Tornado Awareness and Risk Mitigation

February 15, 2022

Housekeeping

- This session is being recorded
- Materials from today's webinar, including the presentations, will be posted to the Code Council web site
- Participants will receive a follow up email and link in the coming days
- We encourage you to participate in the Q&A!
- We will stay on for a short time following the scheduled end of the webinar

Today's Panelists

Marc Levitan
NIST

Pataya Scott
FEMA

Donald Scott
PCS Structural Solutions

Larry Novak
International Code Council

Karl Fippinger
International Code Council

Background for Today's Webinar

- FEMA Mitigation Assessment Team (MAT) concept
  - Observes building performance under severe hazard events
  - Provides design and construction strategic recommendations for reducing damage and protecting lives in hazard areas
- Pre-Mat - Kentucky Tornadoes - December 18-23, 2021
  - Visited over 600 individual sites in 4 days
  - Documented trends in building performance
  - Documented storm shelter construction and performance

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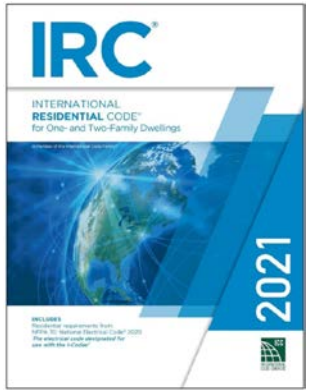
Tornado Awareness and Risk Mitigation

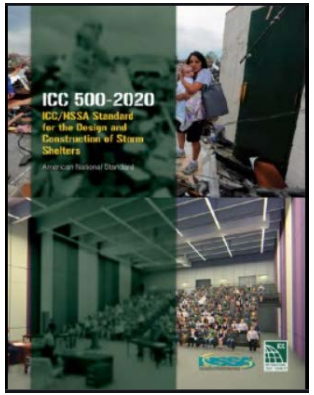
I-Codes

Larry Novak, SE, F. SEI, F. ACI, CERT, LEED AP
Chief Structural Engineer
Codes and Standards Development
International Code Council

Outline

- Tornado Devastation
- 2022 I-Codes
  - IBC International Building Code
  - IRC International Residential Code
  - IEBC International Existing Building Code
- ICC 500-2020: Standard for the Design and Construction of Storm Shelters





Tornado Outbreak - December 10, 2021

Emergency Facilities

Large Structures

Single Family Residential

Single Family Residential

Shelters? Reinforced Concrete ‘vault’ in building

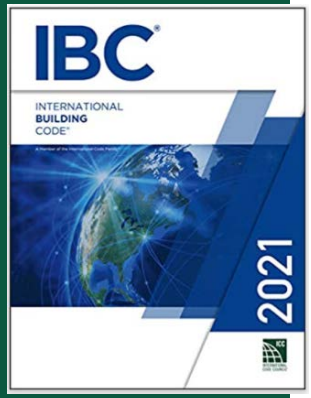
Vintage Shelter

Example of a Modern ICC 500 Shelter

Example of a Modern ICC 500 Shelter

I-Codes
Complete Load Path Required:

Example: IRC SectionR301.1:
… The construction of buildings and structures in accordance with the provisions of this code shall result in a **system that provides a complete load path that meets the requirements for the transfer of loads from their point of origin through the load-resisting elements to the foundation**. …

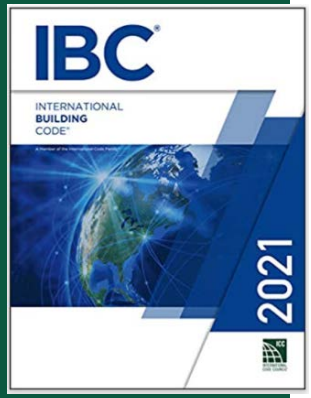


When is a Storm Shelter Required, Per the IBC Section 423:

- Storm shelters constructed in accordance w/ IBC & ICC 500
- Can be Independent or Within Host Buildings
- Required for (in areas of ICC 500 design wind speed 250 mph):

- **Critical Emergency Operations**
  - 911 Call Stations, Emergency Operation Centers, Fire, Rescue, Ambulance & Police Stations
- **Group E Occupancies (Educational thru 12 grade)**
  - Except: day care facilities, accessory to places of religious worship, buildings meeting the requirements for shelter design in ICC 500

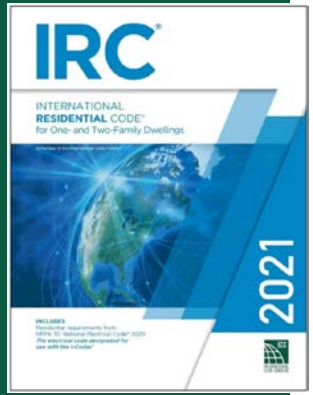
Note: IEBC requires storm shelters to be added in schools with additions that hold greater than 50 occupants (Section 303.2)



Group E Required Occupant Capacity of Storm Shelters, Per the IBC Section 423:

Occupant Capacity shall include all of the Buildings on the Site and shall be the greater of the following:

- Total occupant load of classrooms, vocational rooms and offices in Group E
- Occupant load of the largest indoor assembly space associated with Group E w/Exceptions (see Section 423.5.1)

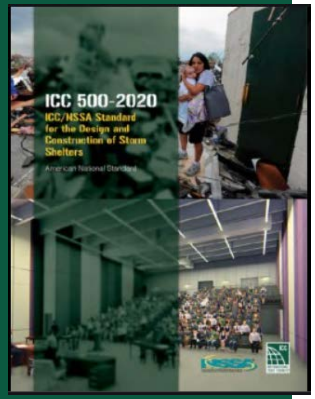


Requirements in the IRC Section R323;

If Storm Shelter is constructed:

- Storm Shelters Shall be Constructed in Accordance w/ ICC 500:
  - Constructed as Detached Buildings or
  - Constructed as Safe Rooms within building

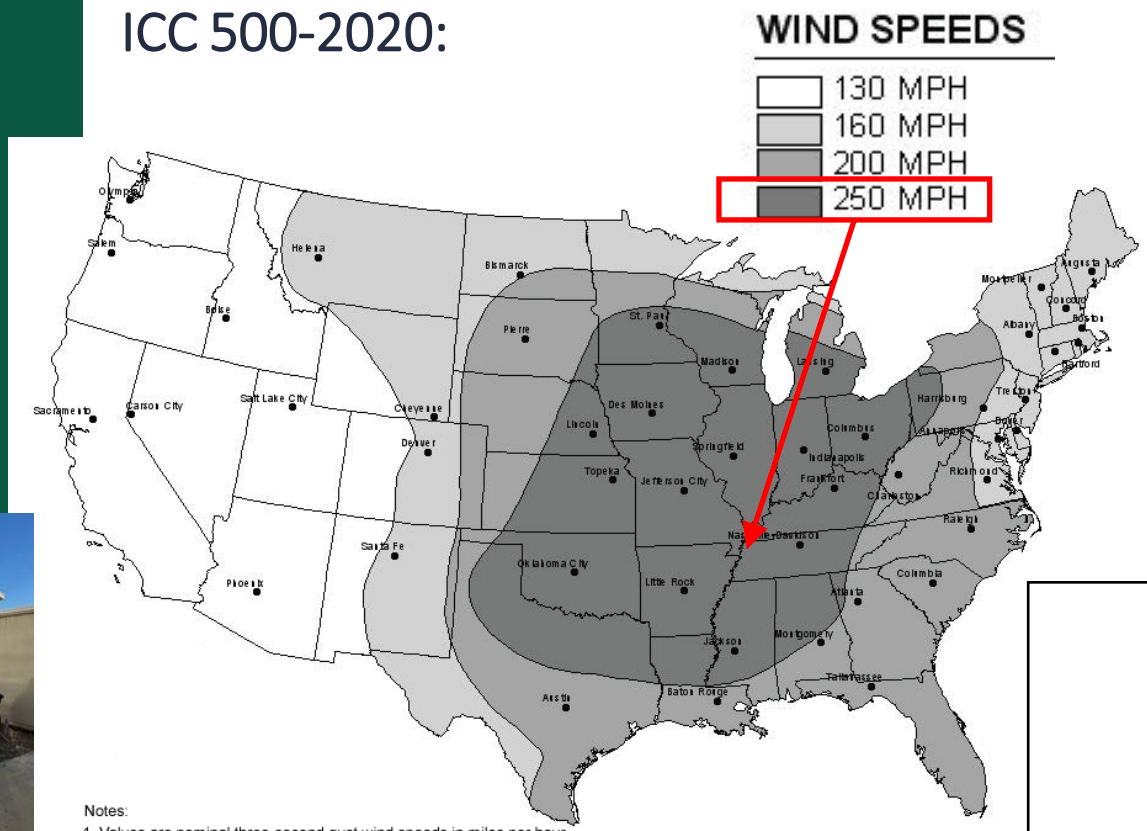
- Permit Required, Construction Documents prepared and sealed by *Registered Design Professional* indicating meets ICC 500
  - Except: components listed and labeled compliance with ICC 500



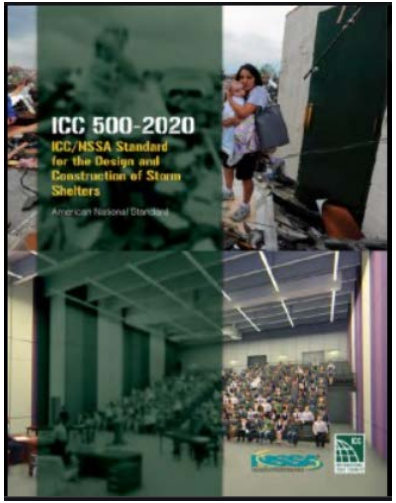
ICC 500-2020:

- Standard for the Design and Construction of Storm Shelters
- 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.
- Standard under continuous maintenance

ICC 500-2020:



Notes:
1. Values are nominal three-second gust wind speeds in miles per hour at 33 feet above ground for Exposure Category C.
2. Multiply miles per hour by 0.447 to obtain meters per second.
3. Location-specific storm shelter design wind speeds shall be permitted to be determined using the ATC Hazards by Location web site https://hazards.atcouncil.org/.



DESIGN WIND SPEEDS, VT, FOR TORNADOES

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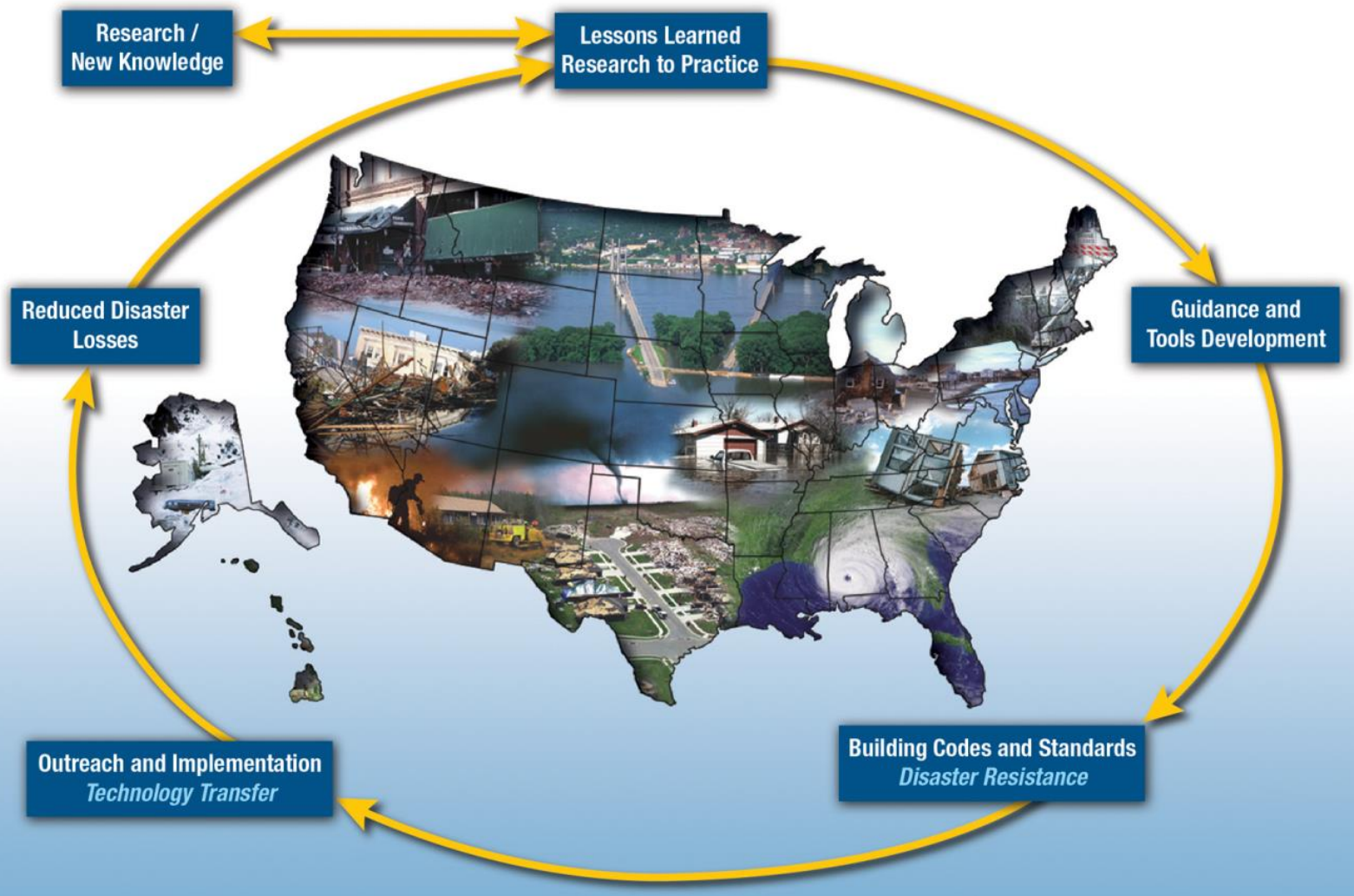
FEMA Building Science Activities

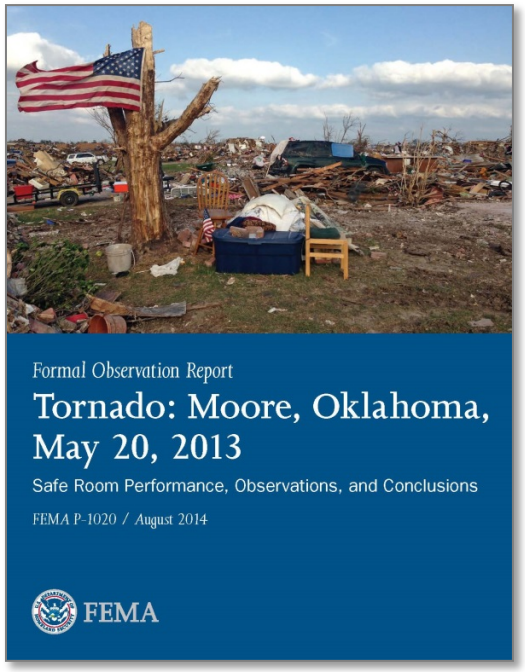


FEMA Mitigation Assessment Team (MAT) & Formal Observation Reports

1999
Oklahoma and Kansas
(FEMA 342)

2011
Alabama and Missouri
(FEMA P-908)

2013
Moore, Oklahoma
(FEMA P-1020)



Bremen, KY

- Shelters very likely saved lives
  - 12 confirmed deaths in Bremen
  - 24 people took shelter in these two
    - Underground (8) installed early 2010s
    - Aboveground (16) constructed late 1970s or 80s

Gibson County, TN – Kenton Elementary School Safe Room

Good morning,

I just wanted to pass along a big THANK YOU! As I am sure you are aware, one of our schools who received a FEMA Safe Room Grant was able to open up on Friday Night during the tornadic activity. The storm shelter was full of community members from Kenton, TN. Kenton took a direct hit and over 50 homes were destroyed but no lives lost. I believe the shelter played a key role in no lives lost. I just wanted to pass this along and let you know how important your work is to saving lives!

