ASCE | KNOWLEDGE & LEARNING

Unit 2

Tornado Load Procedures and Tornado Hazard Maps

1

1

ASCE | KNOWLEDGE & LEARNING

Unit 2 Outline

Tornado Load Procedures and Tornado Hazard Maps

- ASCE 7-22 Tornado Load Framework
- Chapter 32 Scope and Limitations
- Tornado Load Procedures
- Tornado Hazard Maps
- Effective Plan Area
- Tornado Speed and Determination of When Tornado Loads are Not Required
- Summary

Credit: FEMA

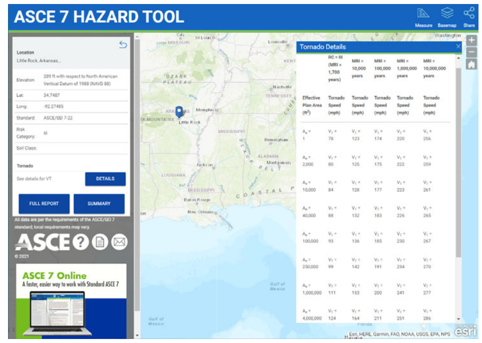
ASCE | KNOWLEDGE & LEARNING

2

2

Unit 2: Learning Outcomes

- Upon completion of this unit, you will be able to :
  - **Summarize** the scope and limitations of ASCE 7-22 tornado load requirements
  - **Identify** tornado load symbols and notations
  - **Explain** the process for development of the tornado hazard maps
  - **Determine** tornado speed for any geographic location, building/facility size, shape, and Risk Category
  - **Determine** if design for tornado loads is required or not
- This is important on the job because …
  - Provides the big picture of when tornado loads are required or not, and how to determine tornado speeds



ASCE 7-22 Tornado Load Framework

ASCE | KNOWLEDGE & LEARNING

Tornado Loads: Placement in 7-22

Note: In the course, when this bright red is used in the context of standards language and requirements, it indicates differences from ASCE 7-16

- **Chapter 1: General**
  - Add tornadoes as a required load
- **Chapter 2: Load Combinations**
  - Add tornado loads to load combinations
- **Chapter 26: Wind Loads**
  - Add requirement that tornado loads be determined per Ch. 32
- **New Chapter 32: Tornado Loads**
  - Complete set of provisions to determine tornado loads
  - Required for RC III and IV in tornado-prone region
  - Heavily reference methods from Ch. 26, 27, 29, 30, 31, w/ modifications
- **New Appendix G: Tornado Hazard Maps for Long Return Periods**
  - For use with tornado PBD and other specialty applications

5

5

ASCE | KNOWLEDGE & LEARNING

Chapter 1: Overview of Tornado Load Changes

CHAPTER 1: GENERAL

- Identify tornado load as a required load, instead of an *extraordinary load or event*
- Update key definitions to include tornadoes
- Define risk categories for use with tornado loads
- Define target reliabilities/annual probabilities of failure for tornado loads

6

6

Chapter 1: Nominal Loads

- Nominal Load Definition

1.2 DEFINITIONS AND SYMBOLS

…

NOMINAL LOADS: The magnitudes of the loads specified in this standard for dead, live, soil, wind, tornado, snow, rain, flood, and earthquake loads.

- Tornadoes also added in several locations having lists/examples of multiple load types, e.g.,

1.5.3 Toxic, Highly Toxic, and Explosive Substances

…

As a minimum, the hazard assessment shall include the preparation and reporting of worst-case release scenarios for each structure under consideration, showing the potential effect on the public for each. As a minimum, the worst-case event shall include the complete failure, for example, instantaneous release of the entire contents of a vessel, piping system, or other storage structure. A worst-case event includes, but is not limited to, a release during the design wind, design tornado, or design seismic event…

