in the design and construction of very tall, irregular structures. The structures are considered irregular if they are not cube-like or do not have a rectangular footprint. They may have wings or appendages like an "L" or they may be "cross-shaped" structures. Figure 4-6 shows examples of buildings with regular and irregular shapes.

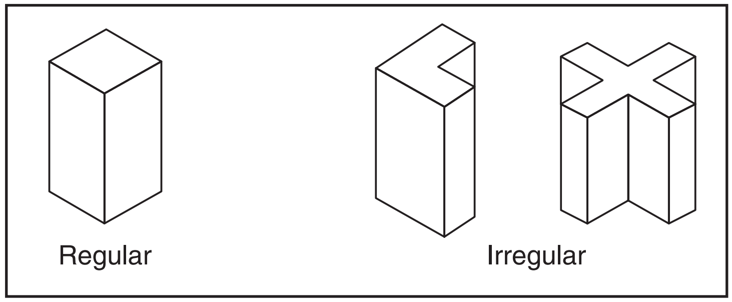


Figure 4-6. Examples of buildings with regular and irregular shapes

The dynamic analysis procedure for these types of structures consists of three parts:

1. A time history analysis is conducted.
2. A response spectrum is developed.
3. A modal analysis of the final structure is performed.

Unless a seismic event has occurred and is documented at the exact building site, some sort of computed ground movement should be developed. This can be done in several ways. One is to use the existing earthquake records and average several of them to produce a composite ground motion. Figure 4-7 is an actual graphical representation of a time response of the ground during a seismic event.

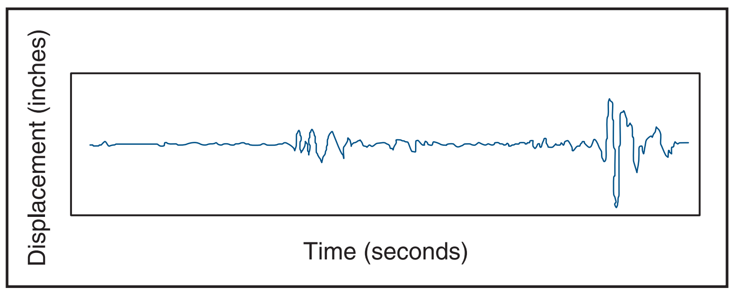


Figure 4-7. Time response of ground during a seismic event

Another way is to synthetically generate this motion using models of geologic phenomena and soil conditions. In either case, the result is a description of the movement and acceleration of the ground. Once this acceleration is defined, the acceleration is used as input in a single-degree-of-freedom system, illustrated in Figure 4-8. The single-degree-of-freedom system is a model of the building system with mass from floors and roof systems consolidated together to represent the building as a mass (M) supported by vertical building elements, with stiffness (k), acted upon by a lateral force (F) representative of the ground acceleration.

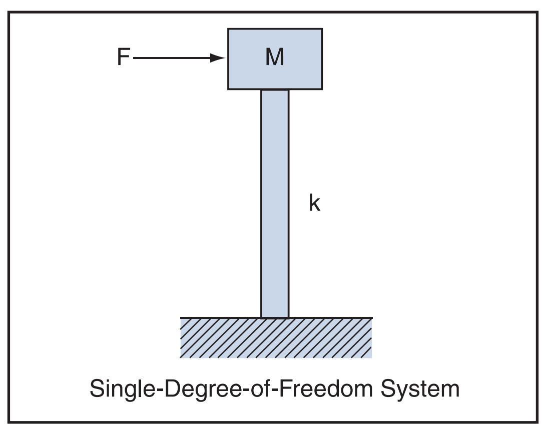


Figure 4-8. Example of a single-degree-of-freedom system

The stiffness (k) of the system can be varied to change the period of the building response to the applied lateral force. When this is done, a plot is made of the acceleration versus the period of the structure (see Figure 4-9). This type of plot is known as a Response Spectrum for the induced earthquake motion and illustrates the elastic structural system response to a particular earthquake motion.

The last step in the dynamic analysis is to perform a modal analysis on the actual building. This type of analysis provides the motion of the building in terms of a single-degree-of-freedom system. Therefore, the response spectrum can be input into the modal analysis to give the building's response to the earthquake.

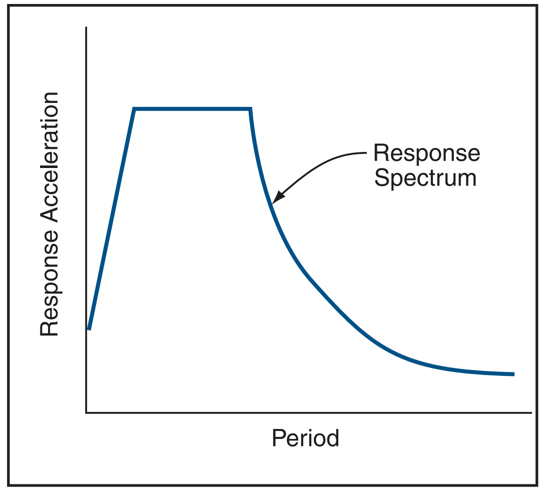


Figure 4-9. Acceleration vs. period of structure

Both the static method and the dynamic method determine the lateral forces acting on the structure. The geographic region of the country in which the safe room is located will dictate which analysis should be used. Once the forces are calculated, they can be input into the load combinations (as seismic load E) used for the design of the safe room.