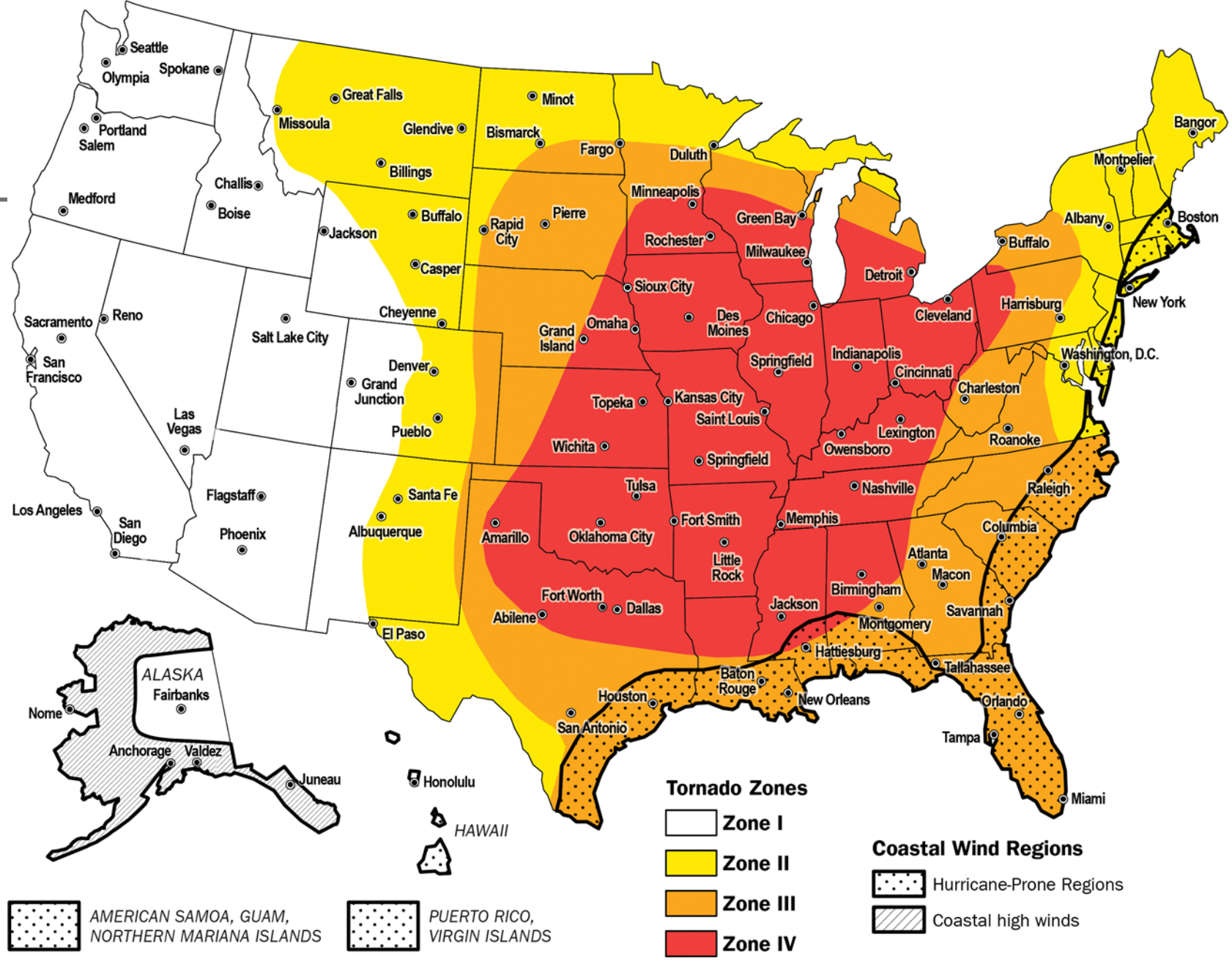
Local Correspondence sent to TEMA, 12/15/21

FEMA P-320 (2021) Overview

- Safe room guidance is primarily intended for homeowners, builders, and contractors
- Updated scope addresses safe rooms for 1- and 2-family dwellings only
- Expanded consumer guidance and information on prefabricated safe rooms
- Prescriptive safe room design plans

FEMA P-320 (2021) Guidance Tool Examples

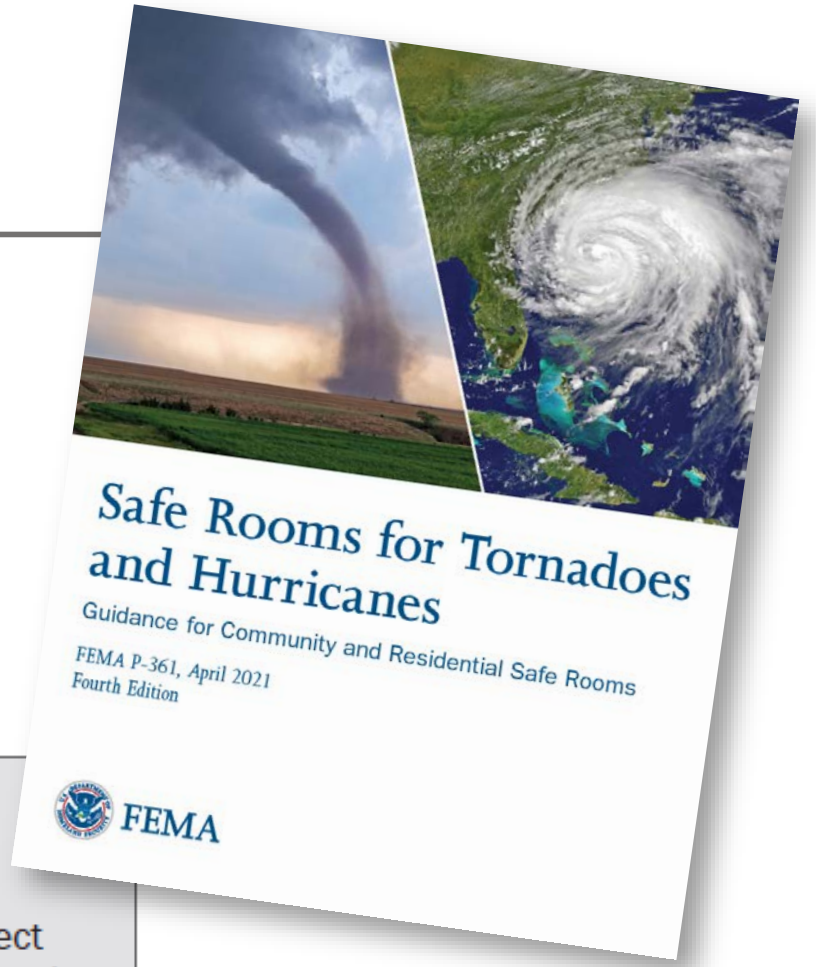
How to Determine if You Need a Safe Room



FEMA

FEMA P-361 (2021) Overview

- Covers community and residential safe rooms
- Planning, and operations and maintenance considerations
- Detailed design and construction criteria for hurricane, tornado, and combined safe rooms



NOTE

FEMA P-361 (2021) UPDATES

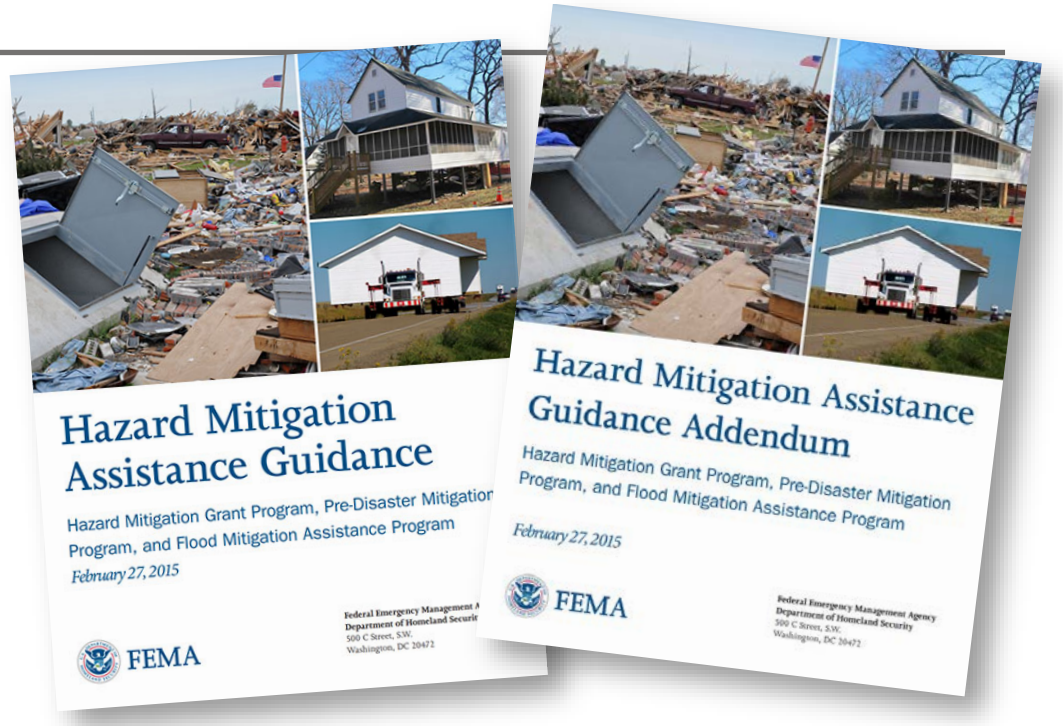
FEMA P-361 (2021) features clarified and updated guidance and revised guidance to reflect another 6 years of post-damage assessments and lessons learned following hurricanes and tornadoes, as well as research in the ever-growing field of wind engineering and safe rooms and storm shelters.

FEMA P-361 and ICC 500

- Both safe rooms and storm shelters provide life-safety protection from hurricanes and tornadoes
- Storm shelters must comply with ICC 500 (most recent edition is 2020)
- FEMA-funded safe rooms must comply with the latest editions of ICC 500 and **FEMA Funding Criteria** provided in FEMA P-361
- The latest **FEMA Funding Criteria** is slightly more conservative for select flood siting and fire safety criteria
- Because safe rooms comply with ICC 500, they also qualify as storm shelters
  - *NOT all storm shelters are safe rooms*
  - *All safe rooms are storm shelters*

FEMA Safe Room Grant Funding

- As of February 2020, FEMA grant programs have provided approximately $1.2 billion in federal funds for safe rooms
- Nearly 26,300 residential safe rooms
- Over 2,200 community safe rooms
- 26 states and territories



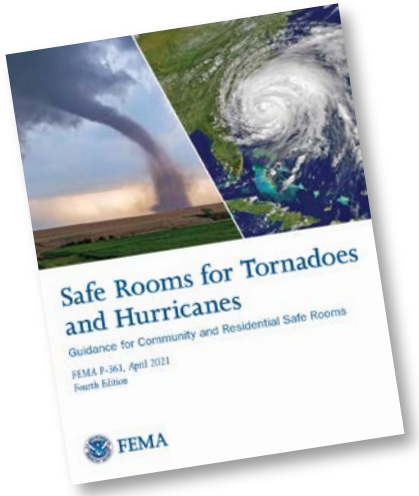
HMA Unified Guidance: ***www.fema.gov/hazard-mitigation-assistance***

State Hazard Mitigation Officer (SHMO): ***https://www.fema.gov/state-hazard-mitigation-officers***

Safe Room Resources

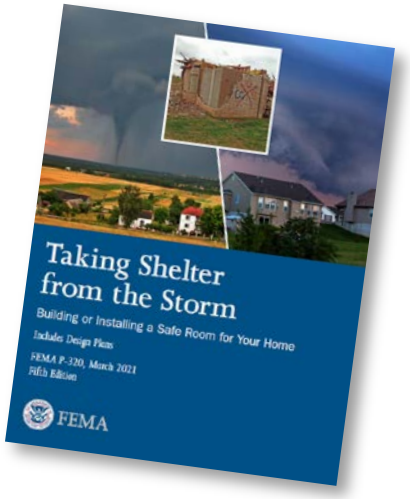
FEMA Safe Room Resources Webpage

https://www.fema.gov/emergency-managers/risk-management/safe-rooms/resources



Additional Resources

- Community Tornado Safe Room Doors Installation and Maintenance Fact Sheet
- Best Available Refuge Area Checklist
- Residential Tornado Safe Room Doors Fact Sheet
- Foundation and Anchoring Criteria for Safe Rooms Fact Sheet
- Flood Hazard Elevation and Siting Criteria for Community Safe Rooms
- Flood Hazard Elevation and Siting Criteria for Residential Safe Rooms
- Additional One-Page Safe Room Resources



Design of Buildings for Tornadoes

Implementation of the Latest Research into ASCE 7-22 Tornado Load Provisions

Marc L. Levitan, Ph.D.
Lead Research Engineer, National Windstorm Impact Reduction Program

ICC Tornado Awareness and Risk Mitigation Webinar
Feb. 15, 2022

National Institute of Standards and Technology
U.S. Department of Commerce

engineering laboratory

Why Haven't We Considered Tornadoes in Conventional Engineering Design?