7

7

Chapter 1: Basic Requirements

- Incorporation of tornadoes into the main load requirements of the chapter

1.3 BASIC REQUIREMENTS

…

1.3.6 Counteracting Structural Actions. All structural members and systems, and all components and cladding in a building or other structure, shall be designed to resist forces caused by earthquakes, wind, and tornadoes, with consideration of overturning, sliding, and uplift, and continuous load paths shall be provided for transmitting these forces to the foundation. …

Note: The letter "C" preceding a chapter or section number designates commentary text

C1.3 BASIC REQUIREMENTS

…

C1.3.1 Strength and Stiffness Buildings and other structures must satisfy strength limit states in which members and components are proportioned to safely carry the design loads specified in this standard to resist buckling, yielding, fracture, and other unacceptable performance. This requirement applies not only to structural components but also to nonstructural elements, the failure of which could pose a substantial safety or other risk. Chapters 30 and 32 of this standard specify wind and tornado loads, respectively, that must be considered in the design of cladding. …

8

8

ASCE | KNOWLEDGE & LEARNING

Chapter 1: Essential Facilities

- Functionality requirements

1.2 DEFINITIONS AND SYMBOLS
…
ESSENTIAL FACILITIES: Buildings and other structures that are intended to remain operational in the event of extreme environmental loading from flood, wind, tornado, snow, or earthquakes.

Note: In the course, yellow highlighted text is used to identify enhanced tornado requirements for Essential Facilities, and buildings/other structures required to maintain the functionality of Essential Facilities

Building Performance

The tornado load provisions support the current trends towards performance-based design and explicit consideration of post-event functionality

9

9

ASCE | KNOWLEDGE & LEARNING

Chapter 1: Risk Category

1.5 CLASSIFICATION OF BUILDINGS AND OTHER STRUCTURES
…
1.5.1 Risk Categorization Buildings and other structures shall be classified based on the risk to human life, health, and welfare associated with their damage or failure by nature of their occupancy or use, according to Table 1.5-1, for the purposes of applying flood, wind, tornado, snow, earthquake, and ice provisions. Each building or other structure shall be assigned to the highest applicable risk category or categories.

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

10

10

ASCE | KNOWLEDGE & LEARNING

IBC Risk Category

- The International Building Code (IBC) has its own, similar Risk Categories
  - IBC table provides non-exhaustive lists of applicable occupancies
- Many of the listed occupancies tie back to IBC Chapter 3 – *Occupancy Classification and Use*

Table 1604.5 Risk Category of Buildings and Other Structures

Risk Category	Nature of Occupancy
I	Buildings and other structures that represent low risk to human life in the event of failure, including but not limited to: • list…
II	All buildings and other structures except those listed in Risk Categories I, III, and IV
III	Buildings and other structures, the failure of which could pose a substantial risk to human life, including but not limited to: • list…
IV	Buildings and other structures designated as essential facilities, including but not limited to: • list…

ASCE | KNOWLEDGE & LEARNING

ASCE | KNOWLEDGE & LEARNING

Chapter 1: Target Reliabilities

- The target reliabilities/annual probabilities of failure for tornado loads are the same as those used for wind loads
  - Applicable to Main Wind Force Resisting Systems

Table 1.3-1.

Target Reliability (Annual Probability of Failure, PF) and Associated Reliability Indices (β) for Load Conditions That Do Not Include Earthquake, Tsunami, or Extraordinary Events.

Basis	Risk Category			
	I	II	III	IV
Failure that is not sudden and does not lead to widespread progression of damage	$P_F = 1.25 \times 10^{-4}$ per year $\beta = 2.5$	$P_F = 3.0 \times 10^{-5}$ per year $\beta = 3.0$	$P_F = 1.25 \times 10^{-5}$ per year $\beta = 3.25$	$P_F = 5.0 \times 10^{-6}$ per year $\beta = 3.5$
Failure that is either sudden or leads to widespread progression of damage	$P_F = 3.0 \times 10^{-5}$ per year $\beta = 3.0$	$P_F = 5.0 \times 10^{-6}$ per year $\beta = 3.5$	$P_F = 2.0 \times 10^{-6}$ per year $\beta = 3.75$	$P_F = 7.0 \times 10^{-7}$ per year $\beta = 4.0$
Failure that is sudden and results in widespread progression of damage	$P_F = 5.0 \times 10^{-6}$ per year $\beta = 3.5$	$P_F = 7.0 \times 10^{-7}$ per year $\beta = 4.0$	$P_F = 2.5 \times 10^{-7}$ per year $\beta = 4.25$	$P_F = 1.0 \times 10^{-7}$ per year $\beta = 4.5$