Code Development

Earthquake codes are under continual refinement as new data become available. This continual refinement attempts to give more accurate models of how a structure responds to ground motion. Seismic events, like wind events, are constantly occurring and continue to test buildings constructed to recently improved codes and standards. An earthquake provides a test for the current procedures; after every event, those procedures are reviewed to ensure they are acting as intended.

An example of code development is the recent acknowledgment that seismic events occurring on the west and east coasts are not expected to be the same type of seismic event. On the west coast, the difference between the common earthquake and the rare earthquake is small. Design codes assume that the rare earthquake is only 50 percent larger than the common earthquake. On the east coast, this is not the case. In this region, the rare earthquake can be as much as 400 percent larger than the common earthquake. Therefore, prior to the release of the 2000 IBC, western U.S. design codes did not fit well to eastern U.S. earthquake requirements.

This poor fit has led to refinements in seismic design procedures. The new procedures attempt to provide a process for evaluating the response of a building when it begins to deform from seismic loads. This approach is needed to ensure that the structure can stretch and bend to resist the rare earthquake. In the western U.S., this is ensured because of the minimal difference between the two different earthquakes; however, this cannot also be assumed in the eastern U.S.

Other Design Considerations

All the elements of the structure should be evaluated for earthquake forces. Not only are the exterior walls loaded, but the interior walls can also receive substantial out-of-place loads. For wind loading, these interior building components are not usually considered, although most codes require interior walls to be designed for some lateral pressures. Seismically-induced forces may be larger than the code-specified lateral wind pressures and, as a result, govern the design in seismically active areas. For areas that may have both wind and seismic activity, the careful evaluation of which forces may govern the design is an important step in the design process. Therefore, the design of these elements and their connections to the main structure are essential to a complete design – one in which both structural and non-structural elements are considered.

Earthquake requirements considered in the design of a safe room can enhance the lateral resistance of the structure to wind loads. For example, seismic loads tend to govern the designs of “heavy” structures constructed with concrete or masonry walls and concrete slab or roofs. In “lighter” structures constructed from framing and light structural systems supporting lightweight (metal or wood) roof systems, wind loads tend to govern. But even if wind loads govern, consideration should be given to the calculated seismic loads to allow the structure to deform without immediate failure. This ability gives the structure reserve capacity that can be useful in extreme-wind events.

Earthquake requirements will also govern the design of all interior non-structural building components, fixtures, and equipment. For exterior-mounted equipment, both seismic and wind loads must be considered, as either may govern the design of the exterior component.

4.5 Other Hazards

It is important that the designer consider other hazards at the building site, in addition to the wind, flood, and seismic hazards already mentioned. One such consideration is the location of a safe room on a building site with possible physical hazards (e.g., other building collapses or heavy falling debris). These siting and location issues are discussed in Chapter 5.

Another consideration is the presence of a hazardous material (HAZMAT) on a site. Older buildings that are retrofitted for safe room use should be inspected for hazardous materials that may be stored near the safe room (e.g., gasoline, chlorine, or other chemicals) or that may have been used in the construction of the surrounding building (e.g., lead paint or asbestos). For example, asbestos may become airborne if portions of the surrounding building are damaged, resulting in the chemical contamination of breathable air. Live power lines, fire, and gas leaks are also safe room design concerns that may need to be addressed at some safe room sites. For example, the case study in Appendix D (Sheet P-1) shows how a gas line, required for gas service to the safe room area when in normal daily use, was fitted with an automatic shutoff valve. This precaution greatly reduces the risk of a gas-induced fire occurring while the safe room is occupied.

4.6 Fire Protection and Life Safety

The safe room should comply with the fire protection and life-safety requirements of the model building code, the state code, or the local code governing construction in the jurisdiction where the safe room is constructed. For single-use extreme-wind safe rooms, the model building codes, life-safety codes, and engineering standards do not indicate square footage requirements or occupancy classifications. For multi-use extreme-wind safe rooms, the codes and standards address occupancy classifications and square footage requirements for the normal use of the safe room. The designer is advised to comply with all fire and life-safety code requirements for the safe room occupant load and not the normal use load; the safe room occupancy load is typically the controlling occupancy load. Chapter 3 presented the recommended square footage requirements for tornado and hurricane safe rooms.

