Unit 5

Tornado Shelters and Safe Rooms

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Unit 5 Outline

Tornado Shelters and Safe Rooms

- Tornado Design Beyond ASCE 7-22 Minimum Requirements
- Storm Shelter/Safe Room Terminology and Purpose
- Development and Overview of the ICC 500 Storm Shelter Standard
- Structural Design Part 1: Loads and Load Combinations
- Structural Design Part 2: Wind Loads
- Structural Design Part 3: Debris Hazards
- FEMA Safe Room Criteria
- Summary

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Unit 5: Learning Outcomes

- Upon completion of this unit, you will be able to:
  - Identify options for higher levels of tornado protection beyond ASCE 7-22 minimums
  - Explain the differences between performance objectives and load procedures for ASCE 7-22 Chapter 32, tornado shelters, and tornado safe rooms
  - Apply the ICC 500 wind load procedures to determine design pressures on a tornado shelter
- This is important on the job because …
  - Establishes a foundation for selection and implementation of the appropriate tornado design solution for various applications
    - ASCE 7-22
    - ICC 500 Storm Shelter
    - FEMA Safe Room

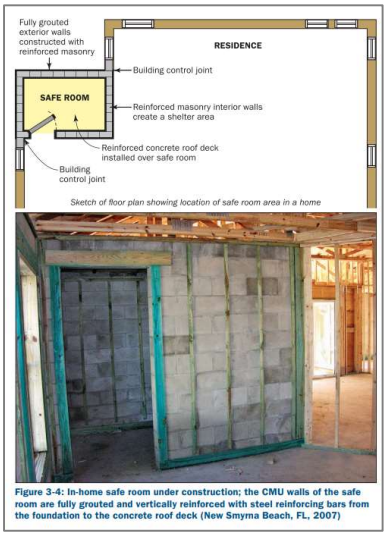

Figure 3-4: In-home safe room under construction; the CMU walls of the safe room are fully grouted and vertically reinforced with steel reinforcing bars from the foundation to the concrete roof deck (New Smyrna Beach, FL, 2007)

https://www.fema.gov/sites/default/files/documents/fema_taking-shelter-from-the-storm_p-320.pdf

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Unit 5: Resources Part 1

- ICC 500-2020 Standard for the Design and Construction of Storm Shelters
  - https://codes.iccsafe.org/content/ICC5002020P1
- 2021 IBC – Section 423
  - https://codes.iccsafe.org/content/IBC2021P1/chapter-4-special-detailed-requirements-based-on-occupancy-and-use#IBC2021P1_Ch04_Sec423
- FEMA P-361 Safe Rooms for Tornadoes and Hurricanes: Guidance for Community and Residential Safe Rooms
  - https://www.fema.gov/sites/default/files/documents/fema_safe-rooms-for-tornadoes-and-hurricanes_p-361.pdf
- FEMA P-320 Taking Shelter from the Storm: Building or Installing a Safe Room for Your Home
  - https://www.fema.gov/sites/default/files/documents/fema_taking-shelter-from-the-storm_p-320.pdf

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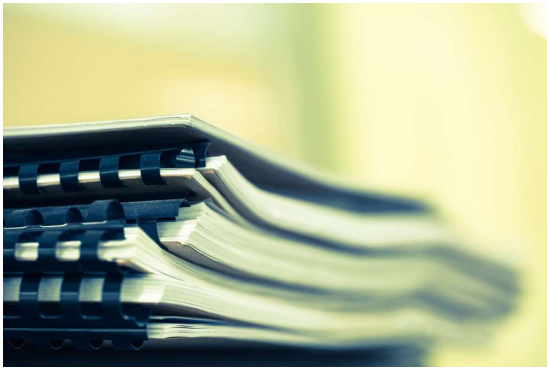
Unit 5: Resources Part 2

- FEMA P-431: Tornado Protection: Selecting Refuge Areas in Buildings
  - https://www.ready.gov/sites/default/files/2020-04/tornado-protection_selecting-refuge-area-in-buildings.pdf
- FEMA P-2062: Guidelines for Wind Vulnerability Assessments of Existing Critical Facilities
  - https://www.fema.gov/sites/default/files/2020-07/guidelines-wind-vulnerability.pdf



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Tornado Design Beyond ASCE 7-22 Minimum Requirements

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ASCE 7-22 Minimum Requirements

- Minimum requirements represent the *least* that can be done
  - Legal minimum when standard is legally adopted as part of a local or state building code
- Minimum requirements may not be appropriate in all situations

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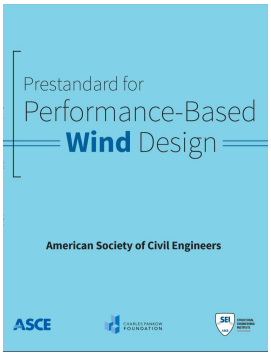
Performance-Based Tornado Design

- Ch. 32 provisions point to general PBD provisions in Chapter 1 and provide for tornado PBD commentary
- Parallel to new section in Chapter 26 on Wind PBD (Section 26.1.3)
- Applications
  - quantify service interruption or loss due to tornadoes
  - improve tornado resistance
  - perform enhanced evaluation of the main wind force resisting system and/or envelope
- Need to adapt Wind PBD procedures for use with tornadoes

32.1.3 Performance-Based Procedures Tornado design of buildings and other structures using performance-based procedures shall be permitted subject to the approval of the Authority Having Jurisdiction. The performance-based tornado design procedures used shall, at a minimum, conform to Section 1.3.1.3 and be documented and submitted to the Authority Having Jurisdiction in accordance with Section 1.3.1.3.



Prestandard available at no cost from ASCE Library

https://ascelibrary.org/doi/book/10.1061/9780784482186

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Beyond the Minimums

Consideration of other performance objectives beyond basic life safety in ASCE 7-22

- Life Safety Protection from Extreme Tornadoes
  - **ICC 500 Storm Shelter**
  - **FEMA Safe Room**
- Functional Performance Objective
  - Use ASCE 7-22 Risk Category IV Essential Facility criteria for any building or facility intended to remain operational after a tornado having 3,000-year RP
  - Select tornado design speed at desired level above Risk Category IV (above 3,000-year return period)
    - Appendix G has probabilistic tornado speeds for 10,000, 100,000, 1M and 10M years, or
    - Select deterministic speed for specific EF rating or other value above 3,000 year RP

Source: NIST

St. Johns Regional Medical Center, Joplin Missouri, May 22, 2011

Source: NIST

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Building Code Requirements for Storm Shelters

- 2009 IBC/IRC (and all later editions)
  - IF building a storm shelter, requirement to comply with ICC 500 Standard for Design and Construction of Storm Shelters
- 2015 IBC (section 423)
  - Installation of tornado shelters required in the 250 mph tornado wind zone, for new
    - Schools
    - Fire, rescue, ambulance, and police stations
    - 911 call centers and emergency operations centers
- 2018 IBC/IEBC
  - Expanded requirements to explicitly include new buildings on existing school campuses, and additions to existing school buildings, over a certain size
  - Occupant capacity requirements for the shelter to house the full population of the school (with exceptions)

- 2021and 2024 IBC/IEBC
  - Revisions to occupancy classification and occupant load
  - Other minor revisions

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2018 IBC Shelter Requirements

SECTION 423
STORM SHELTERS

423.1 General.
This section applies to the construction of storm shelters constructed as separate detached buildings or constructed as rooms or spaces within buildings for the purpose of providing protection from storms that produce high winds, such as tornadoes and hurricanes during the storm. Such structures shall be designated to be hurricane shelters, tornado shelters, or combined hurricane and tornado shelters. Design of facilities for use as emergency shelters after the storm are outside the scope of ICC 500 and shall comply with Table 1604.5 as Risk Category IV Structure.

Table 1604.5 Risk Category IV
- Designated earthquake, hurricane or other emergency shelters

423.2 Construction.
In addition to other applicable requirements in this code, storm shelters shall be constructed in accordance with ICC 500. Buildings or structures that are also designated as emergency shelters shall also comply with Table 1604.5 as Risk Category IV structures.