NIST

Common Misperceptions

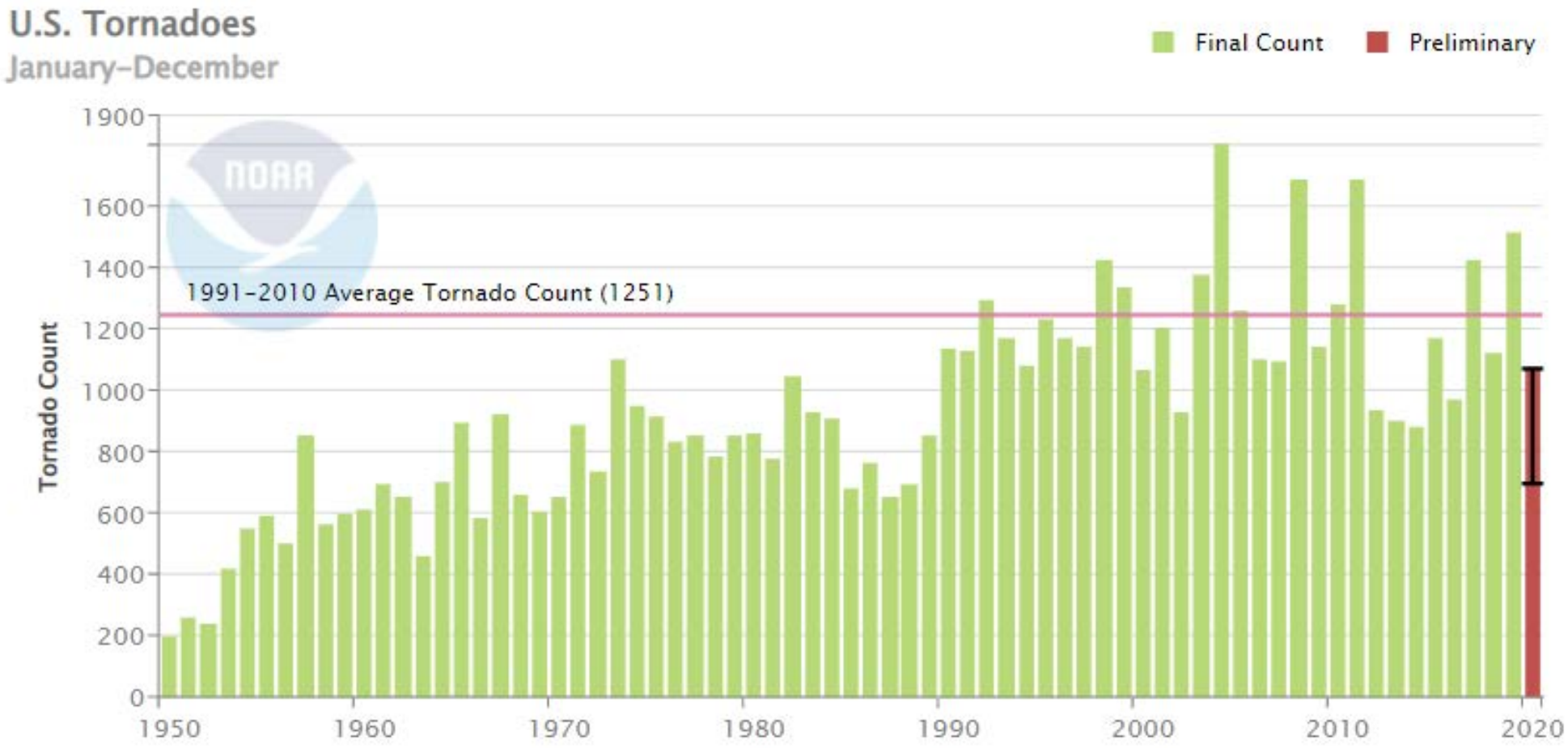
- Too rare
- Losses from tornadoes are small compared to other hazards
- Nothing we can do about them
- Inadequate knowledge
- Buildings would all have to be concrete bunkers
- Too expensive

Photo Credit: NOAA/ITAE

Perceptions may be shaped by the few violent tornadoes per year that make the headlines

How Rare are Tornadoes?

Source: NIST, from NOAA data



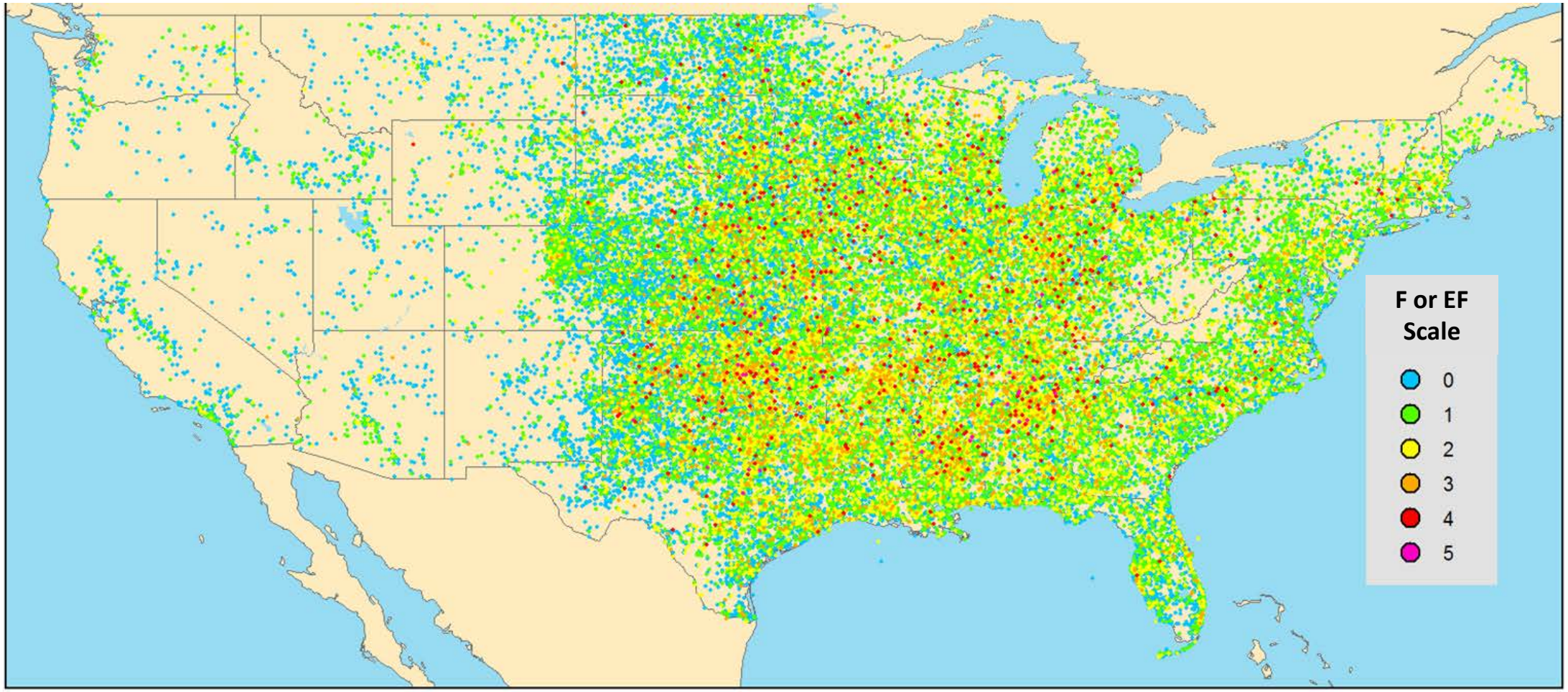
This plot shows the number of *reported* tornadoes per year.
Many tornadoes go unreported.

Where do Tornadoes Occur?

Source: NIST, from NOAA data

Tornadoes occur at many places across the globe, on all continents except Antarctica

U.S Tornadoes: 1995-2016



How Many Lives are Lost in Tornadoes?

Tornadoes kill more people per year in the U.S. than hurricanes and earthquakes combined

<u>Tornado fatalities overwhelmingly occur inside buildings.</u>

High Tornado Death Toll

5,600 killed (1950 – 2011)

Average deaths/year:

Tornadoes:	91.6
Hurricanes:	50.8
Earthquakes:	7.5

Moore OK Tornado – 2013. Damage to the hallway and classrooms of the new main classroom building (complete loss of roof and many walls) where the 7 fatalities occurred (most of the debris has already been removed). This hallway area was a "designated area of safety." NIST SP 1164 (2013)

Storm Shelters for Life Safety Protection

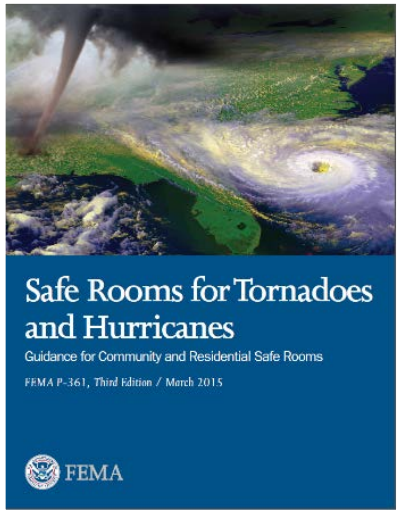
We *can* design for mother nature's worst

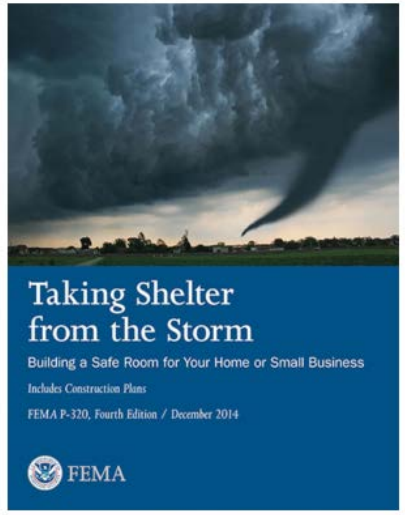
FEMA Safe Rooms are designed for 'near-absolute' life safety protection, ICC 500 Storm Shelters have almost identical requirements

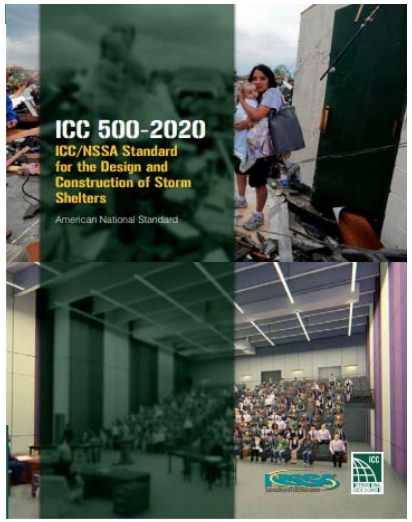
- **250 mph tornado winds**
- **Impact of 15-pound 2x4 traveling at 100 mph**
- **No reported failures of safe rooms or shelters constructed to FEMA or ICC 500 requirements**

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

Source: FEMA







How Much Damage do Tornadoes Cause?

INSURANCE INFORMATION INSTITUTE

Over the 20-year period, 1997 to 2016, events involving tornadoes, including other wind, hail and flood losses associated with tornadoes made up **39.9%** of total catastrophe insured losses, adjusted for inflation.

Hurricanes and tropical storms were a close second largest cause of catastrophe losses, accounting for **38.2%** of losses

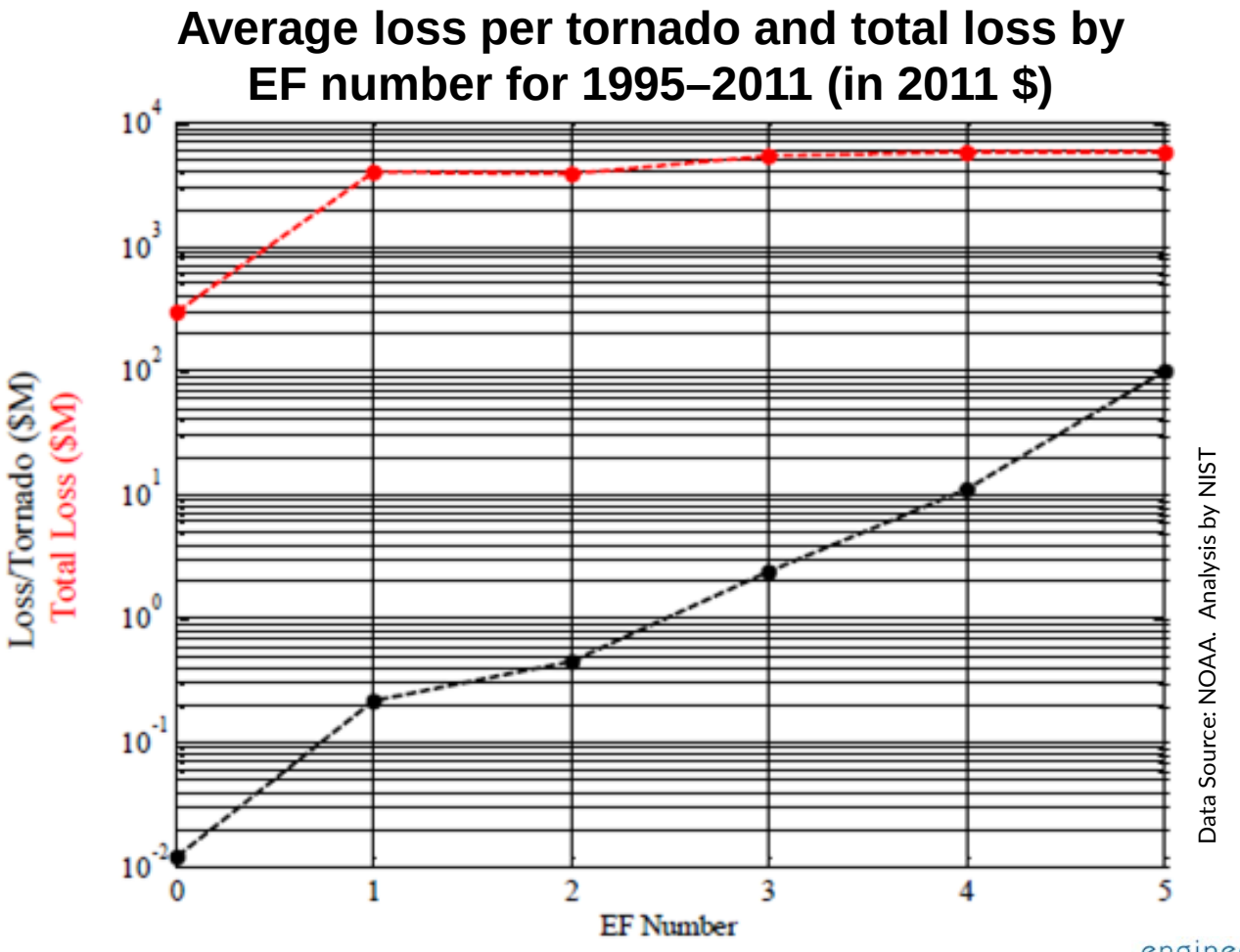
https://www.iii.org/article/spotlight-on-catastrophes-insurance-issues#:~:text=Hurricanes%20and%20tropical%20storms%20were,winter%20storms%20(6.7%20percent)

Isn't Most Damage Caused by the Big Tornadoes?