Notes:

[1] The target reliability indexes are provided for a 50-year reference period, and the probabilities of failure have been annualized. The equations presented in Section 2.3.6 are based on reliability indexes for 50 years, because the load combination requirements in Section 2.3.2 are based on the maximum loads for the 50-year reference period.

[2] Commentary to Section 2.5 includes references to publications that describe the historic development of these target reliabilities for earthquake, tsunami, or extraordinary events.

ASCE | KNOWLEDGE & LEARNING

Chapter 2: Load Combinations

- For combinations where wind load *W* is the principal load, it is replaced with *(W or W_T)*
- No tornado loads in combinations where wind is the coincident (arbitrary point-in-time) load
- No tornadoes in flood combos
- Additional changes to exceptions
- Allowable Stress Design (ASD) load combinations use the same approach
- Load combinations/examples will be covered in detail in Unit 4

Chapter 2: COMBINATIONS OF LOADS

2.2 SYMBOLS

…

W = Wind Load

W_T = Tornado Load determined in accordance with Chapter 32

2.3 LOAD COMBINATIONS FOR STRENGTH DESIGN

2.3.1 Basic Combinations

1a. 1.4D

2a. 1.2D + 1.6L + (0.5L_r or 0.3S or 0.5R)

3a. 1.2D + (1.6L_r or 1.0S or 1.6R) + (L or 0.5W)

4a. 1.2D + 1.0(W or W_T) + L + (0.5L_r or 0.3S or 0.5R)

5a. 0.9D + 1.0(W or W_T)

13

13

ASCE | KNOWLEDGE & LEARNING

Chapter 26: Wind Loads

- Delete the limitation stating that tornadoes have not been considered

Chapter 26
WIND LOADS: GENERAL REQUIREMENTS

….

~~**26.14 TORNADO LIMITATION**~~

~~Tornadoes have not been considered in the wind load provisions.~~

Chapter C26
WIND LOADS: GENERAL REQUIREMENTS

….

~~**C26.14 TORNADO LIMITATION**~~

~~Tornadoes have not been considered in the wind load provisions because of their very low probability of occurrence~~….

<delete the entirety of the C26.14 tornado commentary and associated references>

ASCE | KNOWLEDGE & LEARNING

14

14

Chapter 26: Wind Loads

- While tornadoes are a type of windstorm, tornado loads are treated separately from wind loads
  - Therefore, tornado loads have their own chapter
  - Tornado provisions in Chapter 26 are limited to a requirement calling the need to design for tornado loads per Chapter 32

26.1 PROCEDURES

26.1.1 Scope. Buildings and other structures, including the main wind force resisting system (MWFRS) and all components and cladding (C&C) thereof, shall be designed and constructed to resist the wind loads determined in accordance with Chapters 26 through 31.

Risk Category III and IV buildings and other structures, including the MWFRS and all C&C thereof, shall also be designed and constructed to resist tornado loads determined in accordance with Chapter 32, as applicable.

The provisions of this chapter define basic wind parameters for use with other provisions contained in this standard.

C26.1 PROCEDURES

C26.1.1 Scope.

…

Tornado loads are treated separately from wind loads, as described in Section C32.1.

These two words are pack a lot of punch. Tornado loads will not be required for many RC III/IV structures.