423.3 Critical emergency operations.
In areas where the shelter design wind speed for tornados in accordance with Figure 304.2(1) of ICC 500 is 250 mph, 911 call stations, emergency operation centers and fire, rescue, ambulance and police stations shall comply with Table 1604.5 as a Risk Category IV structure and shall be provided with a storm shelter constructed in accordance with ICC 500.

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2018 IBC Shelter Requirements

423.4 Group E occupancies.
In areas where the shelter design wind speed for tornadoes is 250 mph in accordance with Figure 304.2(1) of ICC 500, all Group E occupancies with an occupant load of 50 or more shall have a storm shelter constructed in accordance with ICC 500.

Exceptions:
1. Group E day care facilities.
2. Group E occupancies accessory to places of religious worship.
3. Buildings meeting the requirements for shelter design in ICC 500.

305.1 Educational Group E.
Educational Group E occupancy includes, among others, the use of a building or structure, or a portion thereof, by six or more persons at any time for educational purposes through the 12th grade.

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2018 IBC Shelter Requirements

423.4.1 Required occupant capacity.
The required occupant capacity of the storm shelter shall include all of the buildings on the site and shall be the greater of the following:

1. The total occupant load of the classrooms, vocational rooms and offices in the Group E occupancy.
2. The occupant load of any indoor assembly space that is associated with the Group E occupancy.

Maximum population likely to be in the school at any time

Exceptions

1. Where a new building is being added on an existing Group E site, and where the new building is not of sufficient size to accommodate the required occupant capacity of the storm shelter for all of the buildings on the site, the storm shelter shall at a minimum accommodate the required occupant capacity for the new building.
2. Where approved by the code official, the required occupant capacity of the shelter shall be permitted to be reduced by the occupant capacity of any existing storm shelters on the site.

No requirement to increase size of new building

423.4.2 Location.
Storm shelters shall be located within the buildings they serve or shall be located where the maximum distance of travel from not fewer than one exterior door of each building to a door of the shelter serving that building does not exceed 1,000 feet (305 m).

Approximately 5 minutes travel time – consistent with FEMA guidance

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2018 IEBC Shelter Requirements

- Added shelter requirements parallel to IBC Section 423.4 (for Group E Occupancies) into the International Existing Building Code
  - Applies to additions to existing buildings
  - Prevents *gaming of the system* to avoid shelters by adding to a building rather than constructing a new building on existing campus
  - 423.4 requirements apply to all 3 methods
    - Work Area Compliance Method-Additions: Section 1106
    - Performance Compliance Methods 1301.2.3.1
    - Prescriptive Compliance Method 502.8

Both sections point to 1106

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Direct Adoption of ICC 500 by States/Territories

In addition to shelter requirements in many AHJs through adoption of 2015 or later IBC, some states have directly adopted shelter requirements

- Alabama
  - Requirements for new K-12 schools to have ICC 500 tornado shelters
  - Requirements for certain higher education buildings (dormitories, classroom buildings) to have tornado shelters
- Illinois
  - Requirements for new K-12 schools to have ICC 500 tornado shelters
- Puerto Rico
  - Requirements for new K-12 schools to have ICC 500 hurricane shelters

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Common Design Strategies for School Shelters

- Gymnasium
- Assembly Center
- Classroom Wing
- Hallways
  - retrofit possibilities for existing schools

Source: FEMA P-361 3rd ed.)

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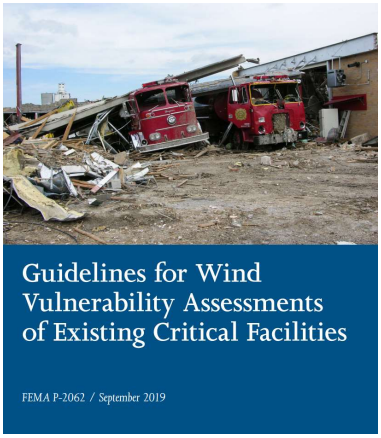
Additional Resources – Vulnerability Assessment of Existing Facilities

- Guidelines for vulnerability assessment of critical facilities affected by hurricanes, tornadoes, and other windstorms
- Methods to assess vulnerability to
  - wind pressure
  - wind-borne debris
  - wind-driven rain



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Tornado Design Beyond ASCE 7-22 Minimum Requirements

Questions / Discussion

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Storm Shelter/Safe Room Terminology and Purpose

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Terminology: Part 1

Stand-alone Shelter

Public Shelter

Red Cross Shelter

Safe Room

In-residence shelter

Community Shelter

Refuge Area

Storm Shelter

Emergency Shelter

Severe Weather Shelter Area

Community Safe Room

Residential Shelter

Best Available Refuge Area

Shelter-in-place

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Terminology: Part 2

- STORM SHELTER. A building, structure or portion thereof, constructed in accordance with ICC 500, designated for use during tornadoes, hurricanes, and other severe windstorms.

(ICC 500-2020)

- SAFE ROOM. An interior room, space within a building, or entirely separate building, designed and constructed to provide near absolute life-safety protection for its occupants from tornadoes or hurricanes. Safe rooms are designed and constructed to meet the criteria in this publication; which all meet or exceed the criteria in ICC 500. Criteria for FEMA safe rooms, "FEMA Funding Criteria," exceed ICC 500 criteria and must be met when FEMA funds are used to construct or install a safe room.

(FEMA P-361, 4th ed.)

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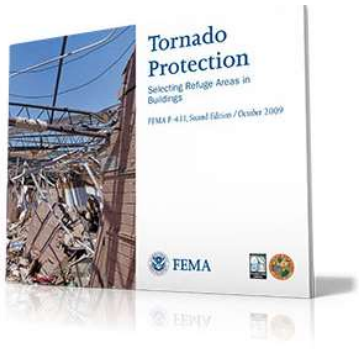
Terminology: Part 3

- BEST AVAILABLE REFUGE AREA. Building area (or areas) that has been determined by an RDP to be least vulnerable to the life threatening effects of extreme-wind incidents relative to other building areas. These areas were not specifically designed as tornado safe rooms, and as a result, occupants may be injured or killed during a tornado. However, people in best available refuge areas are less likely to be injured or killed than people in other areas of a building



Tornado Protection: Selecting Refuge Areas in Buildings, FEMA P-431, Second Edition / October 2009

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ICC 500: Purpose

- The purpose of this standard is to establish minimum requirements to safeguard the public health, safety and general welfare relative to the design, construction and installation of storm shelters constructed for protection from tornadoes, hurricanes and other severe windstorms.
- This standard is intended for adoption by government agencies and organizations for use in conjunction with applicable codes to achieve uniformity in the technical design and construction of storm shelters.

ICC 500-2020

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FEMA 361: Purpose

- The purpose and scope of FEMA P-361 is to provide guidance for safe rooms that provide near-absolute protection for its occupants during an extreme-wind event..
- **Near-absolute protection:** Based on our current knowledge of tornadoes and hurricanes, the occupants of a safe room built according to FEMA P-361 will have a very high probability of being protected from injury or death.

FEMA P-361, 4th ed.

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This Standard Hopes to Prevent This...

Hattie A. Watts
Elementary School
Patterson LA
Hurricane Andrew, 1992

Source: Marc Levitan / LSU Hurricane Center

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And This…

Enterprise High School
Enterprise AL
March 1 2007 Tornado

Source: FEMA

Source: FEMA

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And This…

School Shelter
North Carolina
Hurricane Fran, 1995

Source: NOAA

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And This…

Source: FEMA

Turner Agricivic Center
Arcadia FL
Hurricane Charley, 2004

Source: Marc Levitan / LSU Hurricane Center

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And This…

Lincoln High School
McCLellenville SC
Hurricane Hugo, 1989

Source: NOAA/ National Weather Service

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And This…

Plaza Towers
Elementary School
Moore OK
May 20, 2013
Tornado

Source: Marc Levitan / NIST

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Plaza Towers
Elementary School
Moore OK
May 20, 2013 Tornado

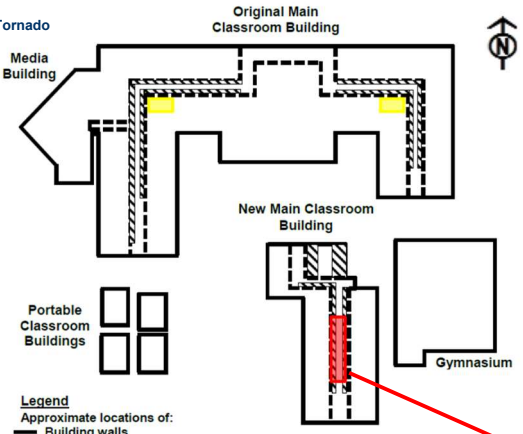
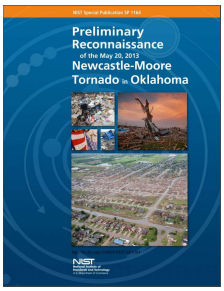


Figure 4-3. Designated areas of safety for tornadoes for the Plaza Towers Elementary School. The yellow shaded areas indicate the locations of bathrooms also used for shelter on May 20, 2013. The area shaded in red indicates where seven school children died.



https://doi.org/10.6028/NIST.sp.1164

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Track Record of Success: Part 1

- "FEMA publications presenting design and construction guidance for both residential and community safe rooms have been available since 1998. Since that time, thousands of safe rooms have been built, and a growing number of these safe rooms have already saved lives in actual events. There has not been a single reported failure of a safe room constructed to FEMA criteria."