Property damage and resulting losses per *individual* tornado (black curve) increase dramatically with EF rating

However, *aggregate* losses for all tornadoes per EF number (red curve) are of the same magnitude (except EF0)

- because there are so many more tornadoes with lower intensities



Source: NIST (2014)

https://doi.org/10.6028/NIST.NCSTAR.3

Opportunity for Tornado Loss Reduction

EF SCALE	
EF #	3-s Gust (mph)
0	65-85
1	86-110
2	111-135
3	136-165
4	166-200
5	Over 200

We don't *have* to design everything to withstand the most violent tornadoes in order to significantly reduce tornado damage

From 1995-2016, of the over 1,200 tornadoes/year

*** 89.1% were EF0-EF1, 97.1% were EF0-EF2**

Most of the area impacted by a tornado does not experience the greatest winds, e.g., in the 2011 EF-5 Joplin Tornado (NIST, 2014)

*** 72% of area swept by tornado experienced EF0-EF2 winds**

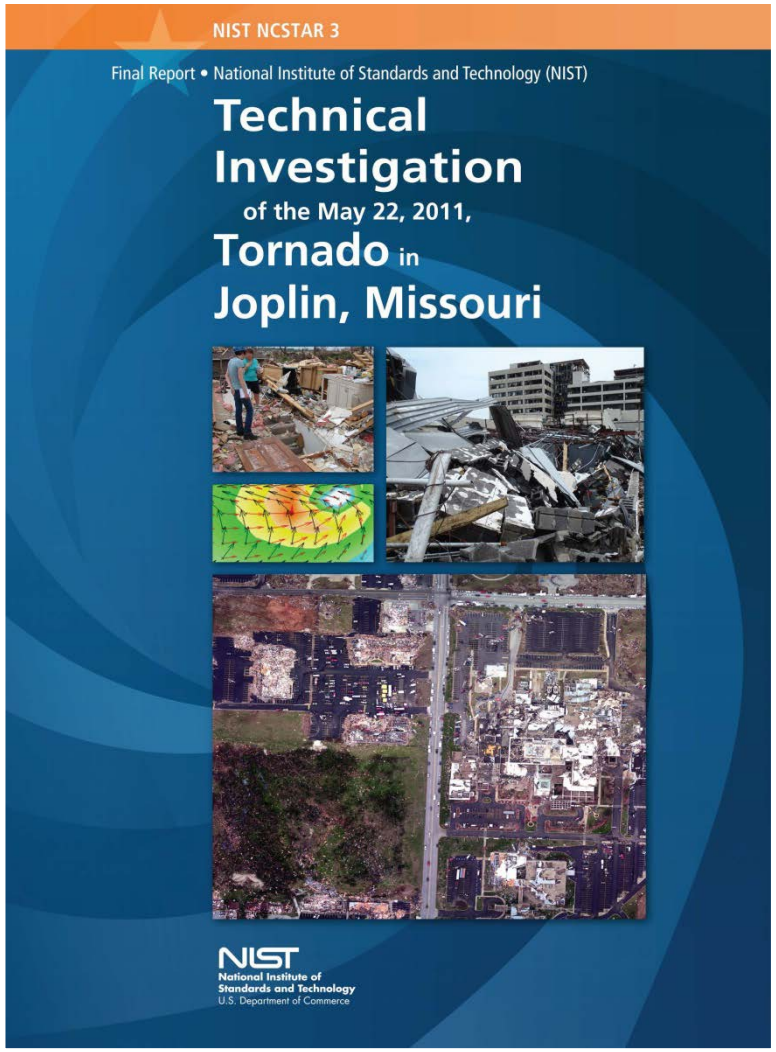
*** 28% experienced EF3-EF5 winds**

Data Source: NOAA. Analysis by NIST

Paradigm Shift Needed

Ignoring tornado hazards in the design of our built environment is not an appropriate response

Genesis of Tornado Loads in ASCE 7-22



http://dx.doi.org/10.6028/NIST.NCSTAR.3

The first tornado study to include storm characteristics, building performance, emergency communication and human behavior together - with assessment of the impact of each on fatalities

16 recommendations for improving:

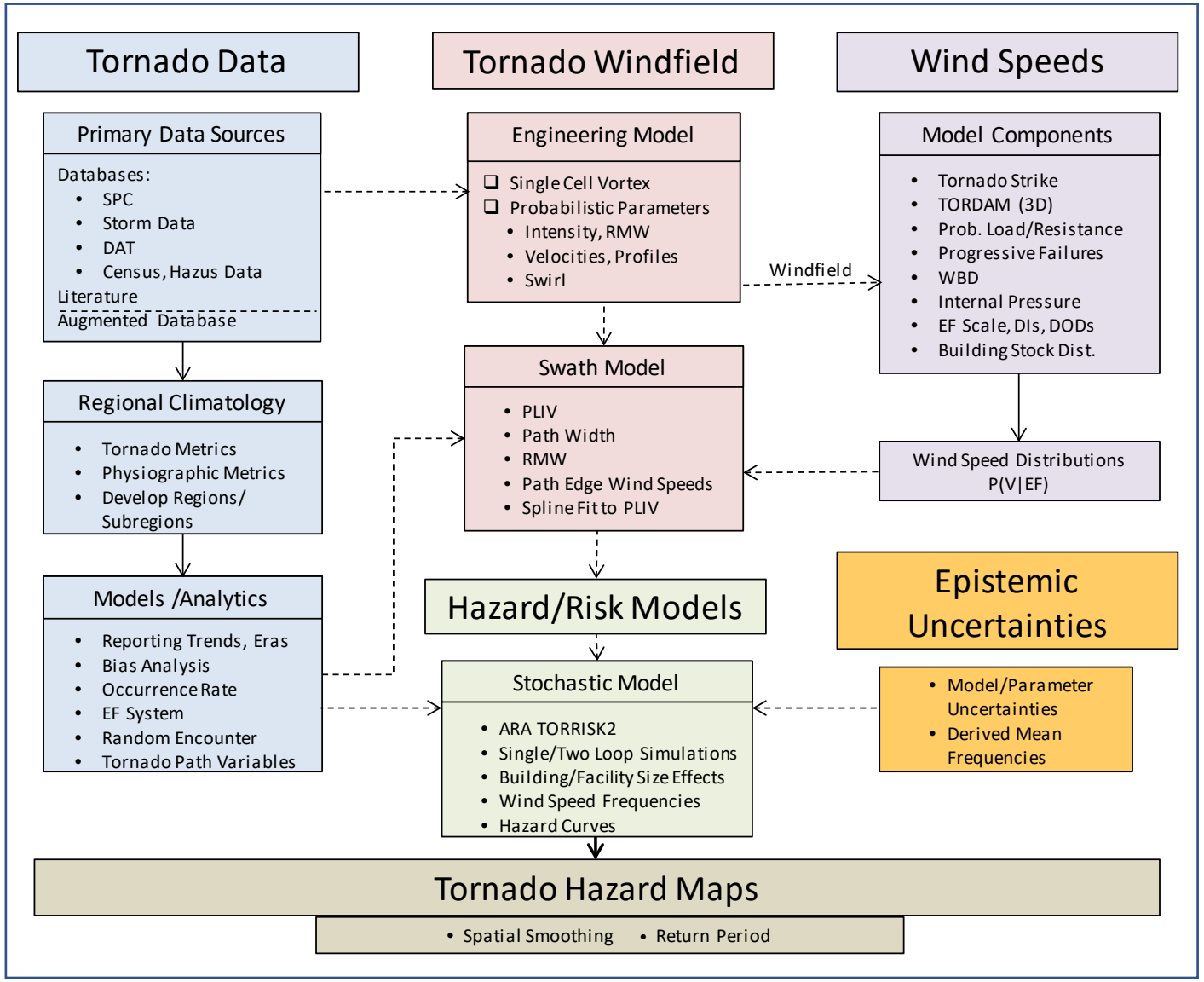
- Tornado hazard characterization
  - **R3 - develop new tornado hazard maps considering spatial estimates of tornado hazard**
- Design and construction of buildings and shelters in tornado–prone regions
  - **R5 - develop performance-based tornado-resistant design standards**
  - **R6 - develop tornado design methodologies**
- Emergency communications that warn of threats from tornadoes

NOTE: Summaries of the recommendations are provided in this presentation for context. The complete recommendations are available in the final report, available through the link shown at left.

Tornado Hazard Maps

Map Development Overview

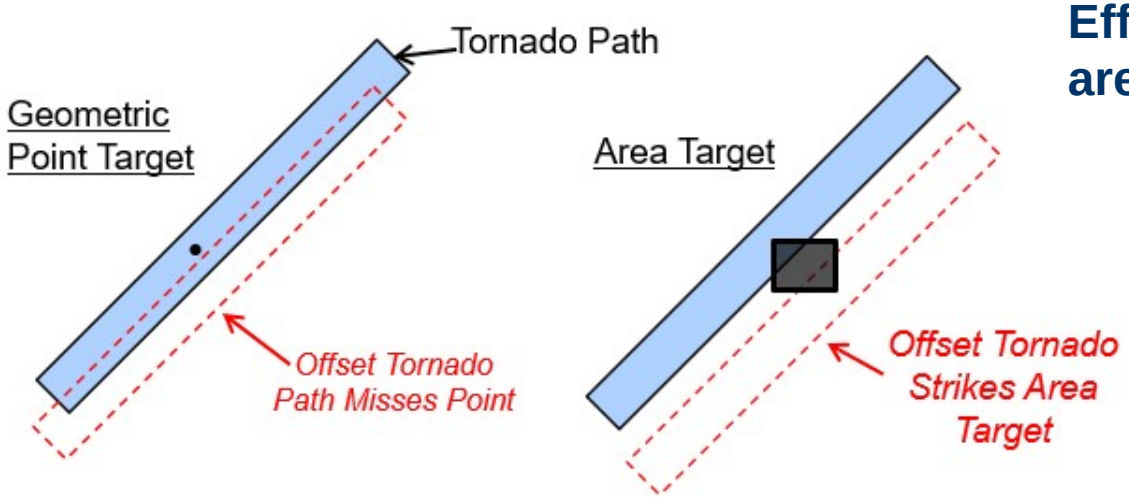
- Tornado Risk Mapping Project Components
- Six year effort, working with Applied Research Associates, Inc. (ARA) under contract to NIST, led by Dr. Larry Twisdale
- The US Nuclear Regulatory Commission supplemented NIST funding to include the analysis of epistemic uncertainties



Target Size Effects

Tornado risk and tornado speeds are a function of building or facility size and shape (effective plan area)

- Tornado strike probabilities increase with increasing plan area of the target building or structure (target size)
- For a given return period (i.e., mean recurrence interval), tornado speeds increase with increasing target size

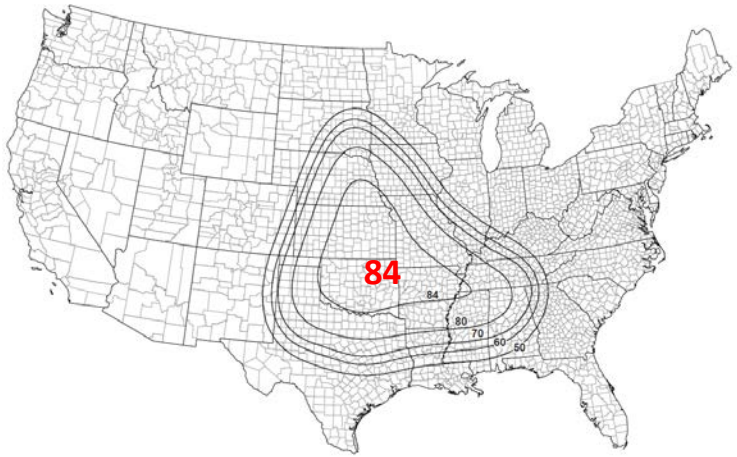
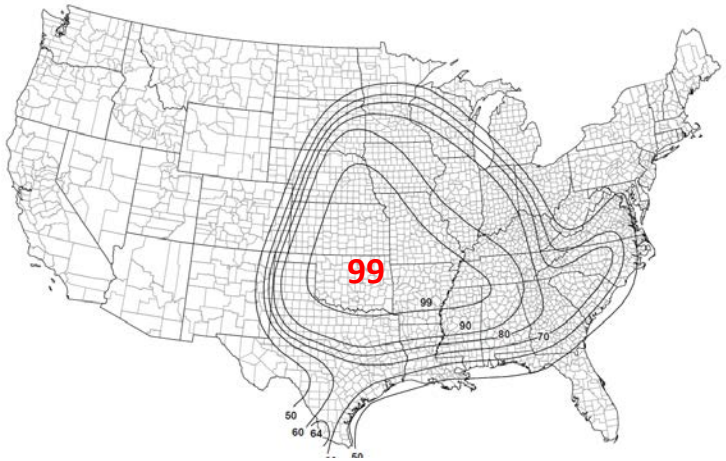
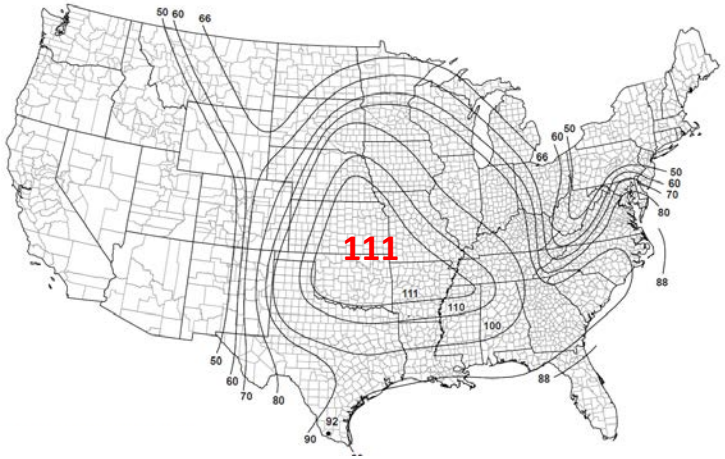
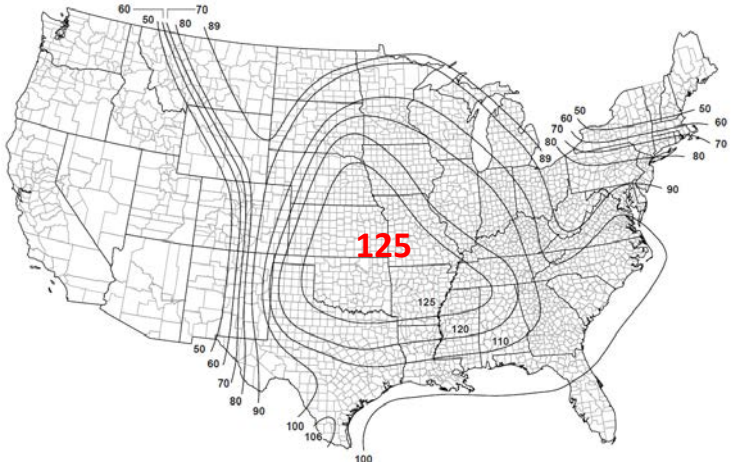


Effects of building or facility plan area on tornado strike probability

"Does the Flap of a Butterfly's Wings in Brazil Set off a Tornado in Texas?"
Edward U. Lorenz, Sc.D.
Professor of Meteorology
Massachusetts Institute of Technology, Cambridge

https://www.ias.ac.in/article/fulltext/reso/020/03/0260-0263

Tornado Hazard Maps - Examples

Effective Plan Area, A_e (ft^2)	Risk Category III (1,700 Year)	Risk Category IV (3,000 Year)
10K		
1M		

8 mapped effective plan area sizes, A_e (target sizes), from 1 to 4M sq ft

Mapped tornado speeds also developed for longer return periods

- 10,000 years
- 100,000 years
- 1,000,000 years
- 10,000,000 years

Tornado speeds are 3-s peak gusts in mph at 33 ft (10 m) height

Tornadic Wind Characteristics

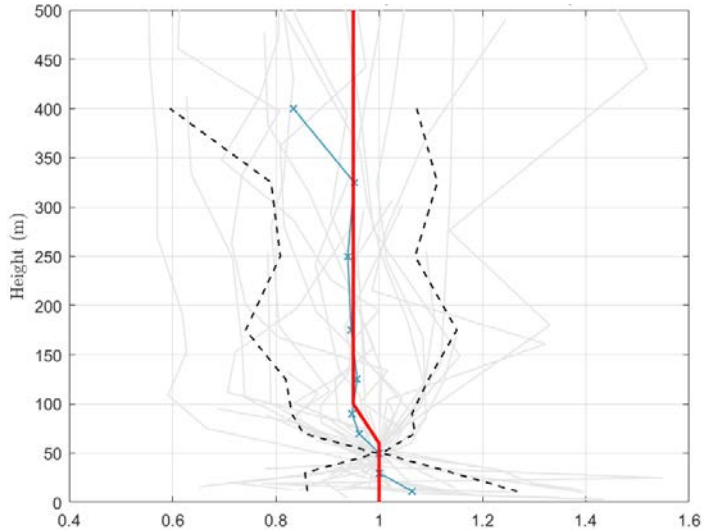
Very different from straight-line winds

- Short duration
- Rapidly changing speeds and directions
- Strong updrafts
- Decreasing speed with height above ground
- Atmospheric Pressure Change