15

15

ASCE 7-22 Tornado Load Framework

Questions / Discussion

marc.l.levitan@gmail.com

16

16

ASCE | KNOWLEDGE & LEARNING

Chapter 32 Scope and Limitations

17

17

Ch. 32 – Tornado Loads

First page of Tornado Load Chapter – Section 32.1

- Scope
- User Note with key explanations and limitations
- Permitted Procedures
  - covered in the next video

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.

Minimum Design Loads and Associated Criteria for Buildings and Other Structures 353

ASCE | KNOWLEDGE & LEARNING

18

18

Ch. 32 – Tornado Loads

Scope

- Risk Category III and IV buildings and other structures
- Located in the tornado-prone region
- For design of
  - Main Wind Force Resisting System (MWFRS), and
  - Components and Cladding (C&C)
- Must resist the greater of tornado loads or wind loads, using load combinations in Chapter 2

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.

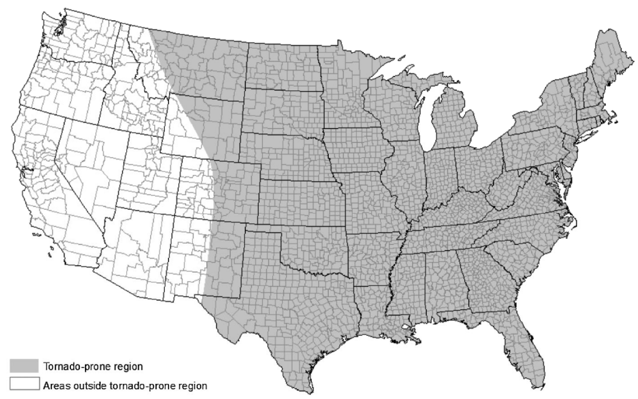


Figure 32.1-1. Tornado-prone region.

ASCE | KNOWLEDGE & LEARNING

19

19

Ch. 32 – Tornado Loads

User Note

- Highlights key features/explanations of tornado load provisions
- Flags critical limitations related to the connection between this Chapter and tornado shelter design
- Points to sections of the commentary for more information on specific topics

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.

ASCE | KNOWLEDGE & LEARNING

20

20

Ch. 32 – Tornado Loads

User Note – Explanation

- Lets users know up front that the tornado load provisions are consistent with key elements of the wind load provisions – not designing for the worst possible windstorms
- Reliability (annual probability of failure) of the MWFRS under tornado loads is approximately the same as for wind loads, computed using Chapter 26 and 27 (Directional Procedure)
- Tornado speeds are based on the same return periods (mean recurrence intervals) as wind speeds

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.

ASCE | KNOWLEDGE & LEARNING

21

21

ASCE | KNOWLEDGE & LEARNING

Reliability/Return Periods

ASCE 7 Ad-hoc Tornado Reliability Working Group

- Collaboration between NIST, ARA, ASCE 7 Load Combinations Subcommittee and Wind Load Subcommittee
- Adapted reliability analysis used for ASCE 7-16 wind map return period analysis for use with tornado load provisions
- 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

Key Finding: Using 1,700- and 3,000-year MRI Tornado 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 structures.

No significant tornado risk at 700-year MRI

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

22

22

Ch. 32 – Tornado Loads

User Note – Tornado Speeds

- NOT designing for the most intense tornadoes
- EF0-EF2 tornadoes constituted about 97% of all reported tornadoes from 1995-2016
- Tornado speed varies as a function of
  - Risk Category
  - Geographic location
  - Effective plan (footprint) area

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.

ASCE | KNOWLEDGE & LEARNING

23

23

Ch. 32 – Tornado Loads

User Note – Tornado Shelter Limitation

- The design of tornado and other storm shelters are governed by the building code and the ICC 500 Storm Shelter Standard
- ICC 500-2020 references ASCE 7-16 wind provisions, with modifications, to determine tornado (and other) loads

Note the following time warp problem (not mentioned in the 7-22 Commentary)

- 2021 IBC references ASCE 7-16
- 2021 IBC references ICC 500-2020, which references ASCE 7-16
- 2018 IBC references ASCE 7-16
- 2018 IBC references ICC 500-2014, which references ASCE 7-10

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.