Source: FEMA P-361, 4th ed.

- Similarly, failures of tornado shelters constructed to the ICC 500 standard (first published in 2008) have not been reported.

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Track Record of Success: Part 2

In-Residence Safe Room
Joplin, MO, May 22, 2011

Source: FEMA

Winston County Commission Community Safe Room
Arley, AL, November 30, 2016

Source: FEMA

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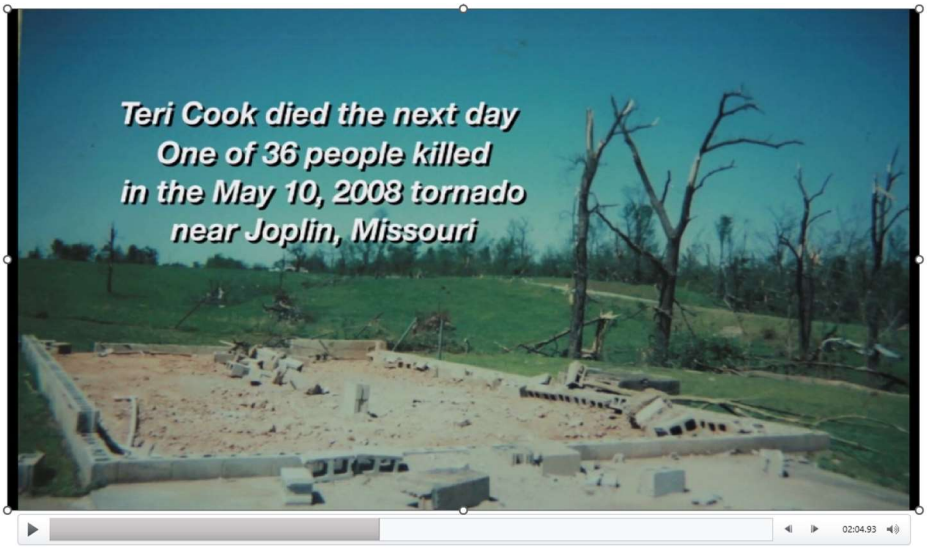

Safe Room Testimonial Video (5 min):
http://www.fema.gov/media-library/assets/videos/81425

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Storm Shelter/Safe Room Terminology and Purpose

Questions / Discussion

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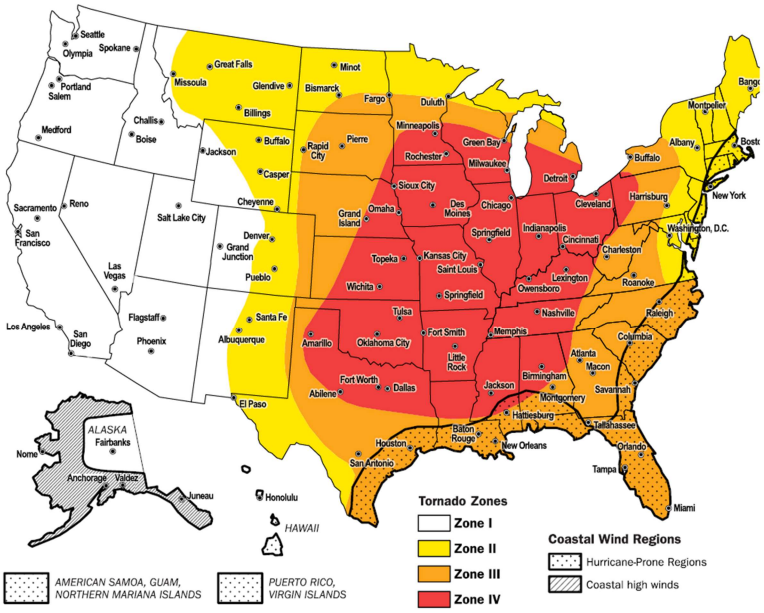

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Development and Overview of the ICC 500 Storm Shelter Standard

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Beginnings – Storm Cellars

Source: Library of Congress, Prints & Photographs Division, FSA/OWI Collection

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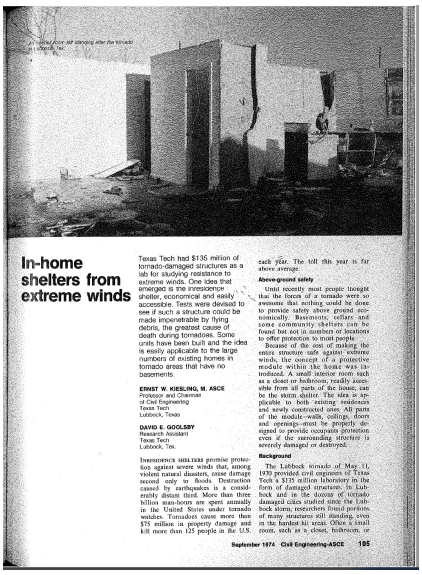
Storm Shelter / Safe Room History

- 1970 - Lubbock tornado
- 1974 - In residence shelter concept
  - Article by Dr. Ernst Kiesling in Civil Engineering
- 1998 – FEMA 320 1st ed - Residential Safe Rooms
- 1999 – Oklahoma City tornado
- 2000 - FEMA 361 published
  - Guidance for Community and Residentials Safe Rooms
- 2008 - ICC 500 Storm Shelter Standard published
- 2009 - IBC and IRC reference ICC 500
- 2015 – IBC requires tornado shelters in
  - Schools and emergency response facilities



In-home shelters from extreme winds

Texas Tech had $135 million of tornado-damaged structures as a lab for studying resistance to extreme winds. One idea that emerged is the inresidence shelter, economical and easily accessible. Tests were devised to see if such a structure could be made imperishable by flying debris, the greatest cause of death during tornadoes. Some units have been built and the idea is easily applicable to the large numbers of existing homes in tornado areas that have no basements.

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INRESIDENCE SHELTERS promise protection against severe winds that, among violent natural disasters, cause damage second only to floods. Destruction caused by earthquakes is a considerably distant third. More than three billion man-hours are spent annually in the United States under tornado watches. Tornadoes cause more than $75 million in property damage and kill more than 125 people in the U.S. each year. The toll this year is far above average.

Above-ground safety

Until recently most people thought that the forces of a tornado were so awesome that nothing could be done to provide safety above ground economically. Basements, cellars and some community shelters can be found but not in numbers or locations to offer protection to most people.

Because of the cost of making the entire structure safe against extreme winds, the concept of a protective module, within the house, was introduced. A small interior room such as a closet or bathroom, readily accessible from all parts of the house, can be the storm shelter. The idea is applicable to both existing residences and newly constructed ones. All parts of the module—walls, ceilings, doors and openings—must be properly designed to provide occupants protection even if the surrounding structure is severely damaged or destroyed.