Guidance and requirements concerning fire protection systems may be found in the model building codes and the life-safety codes. Depending on the occupancy classification of the safe room (in normal use), automatic sprinkler systems may or may not be required. For many safe rooms, an automatic sprinkler system will not be required. However, when automatic sprinkler systems are not required and fire extinguishers are used, all extinguishers should be mounted on the surface of the safe room wall. In no case should a fire extinguisher cabinet or enclosure be recessed into the interior face of the exterior wall of the safe room. This requirement is necessary to ensure that the integrity of the safe room walls is not compromised by the installation of fire extinguishers. Finally, any fire suppression system specified for use within safe rooms should be appropriate for use in an enclosed environment with human occupancy. If a fire occurs during a tornado or hurricane, it may not be possible for occupants of the safe room to ventilate the building immediately after the discharge of the fire suppression system.

Design and Construction Guidance for Community Safe Rooms Part 2
Updated on: 8/19/2012

1. The design of a safe room to resist wind loads relies on the approach to wind load determination taken in _________. For consistency, the designer may wish to use the same document to determine other loads such as dead, live, seismic, flood, and snow loads that may act on the safe room.

    a) AISI
    b) ASCE 7-05
    c) ACI 316
    d) none of the above

2. Where the purpose of a safe room is to provide life-safety protection from both tornadoes and hurricanes, the entire safe room should be designed and constructed using the most restrictive of the two sets of criteria.

    a) True
    b) False

3. Wind and seismic loads should not be considered to act simultaneously.

    a) True
    b) False

4. The exposure category from ASCE-7 to be used for safe rooms is _________.

    a) A
    b) B
    c) C
    d) D

5. The height of a safe room is restricted to no more than 7 feet per FEMA guidelines.

    a) True
    b) False

6. Each community safe room should be sized to accommodate a minimum of one wheelchair space for every _________ occupants.

    a) 20
    b) 50
    c) 200
    d) 500

7. No portion of the envelope, including: roof, wall, opening, door, window, etc. should fail by wind pressure or be breached by the specified windborne debris (at the appropriate debris impact wind speed).

    a) True
    b) False

8. Safe rooms with at least 12 inches of soil cover protecting horizontal surfaces, or with at least ________ inches of soil cover protecting vertical surfaces, do not need to be tested for resistance to missile impact as though the surfaces were exposed.

   a) 10
   b) 18
   c) 36
   d) 50

9. The hurricane community safe rooms are designed to provide occupants life-safety protection for storm durations of at least _________ hours.

   a) 4
   b) 8
   c) 12
   d) 24

10. To show that the safe room provides life-safety protection against flying debris, all _________ should successfully pass the debris impact-resistance product testing.

    a) wall and roof assemblies
    b) window and door assemblies
    c) exterior cladding systems
    d) all of the above

11. The states along the Atlantic and Gulf coasts have some of the highest occurrence rates of smaller tornadoes (EF0-EF2), while the Great Plains region of the country (which includes parts of Texas, Oklahoma, Kansas, and Nebraska) consistently has the highest occurrence rates of larger tornadoes (EF3-EF5).

    a) True
    b) False

12. Tornadoes occasionally accompany tropical storms and hurricanes that move over land. They are most common in the _________ quadrant of the storm center as it comes onshore.

    a) right front
    b) right rear
    c) left rear
    d) left front

13. The highest wind speeds in a tornado occur at a radius measured from the tornado vortex center that can be larger than the edge of the visible funnel cloud's radius. It is important to remember that a tornado's wind speeds cannot be determined solely from its appearance.

    a) True
    b) False

14. _________ is an organized system of strong thunderstorms with a defined circulation and maximum sustained winds of 39 to 73 mph.

a) Tropical depression
b) Tropical storm
c) Hurricane
d) Typhoon

15. Extensive damage is done to roofs, windows, and doors; roof systems on small buildings completely fail; some curtain walls fail. This sort of damage would be described as _________________ on the FEMA C1-C5 scale.

a) moderate
b) extensive
c) extreme
d) catastrophic

16. Damage to buildings from tornados and hurricanes can occur as a result of _________.

a) forces induced by changes in atmospheric pressure (for tornados only)
b) wind-induced forces
c) forces induced by debris impact
d) all of the above

17. Forces on a building due to wind blowing around the structure include _________.

a) translation or sliding
b) overturning
c) racking
d) all of the above

18. The source of flooding includes _________ and flooding from local drainage.

a) floods up to and including the 500-year flood
b) any flood of record
c) flooding from storm surge (costa areas)
d) all of the above

19. The dynamic analysis for these types of structures consists of _________.

a) a time history analysis
b) a response spectrum
c) a modal analysis of the final structure
d) all of the above

20. Even if wind loads govern, consideration should be given to the calculated seismic loads to allow the structure to deform without immediate failure.

a) True
b) False