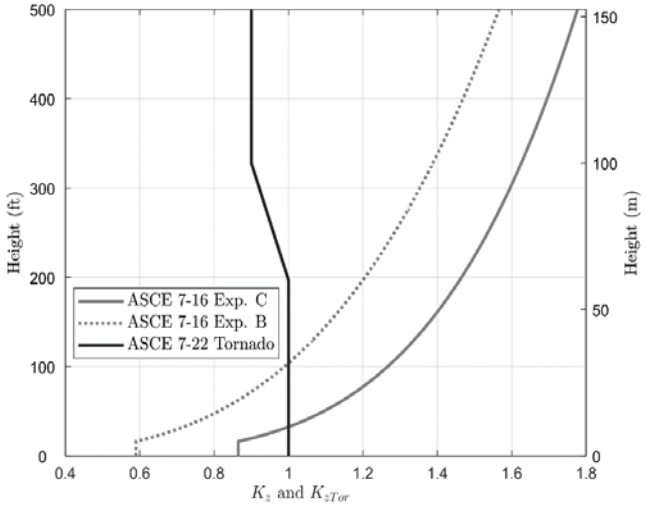
Worked closely with mobile radar community

- analyzed radar-measured tornado wind speeds
- developed tornado velocity pressure profiles

Source: NSF



Normalized Tornado Velocity Profiles



ASCE 7-22 Velocity Pressure Profiles
for Tornadic and Straight-Line Winds

Tornadic Wind-Structure Interaction

NIST

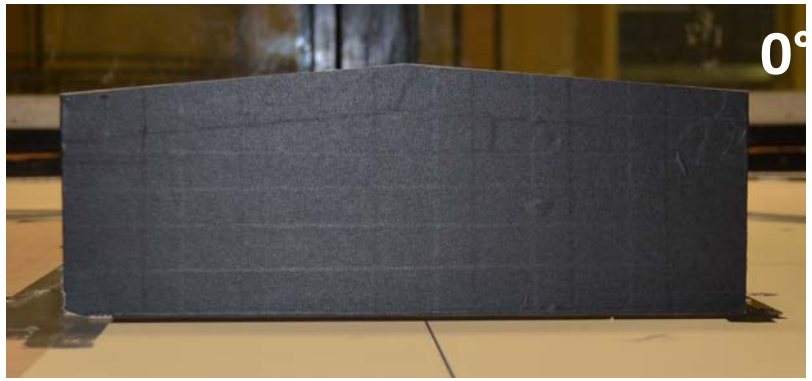
Very different from straight-line winds

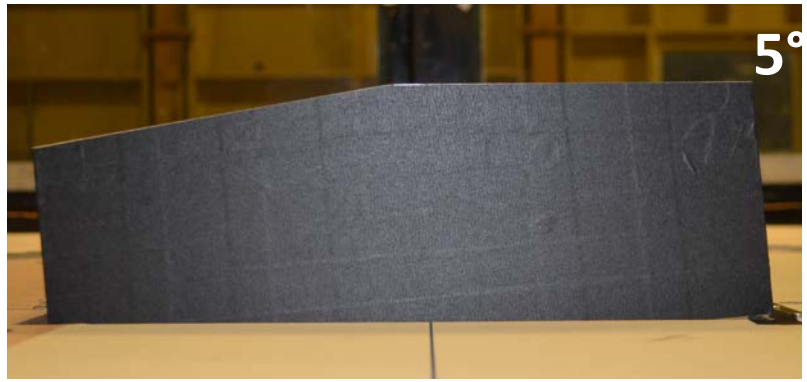
- Short duration
  - Changes to gust effect factor
- Rapidly changing speeds and directions
  - Changes to directionality factor
- Strong updrafts
  - Addition of new factor to account for increase in uplift pressures on roofs

Conducted wind tunnel tests to simulate the effective change in wind angle at the leading edge of the roof

- Decreasing speed with height above ground
  - Changes to velocity pressure exposure coefficient
- Atmospheric Pressure Change
  - Changes to internal pressure coefficient to account for contributions of APC

Wind Direction





engineering laboratory

ASCE/SEI 7-22
Tornado Provision Highlights

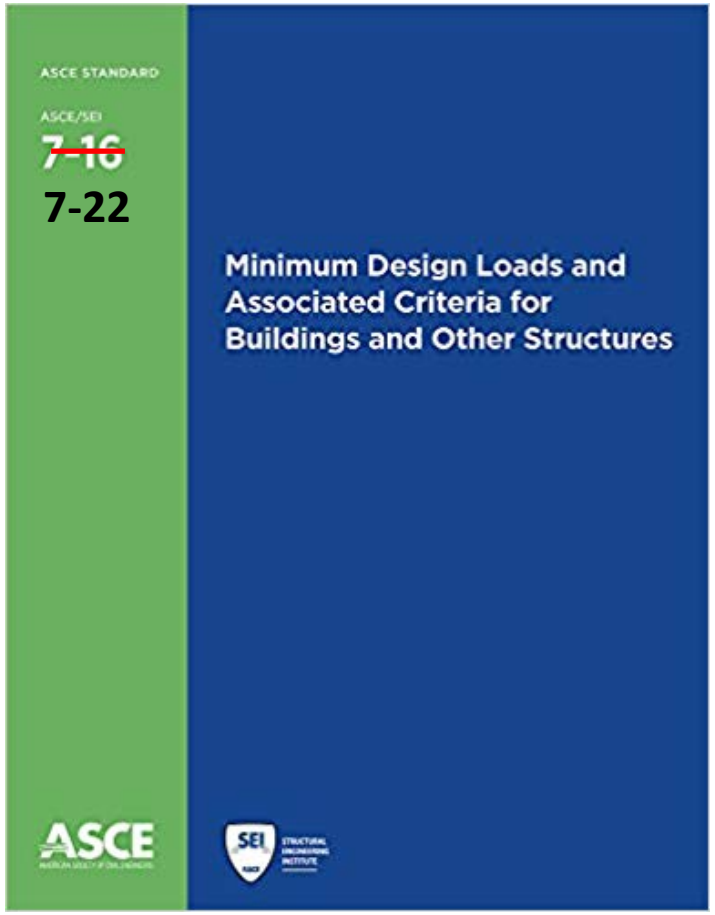
Marc Levitan

Chair
ASCE 7-22 Tornado Task Committee

STRUCTURAL ENGINEERING INSTITUTE

Tornado Loads - New in ASCE 7-22

NOAA Photo Library, NOAA Central Library; OAR/ERL/National Severe Storms Laboratory (NSSL).



Tornado Loads: Placement in 7-22

Red indicates differences from ASCE 7-16

- **Chapter 1: General**
  - Add Tornadoes to Risk Categorization Table 1.5-1
- **Chapter 2: Load Combinations**
  - Add Tornado Loads to load combinations
- **Chapter 26: Wind Loads**
  - Add requirement to check Tornado Loads per Ch. 32
- **New Chapter 32: Tornado Loads**
  - Complete provisions to determine Tornado Loads
- **New Appendix G: Tornado Hazard Maps for Long Return Periods**
  - Tornado speed maps for longer return periods, in support of tornado PBD and other applications

Table 1.5-1 Risk Category of Buildings and Other Structures for Flood, Wind, Tornado, Snow, Earthquake, and Ice Loads

Use or Occupancy of Buildings and Structures	Risk Category
Buildings and other structures that represent low risk to human life in the event of failure	I
All buildings and other structures except those listed in Risk Categories I, III, and IV	II
Buildings and other structures, the failure of which could pose a substantial risk to human life	III
Buildings and other structures designated as essential facilities Buildings and other structures, the failure of which could pose a substantial hazard to the community Buildings and other structures required to maintain the functionality of other Risk Category IV structures	IV

Ch. 32: Tornado Loads

- Built on ASCE 7 wind load procedures framework
  - Designed to provide similar look and feel with the wind provisions for improved ease of use
- Most wind load coefficients and equations are modified to account for differences in tornadic wind and wind-structure interaction
- Despite similarities in procedures, tornado loads are treated separately from wind loads

CHAPTER 32
TORNADO LOADS

32.1 PROCEDURES

32.1.1 Scope Buildings and other structures classified as Risk Category III or IV and located in the tornado-prone region as shown in Figure 32.1-1, including the main wind force resisting system (MWFRS) and all components and cladding (C&C) thereof, shall be designed and constructed to resist the greater of the tornado loads determined in accordance with the provisions of this chapter or the wind loads determined in accordance with Chapters 26 through 31, using the load combinations provided in Chapter 2.

> **User Note:** The tornado loads specified in this chapter provide reasonable consistency with the reliability delivered by the existing criteria in Chapters 26 and 27 for MWFRS, and therefore are only required for Risk Category III and IV buildings and other structures (see Return Period discussion in Section C32.5.1 for more information). The tornado loads are based on tornado speeds using 1,700- and 3,000-year return periods for Risk Category III and IV, respectively (which are the same return periods used for basic wind speeds in Chapter 26). The tornado speed at any given geographic location will range from approximately Enhanced Fujita Scale EF0 – EF2 intensity, depending on the risk category and effective plan area of the building or other structure (see Section C32.5.1). Options for protection of life and property from more intense tornadoes include construction of a storm shelter and/or design for longer-return-period tornado speeds as provided in Appendix G, including performance-based design. A building or other structure designed for tornado loads determined exclusively in accordance with Chapter 32 cannot be designated as a storm shelter without meeting additional critical requirements provided in the applicable building code and ICC 500, the ICC/NSSA *Standard for the Design and Construction of Storm Shelters*. See Commentary Section C32.1.1 for an in-depth discussion on storm shelters.

32.1.2 Permitted Procedures The design tornado loads for buildings and other structures, including the MWFRS and C&C elements thereof, shall be determined using one of the procedures as specified in this section and subject to the applicable limitations of Chapters 26 through 32, excluding Chapter 28.

An outline of the overall process for the determination of the tornado loads, including section references, is provided in Figure 32.1-3.

32.1.2.1 Tornado Loads on the Main Wind Force Resisting System Tornado loads for the MWFRS shall be determined using one or more of the following procedures, as modified by Chapter 32:

1. Directional Procedure for buildings of all heights as specified in Chapter 27 for buildings meeting the requirements specified therein;
2. Directional Procedure for Building Appurtenances (such as rooftop structures and rooftop equipment) and Other Structures (such as solid freestanding walls and solid freestanding signs, chimneys, tanks, open signs, single-plane open frames, and trussed towers) as specified in Chapter 29 for buildings meeting the requirements specified therein; or
3. Wind Tunnel Procedure for all buildings and all other structures as specified in Chapter 31 for buildings meeting the requirements specified therein.

32.1.2.2 Tornado Loads on Components and Cladding Tornado loads on the C&C of all buildings and other structures shall be determined using one or more of the following procedures, as modified by Chapter 32:

1. Analytical Procedures as specified in Parts 1 through 5, as appropriate, of Chapter 30, for buildings meeting the requirements specified therein; or
2. Wind Tunnel Procedure for all buildings and all other structures as specified in Chapter 31, for buildings meeting the requirements specified therein.

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.

32.2 DEFINITIONS

The following definitions apply to the provisions of Chapter 32. Terms not defined in this chapter shall be defined in accordance with Chapters 26 through 31, as appropriate, excluding Chapter 28.

ASCE TORNADO DESIGN GEODATABASE: The ASCE database (version 2020-1.0) of geocoded tornado speed design data.

OTHER STRUCTURES, SEALED: A structure that is completely sealed or has controlled ventilation such that tornado-induced atmospheric pressure changes will not be transmitted to the inside of the structure, including but not limited to certain tanks and vessels.

TORNADO-PRONE REGION: The area of the conterminous United States most vulnerable to tornadoes, as shown in Figure 32.1-1.

Scope

- Risk Category III and IV buildings and other structures
- Located in the tornado-prone region
- Design of MWFRS and C&C
- Must resist the greater of tornado loads or wind loads, using load combinations in Chapter 2

32.1 PROCEDURES

32.1.1 Scope Buildings and other structures classified as Risk Category III or IV and located in the tornado-prone region as shown in Figure 32.1-1, including the main wind force resisting system (MWFRS) and all components and cladding (C&C) thereof, shall be designed and constructed to resist the greater of the tornado loads determined in accordance with the provisions of this chapter or the wind loads determined in accordance with Chapters 26 through 31, using the load combinations provided in Chapter 2.

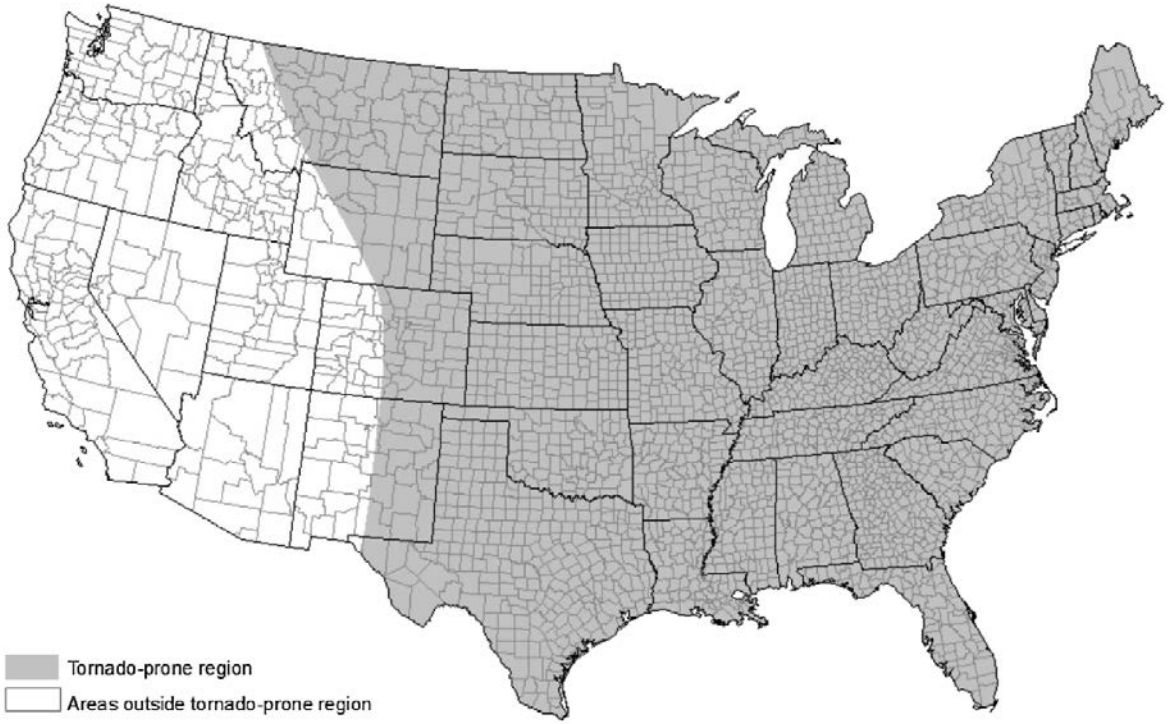


Figure 32.1-1. Tornado-prone region.