Background

The Lubbock tornado of May 11, 1970 provided civil engineers of Texas Tech a $135 million laboratory in the form of damaged structures. In Lubbock and in the dozens of tornado-damaged cities studied since the Lubbock storm, researchers found portions of many structures still standing, even in the hardest hit areas. Often a small room, such as a closet, bathroom, or

September 1974 Civil Engineering-ASCE 105

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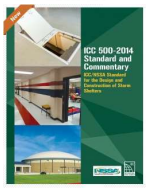
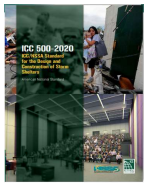
Storm Shelter Standard

ICC/NSSA Standard for the Design and Construction of Storm Shelters

- Initial development began in Spring 2003 as a collaborative effort between
  - International Code Council
  - National Storm Shelter Association (NSSA)
  - Federal Emergency Management Agency
- 1st edition: 2008
- 2nd edition: 2014 https://codes.iccsafe.org/content/ICC5002014
- 2nd edition + Commentary: 2016
- 3rd edition: 2020 https://codes.iccsafe.org/content/ICC5002020P1
- 3rd edition + Commentary: Coming in 2022
- 4th edition: in development for 2023





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ICC 500 Scope: Part 1

- This standard applies to the design, construction, installation and inspection of storm shelters constructed for the purpose of providing protection from tornadoes, hurricanes and other severe windstorms.
- Storm shelters shall be constructed as either separate, detached buildings or rooms or spaces within new or existing buildings.
- Design of facilities for use as emergency shelters after the storm is outside the scope of this standard.

ICC 500-2020

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ICC 500 Scope: Part 2

- Hurricane and Tornado Shelters
- Residential and Community Shelters
- Includes Considerations for
  - Architectural
  - Structural
  - Mechanical
  - Electrical
  - Plumbing
  - Siting
  - Operations (Appendix)

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ICC 500: Chapters

- Chapter 1 – Application and Administration
  - Quality Assurance plan
  - Peer Review Requirements
  - Special Inspections
- Chapter 2 – Definitions
- Chapter 3 – Structural Design Criteria ← Focus for Unit 5
- Chapter 4 – Siting
- Chapter 5 – Occupancy, Means of Egress, and Accessibility
- Chapter 6 – Fire Safety
- Chapter 7 – Shelter Essential Features and Accessories
- Chapter 8 – Test Methods for Impact and Pressure Testing
- Chapter 9 – Referenced Standards
- Appendix A - Storm Shelter Preparedness and Emergency Operations Plan (new in ICC 500-2020)

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Development and Overview of the ICC 500 Storm Shelter Standard

Questions / Discussion

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Structural Design Part 1: Loads and Load Combinations

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ICC 500-2020
Chapter 3 Structural Design Criteria

- **Section 301:** General
- **Section 302:** Load Combinations
- **Section 303:** Loads

Topics in this video

- **Section 304:** Wind Loads
- **Section 305:** Debris Hazards
- **Section 306:** Envelope Component Design and Testing
- **Section 307:** Connection to Foundations or Slabs

The focus in this course is on the Tornado Shelter provisions of ICC 500.
ICC 500 also has additional specific requirements for hurricane shelters

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Section 301 General: Part 1

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

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

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

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Section 301 General: Part 2

- The unique requirements for storm shelter performance necessitate modifications to some of the ASCE 7 loads as described in Chapter 3, including
  - changes to provisions for wind loads, rain loads, roof live loads, hydrostatic loads, and flood loads
  - where modifications to ASCE 7 provisions are made, all of the Chapter 3 requirements are more stringent than ASCE 7.
- Chapter 3 additionally includes provisions for
  - debris hazards
  - envelope component design and testing
  - connections of storm shelters to foundations or slabs
  - penetrations of the storm shelter envelope

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Section 302 Load Combinations

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

- 302.2 Strength Design Combinations
- 302.3 Allowable Stress Design Combinations

- These combinations differ slightly from those found in the I-Codes and ASCE 7, to account for use/occupancy and environmental conditions anticipated during a tornado or hurricane.

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Tornado Shelter Load Combinations

- ICC 500 Loads and Load Combinations are *in addition to* loads and load combinations required in the applicable building code

Strength Design

2018 IBC (excluding F, H, and E)	ICC 500-2020 Tornado Shelter
1.4D	1.4D
1.2D + 1.6L + 0.5(L_r or S or R)	1.2D + 1.6L_T + 0.5L_{rT}
1.2D + 1.6(L_r or S or R) + (f_1L or 0.5W)	1.2D + 1.6L_{rT} + (L_T or 0.5W_T)
1.2D + 1.0W + f_1L + 0.5 (L_r or S or R)	1.2D + 1.0W_T + L_T + 0.5L_{rT}
0.9D + 1.0W	0.9D + 1.0W_T

Similar changes for ASD Combinations

Modifications
- Tornado specific live (L_T), roof live (L_{rT}), wind loads (W_T)
- No rain or snow load included in combinations

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Floor Live Loads

303.2 Floor live loads. Community tornado shelter floors shall be designed for not less than the minimum uniform live loads for assembly occupancies in accordance with the applicable codes.

Seneca Intermediate School multi-purpose Community Safe Room, Seneca, MO.

Source: FEMA

- Community tornado shelters are designed for as little as 5 sq ft of floor space per occupant

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Roof Live Loads

303.3 Roof live loads. Storm shelter roofs shall be designed for minimum live loads specified in the applicable code, but not less than the following:

Tornado shelters: 100 pounds per square foot
Hurricane shelters: 50 pounds per square foot

- Provide for overall robustness to account for loads due to nonspecific debris hazards
- Specifically identified laydown and falling debris hazards addressed in Section 305.3

Source: NIST

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Wheel Loads

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

- Storm shelters located beneath the floor of a garage or other floors or surfaces supporting vehicles should be designed to support wheel loads from vehicles which may drive through, over, or park in the garage or on such surfaces. The purpose is so the storm shelter roof or operable opening of the storm shelter will not collapse or be damaged if driven over by vehicles or equipment.

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Hydrostatic Loads

303.4 Hydrostatic loads. Underground portions of storm shelters shall be designed for buoyancy forces and hydrostatic loads assuming that the ground water level is at the surface of the ground at the entrance to the storm shelter, unless adequate drainage is available to justify designing for a lower ground water level.

- Buoyancy failures of below ground residential shelters have been observed on multiple occasions

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Flood Loads

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

402.6.1 Minimum floor elevation of community tornado shelters. The lowest floor used for the *occupied storm shelter areas* and *occupant support areas* of a *community tornado shelter* shall be elevated to or above the highest of the elevations determined by all of the following:

1. The minimum elevation of the lowest floor required by the authority having jurisdiction.
2. One foot (305 mm) above the base flood elevation.
3. For storm shelters that are Risk Category IV facilities or serving Risk Category IV facilities:
   a. The *500-year flood elevation*.
   b. Two feet (6610 mm) above the *base flood elevation*.

Exceptions

1. For dry floodproofed shelters meeting several conditions
2. Where a *community tornado shelter* is constructed within an existing *host building*, only Item 1 shall apply.

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Structural Design Part 1:
Loads and Load Combinations

Questions / Discussion

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Break

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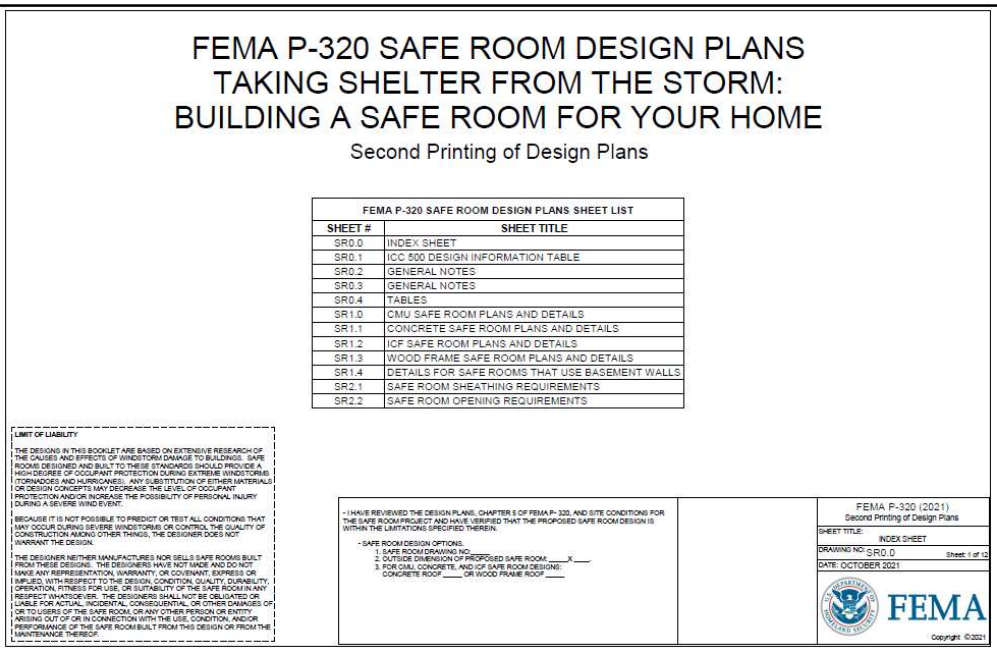