ASCE | KNOWLEDGE & LEARNING

24

24

ASCE | KNOWLEDGE & LEARNING

ASCE 7 vs Tornado Shelter Requirements

Ch. 32 RC IV Tornado Speed

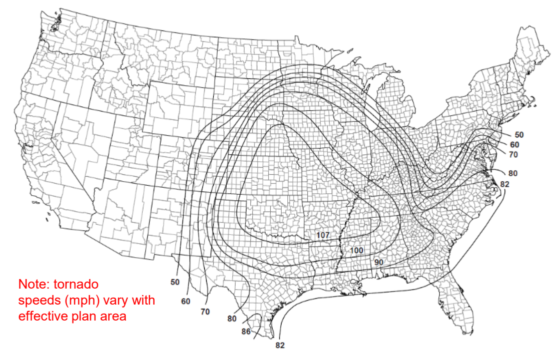


FIGURE 32.5-1E Tornado Speeds for Risk Category IV Buildings and Other Structures, for Effective Plan Area of 100,000 ft^2 (9,290 m^2)

Source: ASCE 7-22

ICC 500 Tornado Shelter Speed

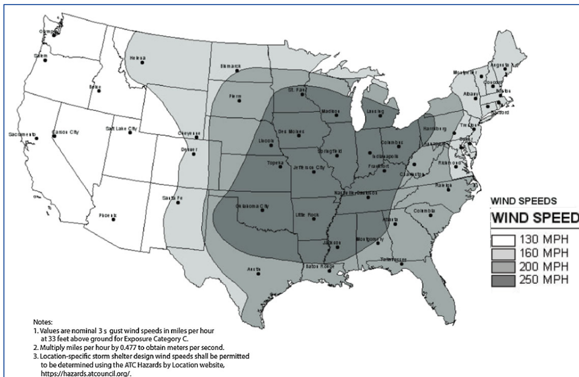


Figure C32.1-1. Tornado wind speeds for design of tornado shelters and tornado safe rooms (ICC 2020).

Source: ASCE 7-22 - Chapter 32 Commentary

25

25

ASCE | KNOWLEDGE & LEARNING

ASCE 7 vs Tornado Shelter Requirements

Ch. 32 RC IV Tornado Speed

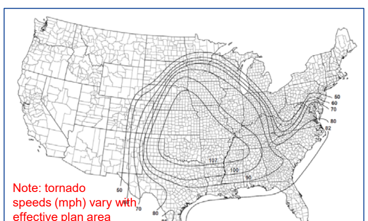


FIGURE 32.5-1E Tornado Speeds for Risk Category IV Buildings and Other Structures, for Effective Plan Area of 100,000 ft^2 (9,290 m^2)

Source: ASCE 7-22

Enhanced Fujita (EF) Scale	
RATING	3-s GUST (mph)
0	65-85
1	86-110
2	111-135
3	136-165
4	166-200
5	200+

ICC 500 Tornado Shelter Speed

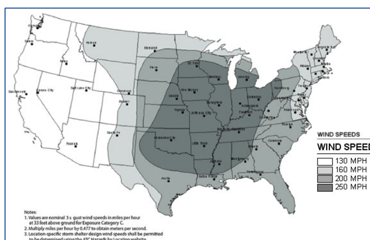


Figure C32.1-1. Tornado wind speeds for design of tornado shelters and tornado safe rooms (ICC 2020).