User Note

- Highlights key features/ explanations of tornado load provisions
- Design tornado speeds range from 60-138 mph, approximately EF0-EF2 intensity,
  - Dependent on Risk Category, geographic location, and effective plan area (target size)
- Return periods for Risk Category III and IV are 1,700 and 3,000 years, respectively (the same as used for wind loads)
- Options for protection from more intense tornadoes include storm shelters and PBD
- Tornado shelters cannot be designed solely using Chapter 32 – pointers to commentary

User Note: The tornado loads specified in this chapter provide reasonable consistency with the reliability delivered by the existing criteria in Chapters 26 and 27 for MWFRS, and therefore are only required for Risk Category III and IV buildings and other structures (see Return Period discussion in Section C32.5.1 for more information). The tornado loads are based on tornado speeds using 1,700- and 3,000-year return periods for Risk Category III and IV, respectively (which are the same return periods used for basic wind speeds in Chapter 26). The tornado speed at any given geographic location will range from approximately Enhanced Fujita Scale EF0 – EF2 intensity, depending on the risk category and effective plan area of the building or other structure (see Section C32.5.1). Options for protection of life and property from more intense tornadoes include construction of a storm shelter and/or design for longer-return-period tornado speeds as provided in Appendix G, including performance-based design. A building or other structure designed for tornado loads determined exclusively in accordance with Chapter 32 cannot be designated as a storm shelter without meeting additional critical requirements provided in the applicable building code and ICC 500, the ICC/NSSA *Standard for the Design and Construction of Storm Shelters*. See Commentary Section C32.1.1 for an in-depth discussion on storm shelters.

Reliability/Return Periods

- Conducted a series of risk informed analyses to compare the proposed tornadic wind load criteria with the reliability delivered by the existing (ASCE 7-16) wind load provisions
  - Collaboration between ASCE 7 Load Combinations Subcommittee and Wind Load Subcommittee
  - Adaptation of the reliability analysis used for ASCE 7-16 wind maps

Key Finding
Using 1,700- and 3,000-year maps for Risk Category III and IV, respectively, the tornadic wind load criteria provide reasonable consistency with the reliability delivered by the existing criteria in Chapters 26 and 27 for main wind force-resisting systems.

ASCE 7-22 Wind and Tornado Map Return Periods

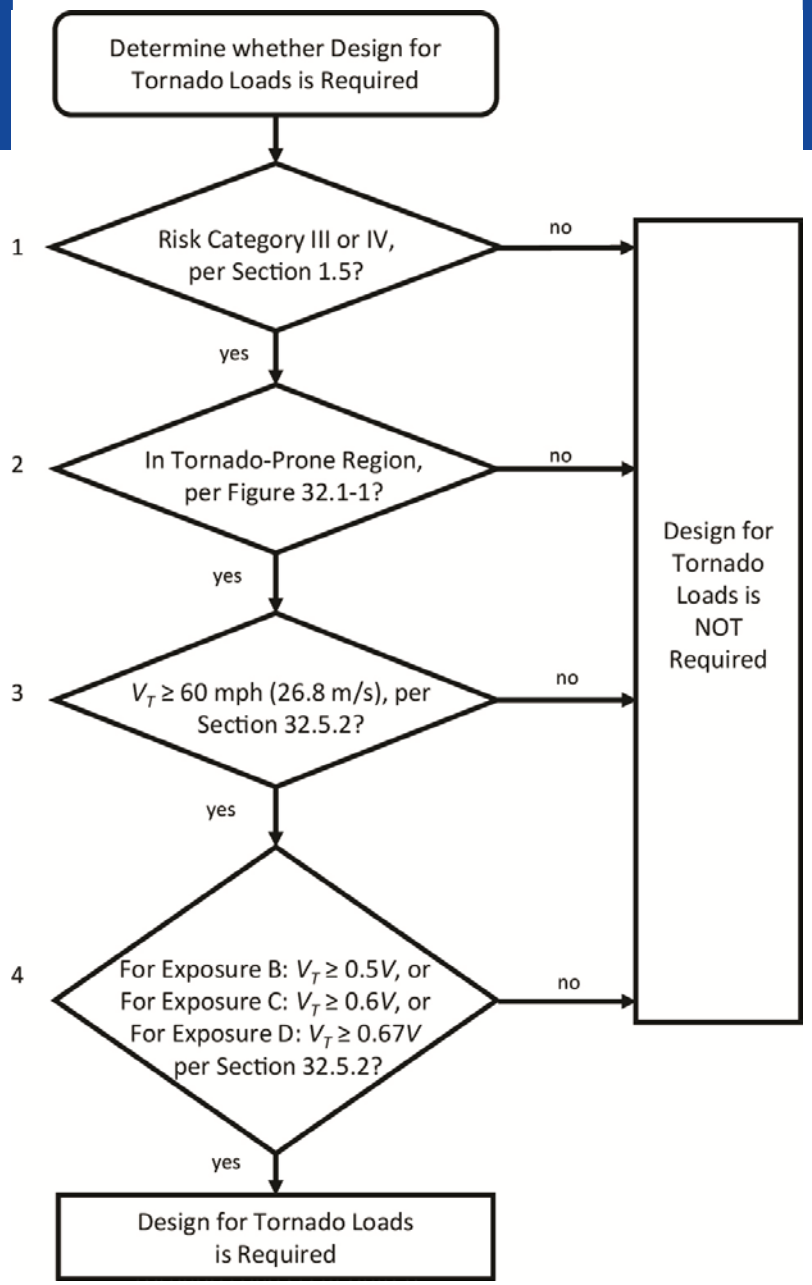
Risk Category	Ch. 26 Wind Return Period (years)	Ch. 32 Tornado Return Period (years)
I	300	n/a
II	700	n/a
III	1,700	1,700
IV	3,000	3,000

No significant tornado risk at 300 and 700 year return periods

Where Design for Tornado Loads is Not Required

A flowchart is provided at the beginning of Chapter 32 identifying the process to determine where design for tornado loads are not required

- Steps 1 and 2 – per Section 32.1.1
- Steps 3 and 4 – per Section 32.5.2
  - The tests on V_T represent approximate threshold tornado speeds at which tornado loads might begin to control some aspect of the wind load design
  - For step 4, the Basic Wind Speed V and the exposure category are determined accordance with Ch. 26, based on the exposure resulting in the greatest wind loads for any wind direction at the site



Where Tornado Loads are Likely to Control

Tornado loads are more likely to control at least some element(s) of the wind load design for structures that

- are located in the central and southeast US (except near the coast where dominated by hurricanes)
- are Risk Category IV
- are designated as Essential Facilities
- have large effective plan areas
- are located in Exposure B
- have low mean roof heights
- are classified as enclosed buildings for wind loads

Nursing Home
Caddo County, Oklahoma
August 19, 2007

Credit: FEMA

Tornado loads can control over wind loads when tornado speeds are as little as half of the basic wind speeds

Where tornado loads control, design uplift pressures on roofs will typically increase. This will help reduce the most common tornado and other windstorm failures.

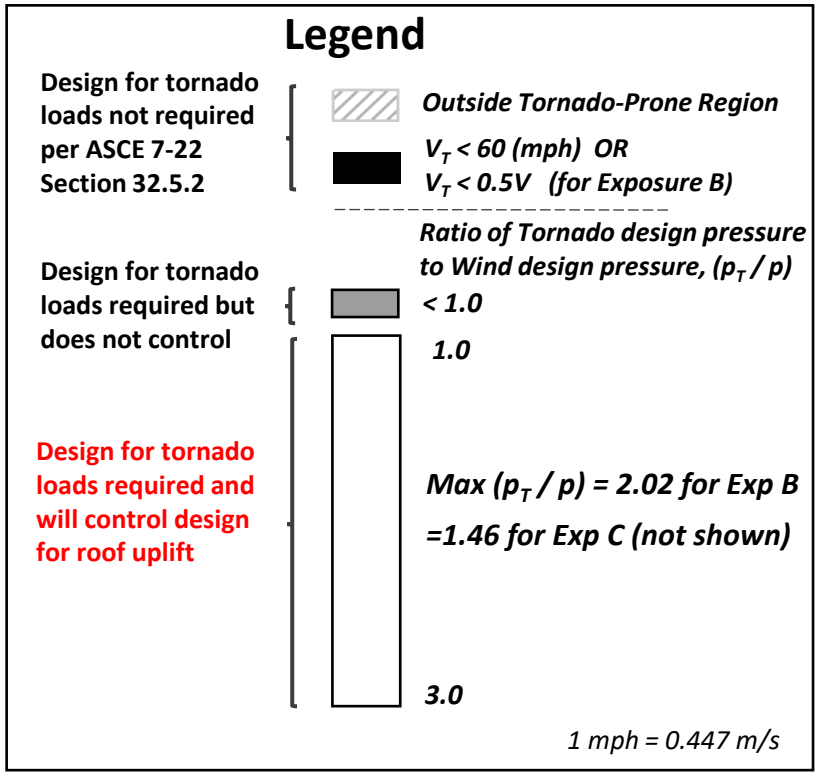
Example: 2-Story Elementary School
MWFRS Mid-Roof Uplift Pressure Ratios

Risk Category III

Effective Plan Area = 100,000 ft^2

Exposure B

Uplift pressures in the field of the roof are almost double the straight-line wind pressures, across much of of the central and southeast US



Where Will Tornado Loads Control?

It depends on a number of variables

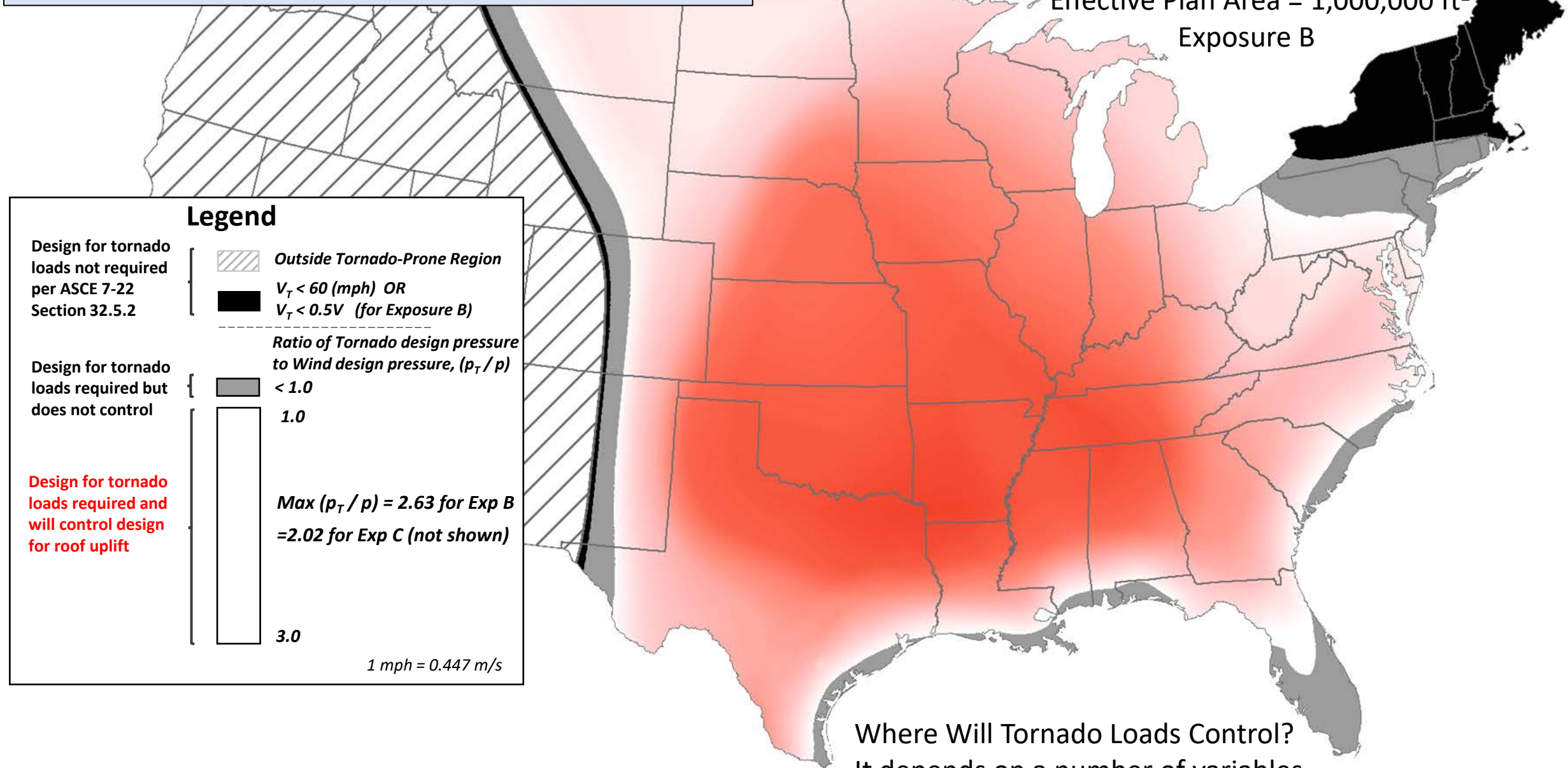
Example: 5-Story Hospital
MWFRS Mid-Roof Uplift Pressure Ratios

Risk Category IV

Effective Plan Area = 1,000,000 ft^2

Exposure B

Tornados will control uplift in the field of the roof over most of the eastern 2/3 of the US for this specific example building



Where Will Tornado Loads Control?

It depends on a number of variables

ICC Tornado Awareness and Risk Mitigation Webinar

ASCE/SEI 7-22

Emerging Trends in Wind Design Safety for the Architectural and Engineering Community

Donald R. Scott, P.E., S.E., F.SEI, F.ASCE
Chair ASCE 7 Wind Load Subcommittee
February 15, 2022

STRUCTURAL ENGINEERING INSTITUTE

Case Study of New Tornado Load Provisions

Case study by Benchmark Harris and Blake Haney, with Huckabee, Inc. Information and graphics used with permission.