FEMA P-320 SAFE ROOM DESIGN PLANS
TAKING SHELTER FROM THE STORM:
BUILDING A SAFE ROOM FOR YOUR HOME

Second Printing of Design Plans

FEMA P-320 SAFE ROOM DESIGN PLANS SHEET LIST	
SHEET #	SHEET TITLE
SR0.0	INDEX SHEET
SR0.1	ICC 500 DESIGN INFORMATION TABLE
SR0.2	GENERAL NOTES
SR0.3	GENERAL NOTES
SR0.4	TABLES
SR1.0	CMU SAFE ROOM PLANS AND DETAILS
SR1.1	CONCRETE SAFE ROOM PLANS AND DETAILS
SR1.2	ICF SAFE ROOM PLANS AND DETAILS
SR1.3	WOOD FRAME SAFE ROOM PLANS AND DETAILS
SR1.4	DETAILS FOR SAFE ROOMS THAT USE BASEMENT WALLS
SR2.1	SAFE ROOM SHEATHING REQUIREMENTS
SR2.2	SAFE ROOM OPENING REQUIREMENTS

LIMIT OF LIABILITY

THE DESIGNS IN THIS BOOKLET ARE BASED ON EXTENSIVE RESEARCH OF THE CAUSES AND EFFECTS OF WINDSTORM DAMAGE TO BUILDINGS. SAFE ROOMS DESIGNED AND BUILT TO THESE STANDARDS SHOULD PROVIDE A HIGH DEGREE OF OCCUPANT PROTECTION DURING EXTREME WINDSTORMS (TORNADOES AND HURRICANES). ANY SUBSTITUTION OF EITHER MATERIALS OR DESIGN CONCEPTS MAY DECREASE THE LEVEL OF OCCUPANT PROTECTION AND/OR INCREASE THE POSSIBILITY OF PERSONAL INJURY DURING A SEVERE WIND EVENT.

BECAUSE IT IS NOT POSSIBLE TO PREDICT OR TEST ALL CONDITIONS THAT MAY OCCUR DURING SEVERE WINDSTORMS OR CONTROL THE QUALITY OF CONSTRUCTION AMONG OTHER THINGS, THE DESIGNER DOES NOT WARRANT THE DESIGN.

THE DESIGNER NEITHER MANUFACTURES NOR SELLS SAFE ROOMS BUILT FROM THESE DESIGNS. THE DESIGNERS HAVE NOT MADE AND DO NOT MAKE ANY REPRESENTATION, WARRANTY, OR COVENANT, EXPRESS OR IMPLIED, WITH RESPECT TO THE DESIGN, CONDITION, QUALITY, DURABILITY, OPERATION, FITNESS FOR USE, OR SUITABILITY OF THE SAFE ROOM IN ANY RESPECT WHATSOEVER. THE DESIGNERS SHALL NOT BE OBLIGATED OR LIABLE FOR ACTUAL, INCIDENTAL, CONSEQUENTIAL, OR OTHER DAMAGES OF OR TO USERS OF THE SAFE ROOM, OR ANY OTHER PERSON OR ENTITY ARISING OUT OF OR IN CONNECTION WITH THE USE, CONDITION, AND/OR PERFORMANCE OF THE SAFE ROOM BUILT FROM THIS DESIGN OR FROM THE MAINTENANCE THEREOF.

- I HAVE REVIEWED THE DESIGN PLANS, CHAPTER 5 OF FEMA P- 320, AND SITE CONDITIONS FOR THE SAFE ROOM PROJECT AND HAVE VERIFIED THAT THE PROPOSED SAFE ROOM DESIGN IS WITHIN THE LIMITATIONS SPECIFIED THEREIN.

- SAFE ROOM DESIGN OPTIONS:
  1. SAFE ROOM DRAWING NO.:
  2. OUTSIDE DIMENSION OF PROPOSED SAFE ROOM: ____X____
  3. FOR CMU, CONCRETE, AND ICF SAFE ROOM DESIGNS:
     CONCRETE ROOF ____ OR WOOD FRAME ROOF ____

FEMA P-320 (2021)
Second Printing of Design Plans
SHEET TITLE: INDEX SHEET
DRAWING NO: SR0.0 Sheet 1 of 12
DATE: OCTOBER 2021

FEMA

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Section 304 Wind Loads

General. Wind loads from hurricanes, W_H, and tornadoes, W_T, shall be determined in accordance with ASCE 7, Chapters 26 through 31, except as modified by this section.

- Wind pressures and forces determined using ASCE 7-16 procedures and equations, with modifications to
  - K_z = Velocity Pressure Exposure Coefficient
  - K_{zt} =Topographic Factor
  - K_d = Wind Directionality Factor
  - V = Shelter Design Wind Speed
  - Enclosure Classification
  - Internal Pressure Coefficient

Velocity Pressure per ASCE 7-16

- Velocity Pressure (psf):

$$q_z = 0.00256 K_z K_{zt} K_d V^2$$

K_z = Velocity Pressure Exposure Coefficient
K_{zt} =Topographic Factor
K_d = Wind Directionality Factor
V = Design Wind Speed (mph), V_H or V_T

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Velocity Pressure per ICC 500-2020

- Velocity Pressure (psf):

$$q_z = 0.00256 K_z K_{zt} K_d V^2$$

K_z = Velocity Pressure Exposure Coefficient
K_{zt} =Topographic Factor
K_d = Wind Directionality Factor
V = Shelter Design Wind Speed
Items in red are modified from ASCE 7

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K_z Velocity Pressure Exposure Coefficient

Velocity profiles remain unchanged, but selection of exposure categories is modified

- Exposure C (open terrain) required for both:
  - Main Wind Force Resisting System (MWFRS), and
  - Components and Cladding (C&C)

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K_{zt} Topographic Factor

Accounts for speedup in wind near top of hills, ridges and escarpments

- Tornado Shelter
  - $K_{zt} = 1.0$
  - Effects of topography on tornado wind speeds are unknown

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K_d Directionality Factor

K_d Accounts for reduced probability of maximum wind speed occurring at the wind direction that maximizes pressure coefficients

- ASCE 7
  - K_d = 0.85
- ICC 500
  - K_d = 1.0
  - Changing wind direction may bring maximum or near maximum wind speeds over a wide range of wind directions

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V Shelter Design Wind Speed

Ultimate Wind Speed
3-sec gust, 10 m, open terrain

Tornado Shelter

- Based on FEMA 361
- 4 zones across the country
- Developed from deterministic analysis
- Annual probability of exceedance estimated to vary from 0.5×10^{-4} to 10^{-6} /year, i.e.,
  - MRI ranges from approximately 20,000-1,000,000 years
- Based on best available data at the time