Source: ASCE 7-22 - Chapter 32 Commentary

ICC 500 has additional, more stringent requirements for shelters compared to ASCE 7 RC IV

ASCE 7-22 Chapter 32

- Design Hazard Levels: **Probabilistic**
  - Same return periods used for basic wind speed
- Tornado Intensity: **generally in EF0 – EF2 range**
- Wind-borne debris: **9-lb lumber 2x4 @ 34 mph**
  - Requirements for glazed openings in essential facilities

ICC 500-2020 Tornado Shelters

- Design Hazard Levels: **Deterministic**
  - Near-worst case scenario/most intense tornadoes
- Tornado Intensity: **EF2 – EF 5 range**
- Wind-borne debris: **15-lb lumber 2x4 @ 80-100 mph**
  - All shelter exterior walls must resist missile impacts

26

26

Chapter 32 Scope and Limitations

Questions / Discussion

marc.l.levitan@gmail.com

27

27

ASCE | KNOWLEDGE & LEARNING

Tornado Load Procedures

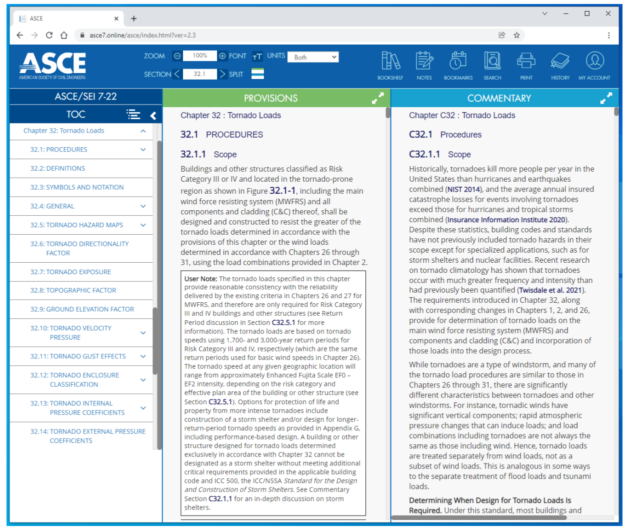
28

28

Ch. 32 Organization Part 1

- **Organization**
  - Ch. 32 Sections 1-13 parallel the same sections in Ch. 26 for ease of use, e.g.,
    - 26.11 Gust Effects
    - 32.11 Tornado Gust Effects
  - The remaining Ch. 32 sections on MWFRS loads, C&C loads, and Wind Tunnel Procedures appear in same order as the wind chapters

ASCE 7 Online



ASCE | KNOWLEDGE & LEARNING

29

29

Ch. 32 Organization Part 2

- Parallel organization for Chapters 26 and 32
- Same provisions for wind and tornado
- No parallel provisions between wind and tornado
  - 32.7 and 32.8 are placeholders for potential future tornado provisions
  - Include brief commentary on state-of-knowledge

Chapter 26 Wind Loads Section numbers and titles	Chapter 32 Tornado Loads Section numbers and titles
26.1 Procedures	32.1 Procedures
26.2 Definitions	32.2 Definitions
26.3 Symbols	32.3 Symbols and Notation
26.4 General	32.4 General
26.5 Wind Hazard Map	32.5 Tornado Hazard Maps
26.6 Wind Directionality Factor	32.6 Tornado Directionality Factor
26.7 Exposure	32.7 Tornado Exposure
26.8 Topographic Effects	32.8 Tornado Topographic Factor
26.9 Ground Elevation Factor	32.9 Ground Elevation Factor
26.10 Velocity Pressure	32.10 Tornado Velocity Pressure
26.11 Gust Effects	32.11 Tornado Gust Effects
26.12 Enclosure Classification	32.12 Tornado Enclosure Classification
26.13 Internal Pressure Coefficients	32.13 Tornado Internal Pressure Coefficients
N/A	32.14 Tornado External Pressure Coefficients