Objectives

- Compare MWFRS and C&C pressures between ASCE 7-16 (non-tornado) and tornado provisions in the DFW Area
- Consider cost impact

Facilities

- Risk Category III
  - New Elementary School, $V_T = 90$ mph
  - New High School, $V_T = 102$ mph
- Risk Category IV
  - New Fire Station, $V_T = 97$ mph
  - New Hospital Campus, $V_T = 123$ mph

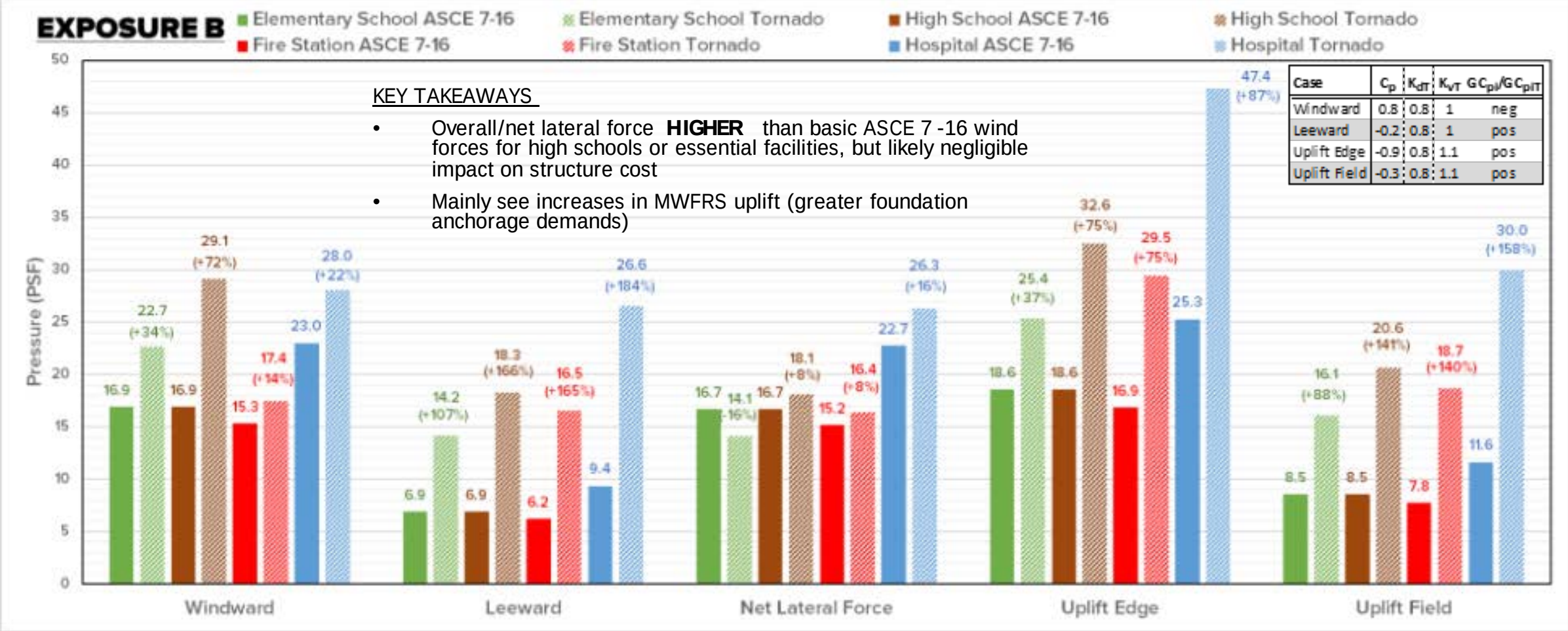
Key Variables

- Assumed Effective Plan Areas (ft^2):
  - Elementary school: 100K
  - High schools): 500K
  - Fire stations: 15K
  - Hospital campuses: 1M
- Assumed mean roof heights:
  - Elementary & high schools (two-story): 33 ft
  - Fire stations: 20 ft
  - Hospital campuses (mostly five-story buildings): 80 ft
- Exposure B & C considered
- Enclosure for tornado loads
  - Elementary & high schools: **no** impact-resistant glazing = partially enclosed
  - Fire stations & hospitals **require** impact-resistant glazing = enclosed
  - For basic ASCE 7-16 wind loads, all buildings in this study are enclosed

Case Study of New Tornado Load Provisions

MWFRS

Case study by Benchmark Harris and Blake Haney, with Huckabee, Inc. Information and graphics used with permission.



KEY TAKEAWAYS

- Overall/net lateral force **HIGHER** than basic ASCE 7 -16 wind forces for high schools or essential facilities, but likely negligible impact on structure cost
- Mainly see increases in MWFRS uplift (greater foundation anchorage demands)

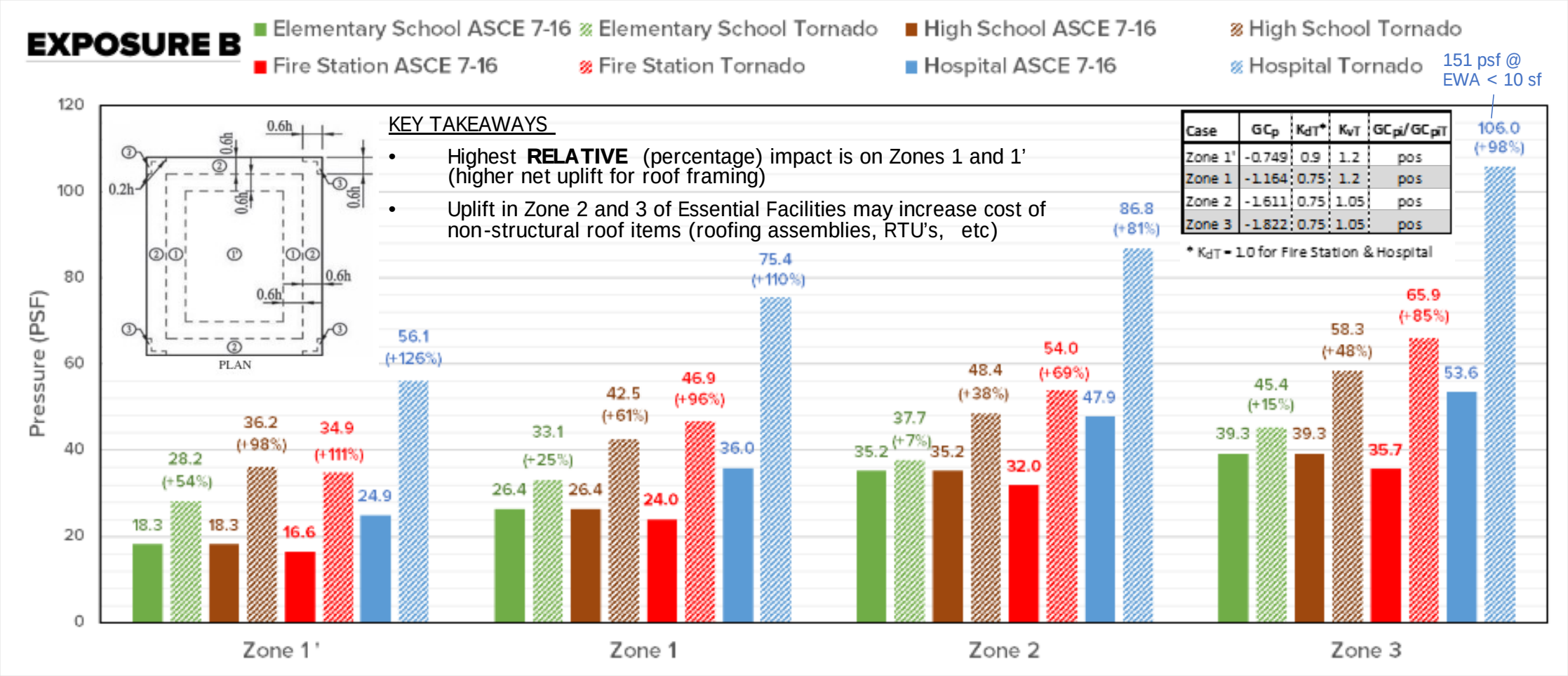
Case	C_p	K_{dT}	K_{vT}	GC_{pi}/GC_{piT}
Windward	0.8	0.8	1	neg
Leeward	-0.2	0.8	1	pos
Uplift Edge	-0.9	0.8	1.1	pos
Uplift Field	-0.3	0.8	1.1	pos

ICC Tornado Awareness and Risk Mitigation

Case Study of New Tornado Load Provisions

C&C – Effective Wind Area = 200 sf

Case study by Benchmark Harris and Blake Haney, with Huckabee, Inc. Information and graphics used with permission.



Case	GC_p	K_{dT}*	K_{vT}	GC_{pi}/GC_{piT}
Zone 1'	-0.749	0.9	1.2	pos
Zone 1	-1.164	0.75	1.2	pos
Zone 2	-1.611	0.75	1.05	pos
Zone 3	-1.822	0.75	1.05	pos

* K_{dT} = 1.0 for Fire Station & Hospital

Case Study of New Tornado Load Provisions

Case study by Benchmark Harris and Blake Haney, with Huckabee, Inc. Information and graphics used with permission.

This cost study only considered primary structural steel, foundation concrete and reinforcing, and exterior wall stud costs.

It did not include other costs, including but not limited to:

- roofing assemblies
- rooftop equipment (including anchorages)
- miscellaneous steel
- glazing

ADDITIONAL COSTS DUE TO TORNADO PROVISIONS:

EXPOSURE B

School Type	Steel	Diaph. Connection	Foundation Anchorage	Wall Studs	Total
ES	$ 24,240.30	$ -	$ -	$ 24,120.00	$ 48,360.30
HS	$ 139,777.61	$ 7,500.50	$ 20,000.00	$ 90,000.00	$ 257,278.11

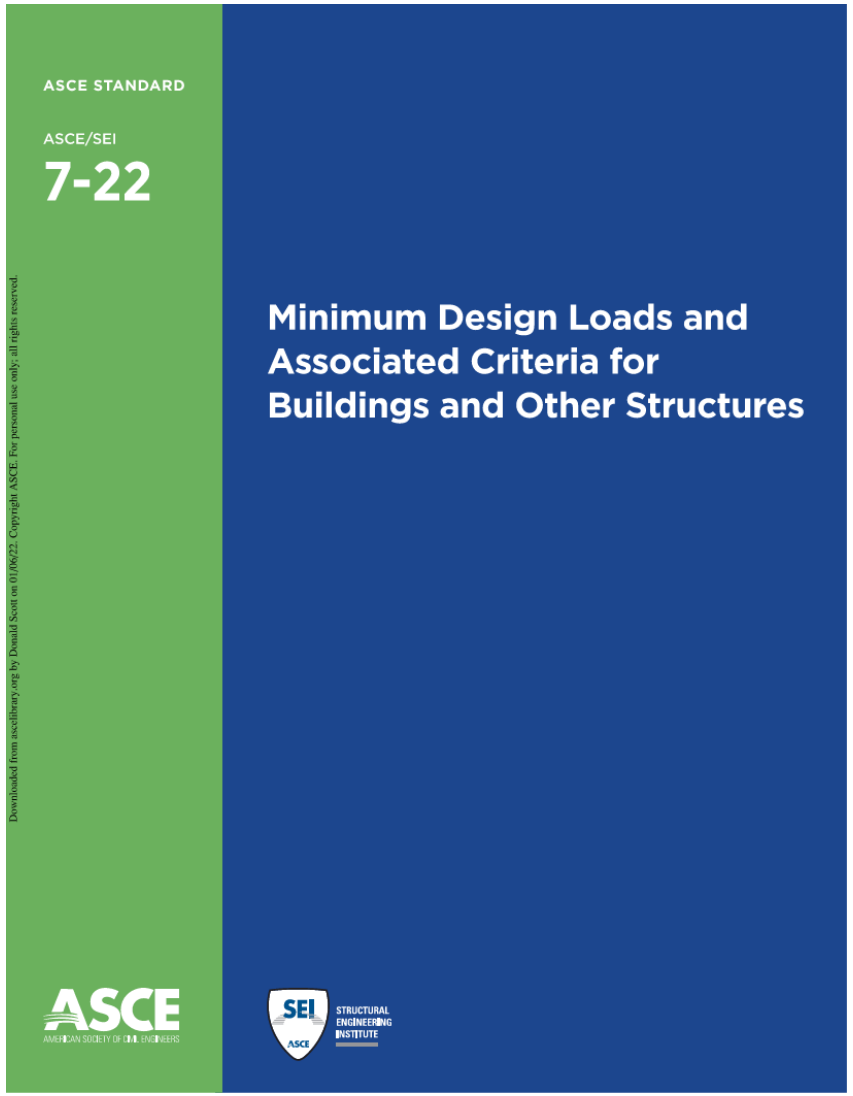
EXPOSURE C

School Type	Steel	Diaph. Connection	Foundation Anchorage	Wall Studs	Total
ES	$ 24,240.30	$ -	$ -	$ -	$ 24,240.30
HS	$ 139,777.61	$ -	$ 20,000.00	$ -	$ 159,777.61

Consider this in the context of the overall building cost:

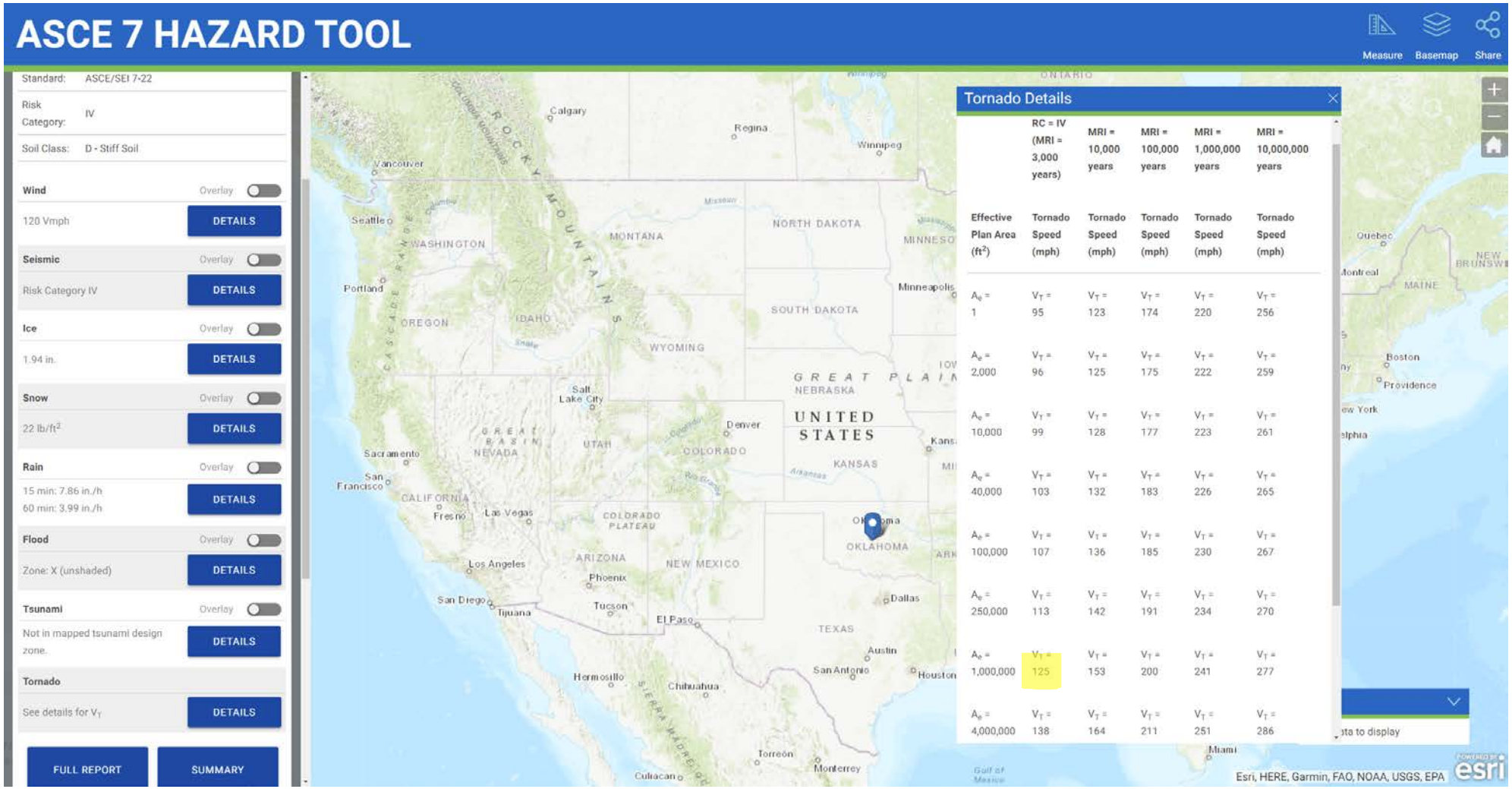
School Type	Budget	Cost Increase EXPOSURE B		Cost Increase EXPOSURE C	
ES	$20M	$ 48,360.30	+0.24%	$ 24,240.30	+0.12%
HS	$200M	$ 257,278.11	+0.13%	$ 159,777.61	+0.08%