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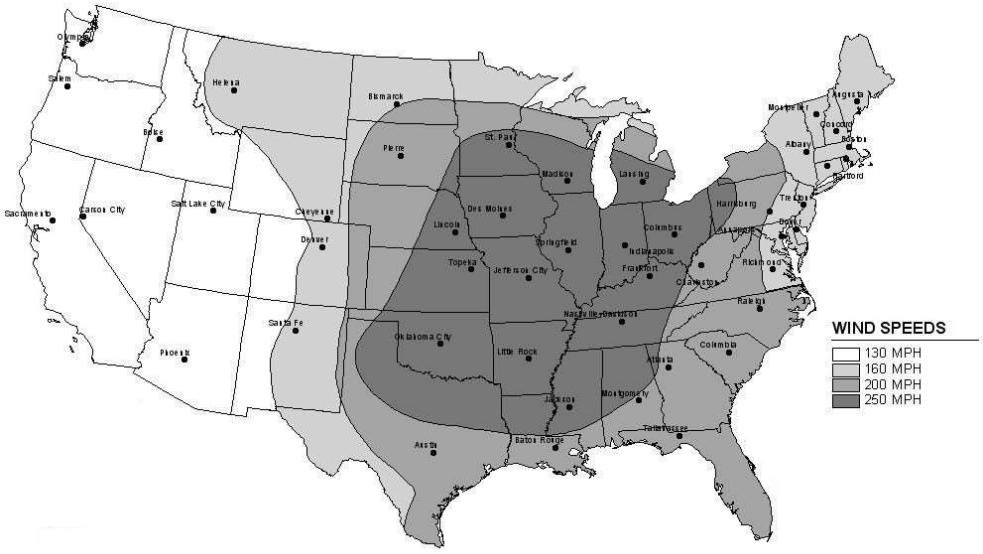
Tornado Shelter Design Wind Speed



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Enclosure Classification

- ICC 500 Section 304.6
- Use procedure from ASCE 7 to determine classification, except for Community Shelters – the largest door or window or other protected opening on each side of the building must be considered in turn as being open

Experience has shown that even if openings are not breached, people may open shelter doors and windows during the storm

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Opening Protective Installation

- Tornado Shelters
  - Must be permanently affixed
  - Must be manually operable from inside the shelter

Any type of operable protective device should have a regular maintenance and testing program.

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Tornado Shelter Window Protection

- Impact resistant glazing
- Permanently affixed external protection (e.g. perforated metal screens)
- Interior shutters

Interior operated safe room shutters in multi-purpose classroom/safe room. Image on left is normal usage; image on right shows shutters in 'lock down' position where they are closed and latched (*source: FEMA P-361 3rd ed*)

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Internal Pressure

APC = Atmospheric Pressure Change

- Tornado shelters
  - APC must be considered – 3 options
  - GC_{pi} = +/- 0.18 + APC contribution, or
  - GC_{pi} = +/- 0.18 + design for venting, or
  - GC_{pi} = +/- 0.55

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Shelters in Host Buildings

304.8 Shielding of storm shelters by host and adjacent buildings. Storm shelters enclosed in, partially enclosed in or adjacent to host buildings or adjacent to other buildings not designed for the load requirements of Chapter 3 shall be designed considering the host building and adjacent buildings to be destroyed and the shelter to be fully exposed.

- Shelters Enclosed or Partially Enclosed in a Host Building
  - e.g., in-residence shelter, shelter is wing of a building
  - Wind loads must consider host building has been destroyed and the shelter is completely exposed
  - Shelters must be designed to resist the maximum force that could be transmitted to the storm shelter equal to the ultimate failure strength of the host building connection or element being connected

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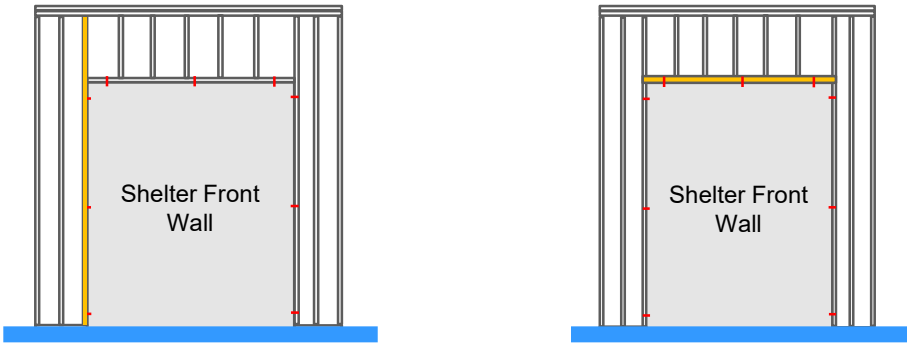
Shelters Connected to Host Buildings

304.9 Storm shelters connected to host buildings. Where an element or component of the host building is connected to a storm shelter, the storm shelter shall be designed to resist the maximum force that could be transmitted to the shelter equal to the ultimate failure strength of the connection or element being connected, whichever is lower, concurrent with the other wind loads on the storm shelter required by Chapter 3.



Connection Detailing Impacts Loads Transmitted to Shelter

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Structural Design Part 2: Wind Loads

Questions / Discussion

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Section 305 Debris Hazards

- Debris Impact Criteria
  - Apply to all exterior surfaces providing protection for shelter occupants
- Windborne missiles
  - Different for tornado and hurricane
  - All components of the storm shelter envelope must meet impact test requirements
- Laydown and Falling Debris Hazards
  - Impact loads on shelter roof

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Windborne Debris

305.1 Wind-borne debris. All storm shelters shall be designed for the impact loads of wind-borne debris in accordance with Section 305.1.1 through 305.2.2.

305.1.1 Missile criteria for tornado shelters. The missile testing for all components of the storm shelter envelope for tornado shelters shall be a 15-pound (6.8 kg) sawn lumber 2 by 4 traveling at the speeds shown in Table 305.1.1.

TABLE 305.1.1
SPEEDS FOR 15-lb SAWN LUMBER 2 × 4 MISSILE
FOR TORNADO SHELTERS

DESIGN WIND SPEED	MISSILE SPEED AND SHELTER IMPACT SURFACE
130 mph	80 mph Vertical Surfaces 53 mph Horizontal Surfaces
160 mph	84 mph Vertical Surfaces 56 mph Horizontal Surfaces
200 mph	90 mph Vertical Surfaces 60 mph Horizontal Surfaces
250 mph	100 mph Vertical Surfaces 67 mph Horizontal Surfaces

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Section 306 Component Design and Testing

- ICC 500 Section 306
- Wall and roof assemblies must meet both pressure and missile impact requirements
- Openings must either:
  - Be debris impact resistant, or
  - Have impact resistant coverings (i.e., opening protectives)
- Chapter 8 provides test methods for impact and pressure testing

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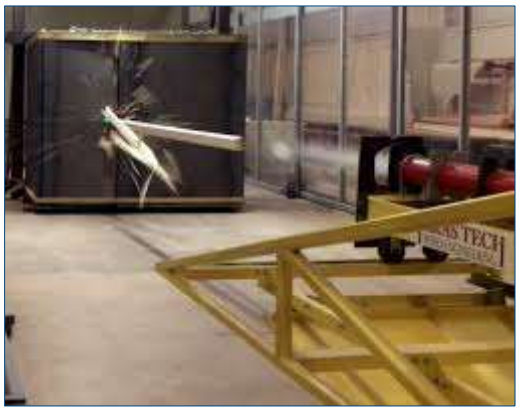
Missile Impact Testing



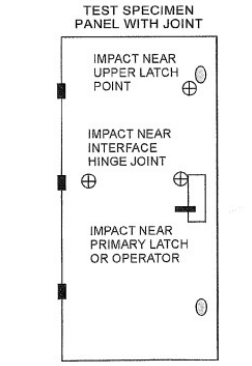


FIGURE 804.9.5(1)
DOORS AND OTHER ENTRY/EGRESS SYSTEMS

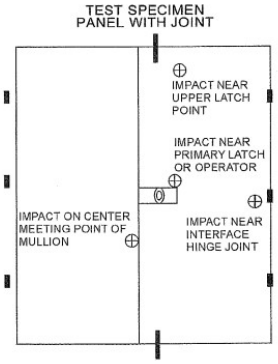


FIGURE 804.9.5(2)
DOORS AND OTHER ENTRY/EGRESS SYSTEMS

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Wall Assemblies Missile Impact Test Video

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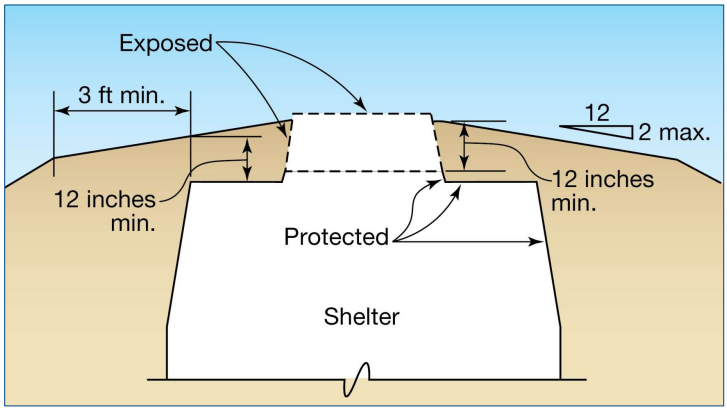
ICC 500 Section 305.2.2

Soil Cover as Protection from Debris Impact



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Section 305.2 Laydown & Falling Debris Hazards

- Significant changes from 2014 edition
  - Revised terminology and definitions
  - Requires explicit treatment and determination of impact loads, not just 'siting' consideration

Laydown Hazard

Source: FEMA

Falling Debris Hazard

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Laydown Hazard Definition

Laydown Hazard. Adjacent building elements, other structures and natural objects, that could fall onto the roof of a *storm shelter*, such as exterior walls of adjacent single story structures, self-supporting towers, poles or large trees.