ASCE | KNOWLEDGE & LEARNING

30

30

ASCE | KNOWLEDGE & LEARNING

Ch. 32 Organization Part 3

Wind Load Chapters Section numbers and titles	**Chapter 32 Tornado Loads** Section numbers and titles
Ch. 27 Wind Loads on Buildings: MWFRS (Directional Procedure)	32.15 Tornado Loads on Buildings: MWFRS
Ch. 28 Wind Loads on Buildings: MWFRS (Envelope Procedure)	N/A
Ch. 29 Wind Loads on Building Appurtenances & Other Structures: MWFRS (Directional Procedure)	32.16 Tornado Loads on Building Appurtenances & Other Structures: MWFRS
Ch. 30 Wind Loads: C&C	32.17 Tornado Loads: C&C
Ch. 31 Wind Tunnel Procedure	32.18 Tornado Loads: Wind Tunnel Procedure
26.14 Consensus Standards and Other Referenced Documents	32.19 Consensus Standards and Other Referenced Documents
Appendix F: Wind Hazard Maps for Long Return Periods (new in ASCE 7-22)	Appendix G : Tornado Hazard Maps for Long Return Periods

ASCE | KNOWLEDGE & LEARNING

31

31

ASCE | KNOWLEDGE & LEARNING

Symbols Part 1

- **Notes on Symbols**
  - Use wind load chapter symbols for symbols not defined in Ch. 32
  - Tornado-specific versions of wind load parameters are identified through addition of "Tornado" to parameter name and addition of subscript capital *"T"*, to the symbol, e.g.,
    - Gust Effect Factor becomes Tornado Gust Effect Factor
    - *G* becomes G_T
  - Exception: Velocity Pressure Exposure Coefficient
    - K_z becomes K_{zTor} instead of K_{zT}, to avoid confusion with K_{zt}, the topographic factor for wind loads

32.3 SYMBOLS AND NOTATION

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

A_e = Effective plan area of the building, other structure, or facility, ft^2 (m^2), as defined in Section 32.5.4

F_{hT} = Lateral design tornado force for rooftop structures and equipment from Equation (32.16-3), lb (N)

F_T = Design tornado force for certain other structures from Equation (32.16-2), lb (N)

F_{vT} = Vertical design tornado force for rooftop structures and equipment from Equation (32.16-4), lb (N)

G_T = Tornado gust-effect factor as defined in Section 32.11

GC_{piT} = Product of internal pressure coefficient that includes the effects of atmospheric pressure change and gust-effect factor, to be used in determination of tornado loads for buildings and some other structures, as determined in Section 32.13

K_{dT} = Tornado directionality factor as defined in Section 32.6

K_{hTor} = Tornado velocity pressure exposure coefficient evaluated at height $z = h$, as determined in Section 32.10

K_{vT} = Tornado pressure coefficient adjustment factor for vertical winds as defined in Section 32.14

32

32

Symbols Part 2

K_{zTor} = Tornado velocity pressure exposure coefficient evaluated at height z, as determined in Section 32.10
p_{pT} = Combined net tornado design pressure on a parapet from Equation (32.15-3), lb/ft^2 (N/m^2)
p_T = Design tornado pressure to be used in determination of tornado loads for buildings and for certain other structures, lb/ft^2 (N/m^2)
q_{hT} = Tornado velocity pressure evaluated at height $z = h$, lb/ft^2 (N/m^2)
q_{pT} = Tornado velocity pressure evaluated at top of parapet from Equations (32.15-3) and (32.17-4), lb/ft^2 (N/m^2)
q_{zop} = Tornado velocity pressure internal pressure determination for partially enclosed buildings, lb/ft^2 (N/m^2)
q_{zT} = Tornado velocity pressure evaluated at height z above ground, lb/ft^2 (N/m^2)
V_T = Tornado speed obtained from Figures 32.5-1 and 32.5-2, mi/h (m/s). The tornado speed corresponds to a 3 s gust speed at 33 ft (10 m) above the ground.
z_{op} = Level of the lowest opening in the building that could affect the positive internal pressure, lb/ft^2 (N/m^2)

C32.3 SYMBOLS AND NOTATION

The following notations apply to the Commentary for Chapter 32:

ABL = Atmospheric boundary layer
APC = Atmospheric pressure change
DI = Damage indicator
DOD = Degree of damage
EF Scale = Enhanced Fujita Scale
FEMA = Federal Emergency Management Agency
FR12 = One-and-two-family residence DI in the EF Scale
ICC = International Code Council
MRI = Mean recurrence interval
NWS = National Weather Service
PV = Photovoltaic

33

33

Definitions

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.