ICC Tornado Awareness and Risk Mitigation



- Wind Speed Maps / ASCE Hazard Tool
- Velocity Pressure / Directionality Factor
- Removal of Tabulated Procedures / MWFRS & C&C Provisions
- Elevated Buildings
- Roof Pressures for Load Cases
- Simplified Sloped Roof Pressure Coefficients
- Loads on Building Canopies
- Tornado Loads for Risk Category III & IV Structures

Wind Speed Maps / ASCE Hazard Tool – https://asce7hazardtool.online – *FREE!*



Effective Plan Area (ft²)	Tornado Speed (mph) RC = IV (MRI = 3,000 years)	Tornado Speed (mph) MRI = 10,000 years	Tornado Speed (mph) MRI = 100,000 years	Tornado Speed (mph) MRI = 1,000,000 years	Tornado Speed (mph) MRI = 10,000,000 years
A_e = 1	V_T = 95	V_T = 123	V_T = 174	V_T = 220	V_T = 256
A_e = 2,000	V_T = 96	V_T = 125	V_T = 175	V_T = 222	V_T = 259
A_e = 10,000	V_T = 99	V_T = 128	V_T = 177	V_T = 223	V_T = 261
A_e = 40,000	V_T = 103	V_T = 132	V_T = 183	V_T = 226	V_T = 265
A_e = 100,000	V_T = 107	V_T = 136	V_T = 185	V_T = 230	V_T = 267
A_e = 250,000	V_T = 113	V_T = 142	V_T = 191	V_T = 234	V_T = 270
A_e = 1,000,000	V_T = 125	V_T = 153	V_T = 200	V_T = 241	V_T = 277
A_e = 4,000,000	V_T = 138	V_T = 164	V_T = 211	V_T = 251	V_T = 286

Elevated Buildings

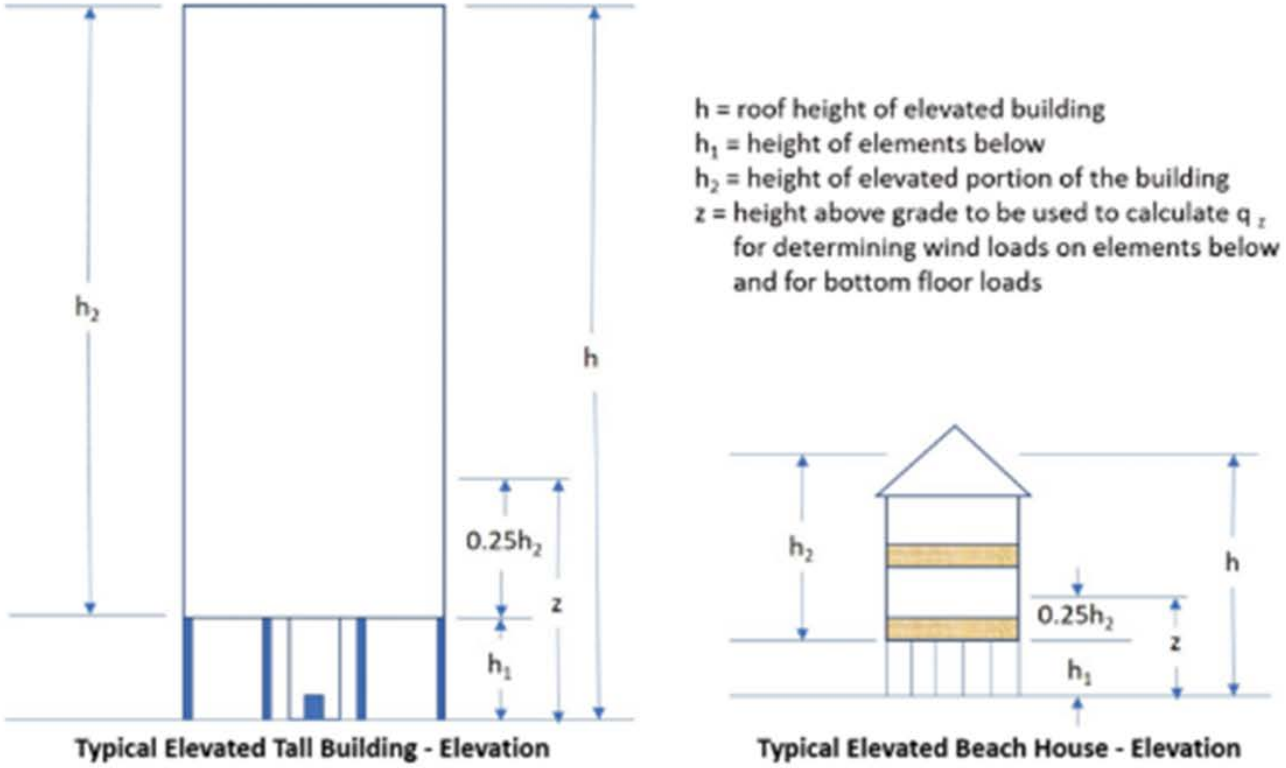
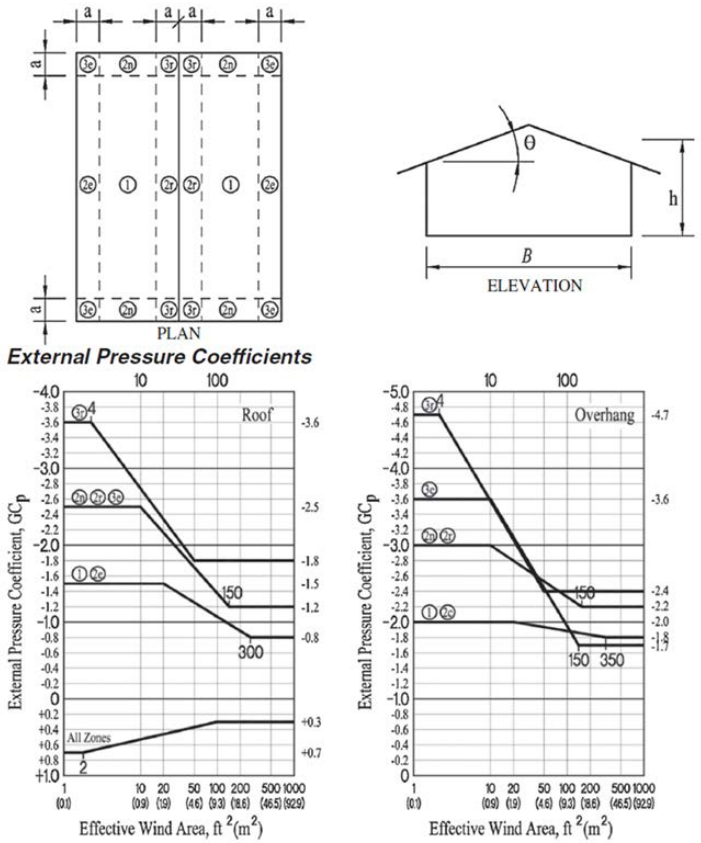


Figure C27.3-1. High-rise and low-rise examples of dimensions and heights used in Section 27.3.1.1.

Simplified Sloped Roof Pressure Coefficients



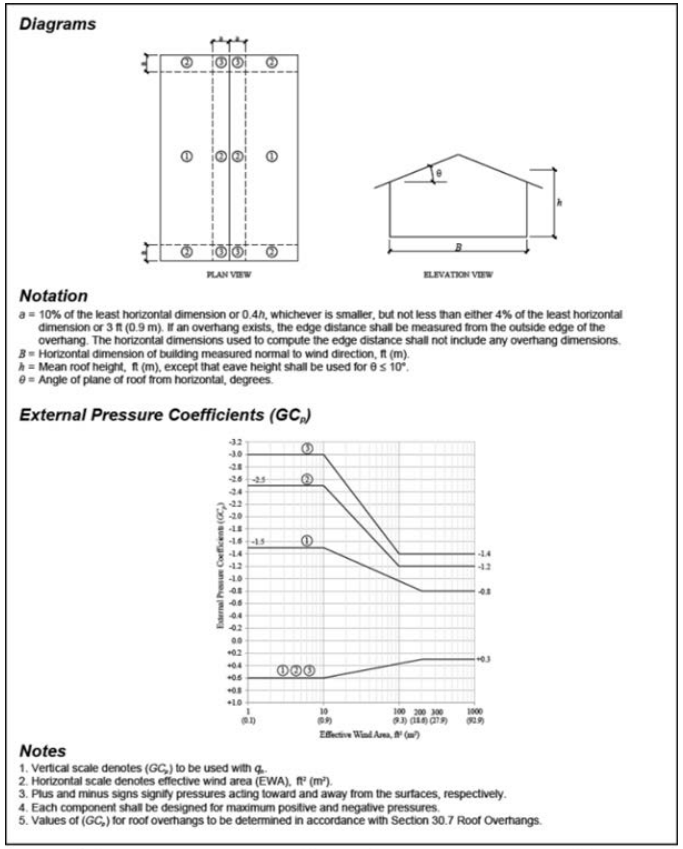
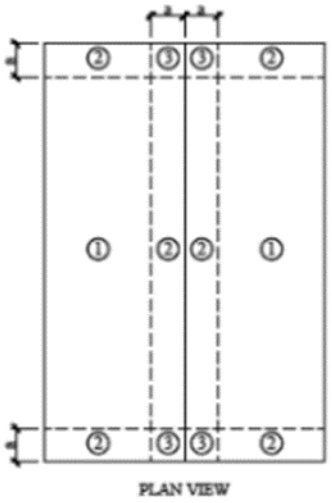
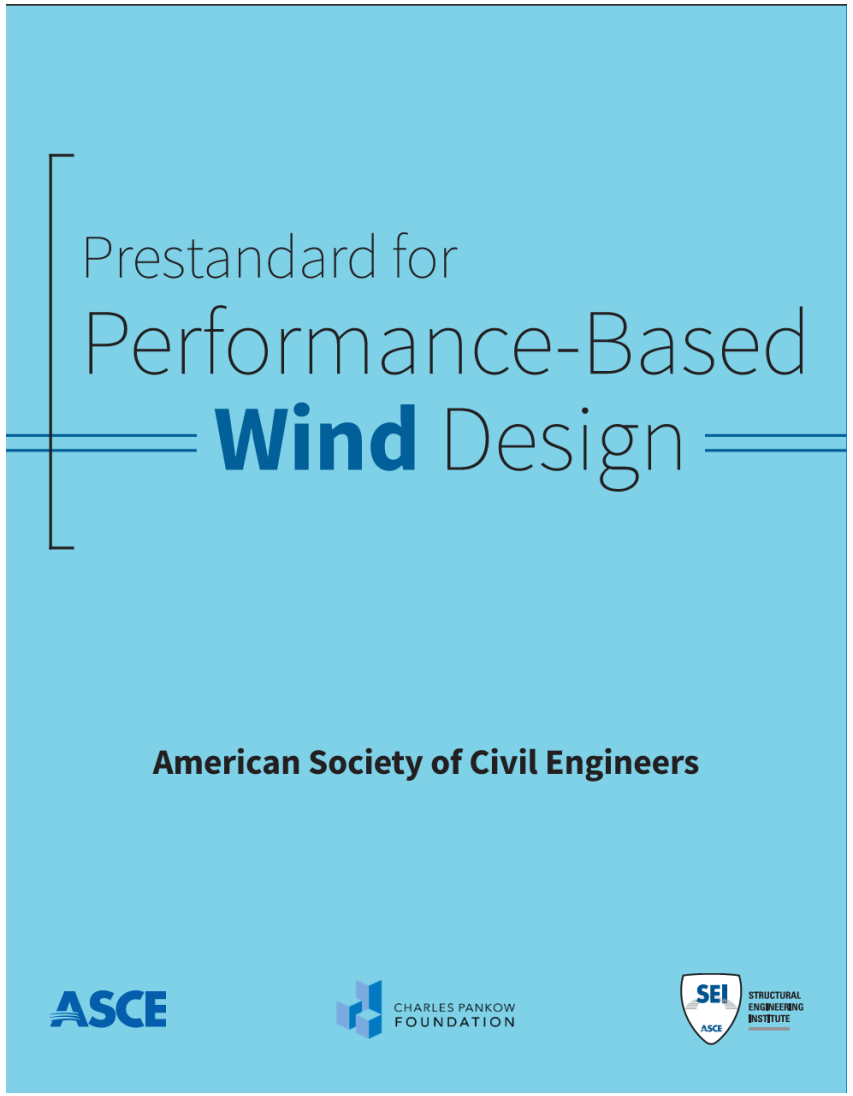


Figure 30.3-2C. Components and cladding [$h \le 60$ ft ($h \le 18.3$ m)]: external pressure coefficients, (GC_{pi}), for enclosed, partially enclosed, and partially open buildings—gable roofs, $20° < \theta \le 27°$.



ICC Tornado Awareness and Risk Mitigation



1.3.1.3 Performance-Based Procedures Structural and non-structural components and their connections designed with performance-based procedures shall be demonstrated by analysis in accordance with Section 2.3.5 or by analysis procedures supplemented by testing to provide a reliability that is generally consistent with the target reliabilities stipulated in this section. Structural and nonstructural components subjected to dead, live, environmental, and other loads except earthquake, tsunami, flood, and loads from extraordinary events shall be based on the target reliabilities in Table 1.3-1. Structural systems subjected to earthquake shall be based on the target reliabilities in Tables 1.3-2 and 1.3-3. The design of structures subjected to tsunami loads shall be based on the target reliabilities in Table 1.3-4. Structures, components, and systems that are designed for extraordinary events using the requirements of Section 2.5 for scenarios approved by the Authority Having Jurisdiction shall be based on the target reliabilities in Table 1.3-5. The analysis procedures used shall account for uncertainties in loading and resistance.

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.

QUESTIONS?

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STRUCTURAL ENGINEERING INSTITUTE

Safe Room Resources

- FEMA P-320 - Taking Shelter from the Storm: Building or Installing a Safe Room for Your Home
- FEMA P-361 - Safe Rooms for Tornadoes and Hurricanes: Guidance for Community and Residential Safe Rooms
- Community Tornado Safe Room Doors Installation and Maintenance Fact Sheet
- Best Available Refuge Area Checklist
- Residential Tornado Safe Room Doors Fact Sheet
- Foundation and Anchoring Criteria for Safe Rooms Fact Sheet
- Highlights of ICC 500-2020
- Flood Hazard Elevation and Siting Criteria for Community Safe Rooms
- Flood Hazard Elevation and Siting Criteria for Residential Safe Rooms
- Additional One-Page Safe Room Resources