Source: Marc Levitan/NIST

Source: Barbara Watson, NOAA/NWS

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Laydown Hazard Examples

Source: FEMA

Source: Marc Levitan/LSU Hurricane Center

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Falling Debris Hazard Definition

Falling Debris Hazard. Exterior components, cladding, and appurtenances, such as parapet walls, masonry cladding, or rooftop equipment, that could fall onto the roof of a *storm shelter* from wind damage to adjacent, taller buildings or taller sections of a *host building*.

Source: FEMA

Source: FEMA

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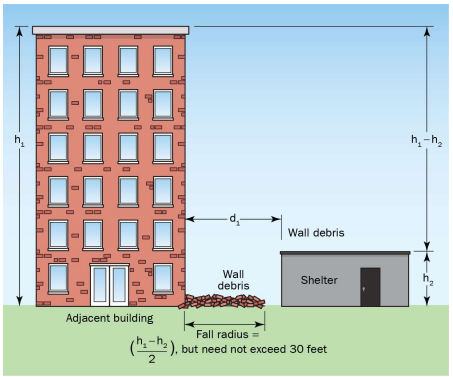
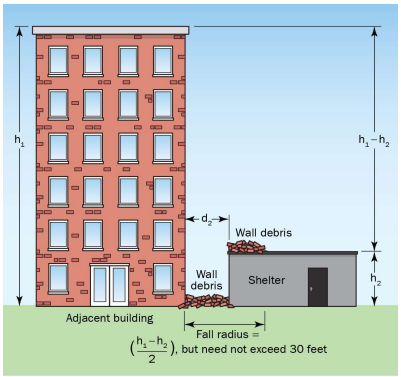
Laydown Radius

- Shelter roofs must be designed for impact loads (with minimum impact factor of 2.0)
  - If within laydown radius for laydown hazard or fall radius of falling debris hazard

Falling Debris Radius



Source: FEMA



Source: FEMA

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Structural Design Part 3: Debris Hazards

Questions / Discussion

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FEMA Safe Room Criteria

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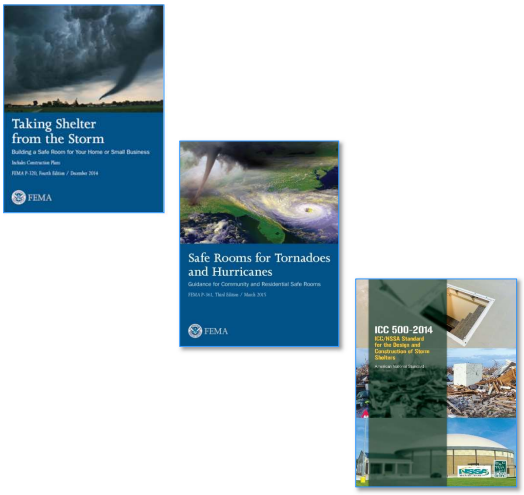
Background on FEMA Safe Rooms

- Post-disaster studies have been conducted since the 1970s to determine safe room design
- FEMA technical building science teams observe and assess building performance after disasters of national significance in the United States
- FEMA P-320 was first released in 1998 based on team observations and research from Texas Tech University
- The first edition of FEMA P-361 was released in 2000
- FEMA was involved with the development of ICC 500, the first consensus code for storm shelters released in 2008



Source: FEMA P-361 1-Day Training – Introduction and Module A1

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Codes/Standard vs. FEMA Building Science Publications

Building Codes and Standards

- Written by technical expert panels/committees
- Consensus documents, publicly balloted
- When adopted, may be enforced by the building department
- Can only reference other consensus codes and standards
- Products may be approved through code "evaluation services"
- Laboratories and testing agencies provide product approvals and compliance certificates

Building Science Publications

- Written by technical expert panels/committees
- Evaluated by Review Committees, not publically balloted
- Typically, not adopted and therefore, not enforceable by the building department
- If adopted through special legislative rule or action, guidance may be enforced by the building department (rare)
- Only when part of a grant program does the design criteria change from "should" to "shall"

Source: FEMA P-361 1-Day Training – Introduction and Module A1

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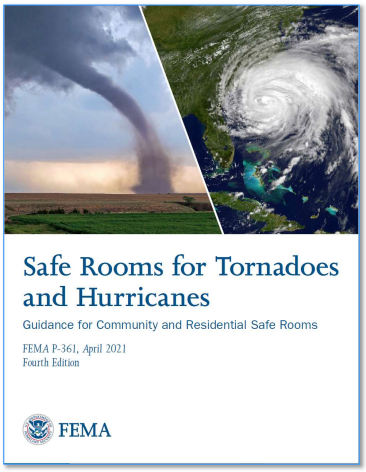
FEMA P-361 Organization

Part A: Information that safe room planners, designers, owners, operators, and emergency management officials may find useful in planning, designing, and operating a safe room

Part B: Arranged so the chapter order and content are in sequence with the first eight chapters of ICC 500



Source: FEMA P-361 1-Day Training – Introduction and Module A1

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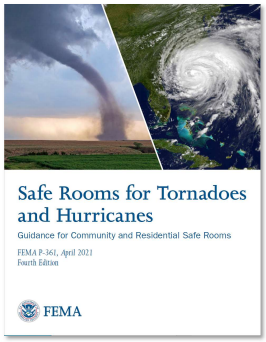
FEMA P-361 and ICC 500 Comparison

- Both safe rooms and storm shelters provide life-safety protection from hurricanes and tornadoes
- FEMA P-361 provides recommended criteria and best practices, while ICC 500 is a minimum standard
- Safe rooms must comply with ICC 500 **and** FEMA P-361 which is higher for some criteria
  - FEMA's Recommended Criteria described in FEMA P-361 Part B
- Because safe rooms comply with ICC 500, they also qualify as storm shelters
- Safe rooms are eligible for FEMA grant funding



Source: FEMA P-361 1-Day Training – Introduction and Module A1

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Differences Between P-361 and ICC 500

Appendix D: Comparison Matrix of Differences between ICC 500 Requirements and FEMA Funding Criteria

ICC 500-2020 Reference	ICC 500 Requirement[a]	FEMA Funding Criteria for Safe Rooms[b]
Section 106.2.1 Design Information	For the areas of a building designed for occupancy as a storm shelter, the following information shall be provided within the construction documents: 1. A statement that the design conforms to the provisions of the *ICC 500 Standard for the Design and Construction of Storm Shelters*, with the edition year specified.	1. A statement that the design conforms to the provisions of the *ICC 500 Standard for the Design and Construction of Storm Shelters*, with the edition year specified **and to the FEMA Funding Criteria of FEMA P-361, with the edition year specified.**
Section 302.1 Load Combinations, General	The *storm shelter* shall be designed to resist the load combinations specified in Section 302.2 or 302.3. *Storm shelters* that are designed as combination tornado and *hurricane shelters* shall comply with requirements for both sets of load combinations using either Section 302.2 or 302.3.	**For all residential safe rooms, only the tornado shelter load combinations specified in Section 302.2 or 302.3 are required to be applied, regardless of safe room type, tornado, hurricane, or combination.**
Section 304.1 Wind Loads, General	Wind loads from hurricanes, W_h, and tornadoes, W_T, shall be determined in accordance with ASCE 7, Chapters 26 through 31, except as modified by this section.	**For all residential safe rooms, only wind loads from tornadoes, W_T, are required to be applied, regardless of safe room type, tornado, hurricane, or combination.**
Section 304.2 Design wind speed	For tornado shelters, the *storm shelter* design wind speed, V_T, shall be in accordance with Figure 304.2(1). For hurricane shelters, the *storm shelter* design wind speed, V_h, shall be in accordance with Figure 304.2(2). For *storm shelters* in Alaska the *design wind speed*, V_h, shall be in accordance with Figure 304.2(3). [c]	**For all residential safe rooms, the design wind speed, V_T, is required to be 250 mph, regardless of geographic location and type of safe room, tornado, hurricane, or combination.**
Section 305.1 Wind-borne debris	All *storm shelters* shall be designed for the impact loads of wind-borne debris in accordance with Section 305.1.1 through 305.2.2.	**For all residential safe rooms, only the tornado shelter missile criteria are required to be applied, regardless of safe room type, tornado, hurricane, or combination.**

APPENDIX D, FEMA P-361 4th ed.

Additional differences include:

- Impact protective systems
- Flood-related criteria
  - Minimum floor elevations
  - Siting
- Fire Resistance Requirements

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Types of Safe Rooms: Part 1

Residential safe room: Serves occupants of **dwelling units** and has an occupant load not exceeding 16 persons

Community safe room: Any safe room not defined as a residential safe room

Source: FEMA P-361 1-Day Training – Introduction and Module A1

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Types of Safe Rooms: Part 2

Stand-alone safe room: A separate building designed and constructed or retrofitted to withstand extreme winds and the impact of wind-borne debris during tornadoes, hurricanes, or other extreme-wind events.

Internal safe room: A specially designed and constructed room or area within or attached to a larger building. It should be structurally independent of the larger building, but provide the same wind and wind-borne debris protection as a stand-alone safe room.

Source: FEMA P-361 1-Day Training – Introduction and Module A1

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Types of Safe Rooms: Part 3

Above-ground safe room

Below-ground safe room

Source: FEMA P-361 1-Day Training – Introduction and Module A1

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Types of Safe Rooms: Part 4

Prefabricated safe room: A safe room that has been assembled off-site and transported to the site where it will be installed

Site-built safe room: Any safe room not defined as prefabricated safe room

Source: FEMA P-361 1-Day Training – Introduction and Module A1 95

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Safe Room Tools and Resources: Part 1

- Safe Room Website
  - http://www.fema.gov/safe-room-resources
- Safe Room Door Assemblies and Components
- Example Operations and Maintenance Plans for Community Safe Rooms
- FEMA P-361 History and Relevant FEMA Building Science Activities
- Legacy FEMA P-361 Case Studies
- Previous Missile Impact Tests for Wood Sheathing
- Wall Sections That Passed Previous Missile Impact Tests

Source: FEMA P-361 1-Day Training – Introduction and Module A1 96

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Safe Room Tools and Resources: Part 2

- http://www.fema.gov/safe-room-resources
- Safe room funding
- Publications and documents available for download include:
  - Fact Sheets including Residential Tornado SR Door FS
  - Flood Hazard 'Quick Guides'
  - Post-disaster Reports and Recovery Advisories
  - FEMA P-388: Safe Room Resources CD
  - Much more!

Source: FEMA P-361 1-Day Training – Introduction and Module A1

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FEMA Safe Room Criteria

Questions / Discussion

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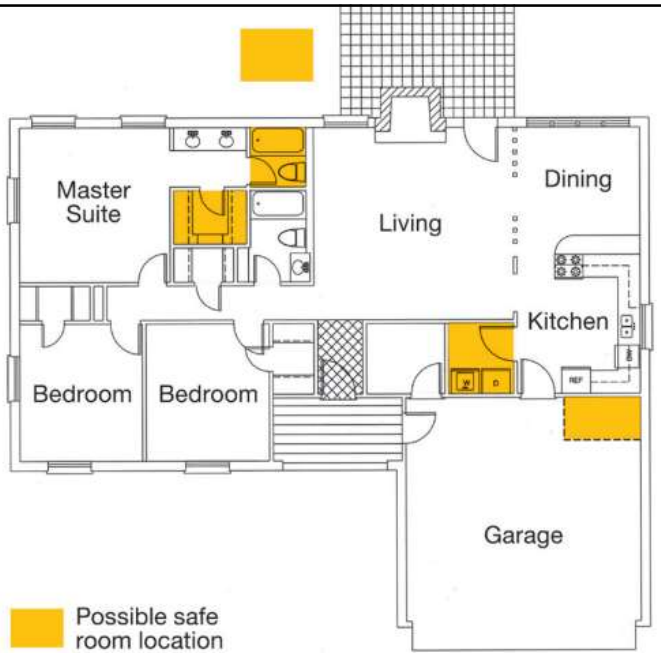

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Summary

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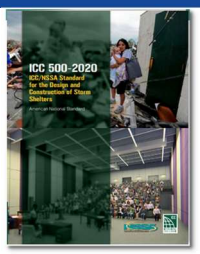
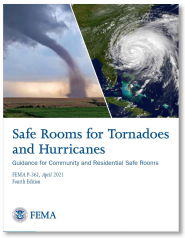
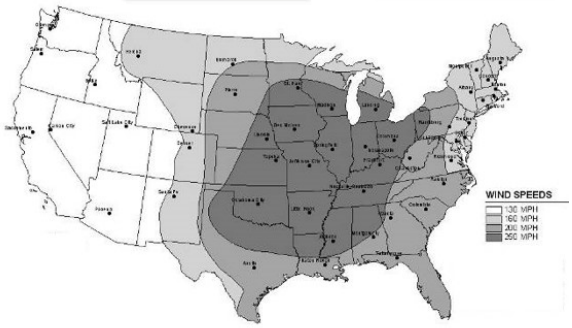
Unit 5: Summary Part 1

- ASCE 7-22 Minimum Tornado Design
  - Minimum means can't do less
  - Minimum may not always be appropriate
- Beyond ASCE 7-22 Minimums
  - Performance-Based Tornado Design
  - Use Risk Category IV Essential Facility Criteria
  - Select greater tornado speed
- For 'Near-Absolute Life Safety Protection, use
  - ICC 500 Storm Shelter
  - FEMA Safe Room
- IBC Requires Tornado Shelters in
  - Schools (IEBC also requires for additions)
  - Emergency response facilities







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Unit 5: Summary Part 2

- Storm Shelter
  - Constructed to ICC 500 Standard
- Safe Room
  - Constructed to FEMA criteria
  - All Safe rooms are also storm shelters
    - FEMA funding criteria all exceed ICC 500
- Shelters and Safe Rooms have a track record of success
  - No known failures
- ICC 500 loads other than wind are based on applicable building code, with modifications

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Unit 5: Summary Part 3

- Special Tornado Loads include
  - Floor Live Load
  - Roof Live Load
  - Wheel Loads
  - Hydrostatic loads
- ICC 500 load combinations are in addition to those from the applicable building code
- ICC 500 wind loads are based on ASCE 7-16, with modifications to
  - K_z = Velocity Pressure Exposure Coefficient
  - K_{zt} =Topographic Factor
  - K_d = Wind Directionality Factor
  - V = Shelter Design Wind Speed
  - Enclosure Classification
  - Internal Pressure Coefficient – for APC

Strength Design Tornado Shelter Load Combinations

1.4D

$1.2D + 1.6L_T + 0.5L_{rT}$

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

$1.2D + 1.0W_T + L_T + 0.5L_{rT}$

$0.9D + 1.0W_T$

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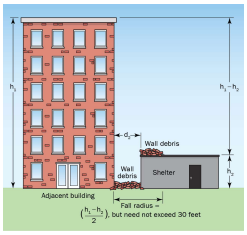
Unit 5: Summary Part 4

- Window Protection Requirements
  - Must be permanently affixed
  - Must be manually operable from inside the shelter
- Protection Options Include
  - Impact resistant glazing
  - External screens
  - Interior shutters
- Missile Criteria
  - 15 lb 2x4 at 100 mph for V_T=250 mph zone
- Laydown and Falling Debris Hazards
  - Impact loads on shelter roof
  - Minimum impact factor of 2.0



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Tornado Load Design per ASCE 7-22 and the 2024 International Building Code

Seminar Completed!

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