34

34

ASCE | KNOWLEDGE & LEARNING

Sign Convention

32.4 GENERAL

32.4.1 Sign Convention. The combined effects of internal pressures and atmospheric pressure change, expressed in coefficient form by GC_{piT}, shall follow the same sign convention as provided in Section 26.4, where positive pressure acts toward the surface and negative pressure acts away from the surface.

32.4.2 Critical Load Condition. Values of external pressures shall be combined algebraically with the combined effects of internal pressures and atmospheric pressure change to determine the most critical load.

- Tornado loads use the same sign convention as wind loads, including for internal pressures induced by APC

ASCE | KNOWLEDGE & LEARNING

35

35

ASCE | KNOWLEDGE & LEARNING

Wind vs Tornado Load Procedures Part 1

Ch. 26 Wind Load Procedures

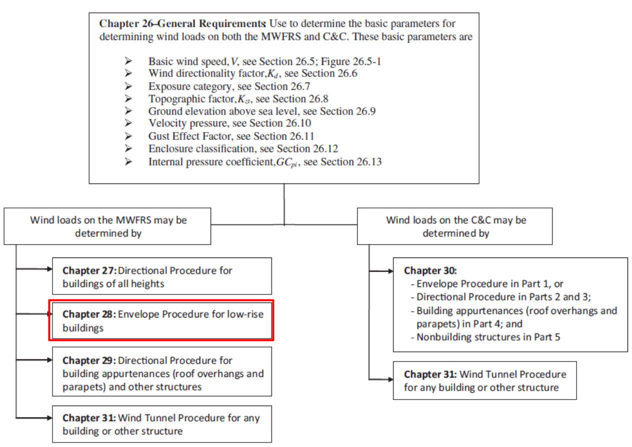


Figure 26.1-1. Outline of process for determining wind loads.

Ch. 32 Tornado Load Procedures

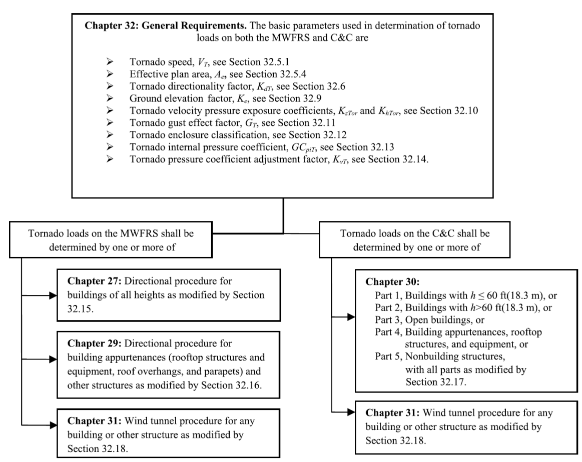


Figure 32.1-3. Outline of process for determining tornado loads.

36

Wind vs Tornado Load Procedures Part 2

Ch. 26 Wind Load Procedures

Chapter 26–General Requirements Use to determine the basic parameters for determining wind loads on both the MWFRS and C&C. These basic parameters are

- Basic wind speed, V, see Section 26.5; Figure 26.5-1
- Wind directionality factor, K_d, see Section 26.6
- Exposure category, see Section 26.7
- Topographic factor, K_{zt}, see Section 26.8
- Ground elevation above sea level, see Section 26.9
- Velocity pressure, see Section 26.10
- Gust Effect Factor, see Section 26.11
- Enclosure classification, see Section 26.12
- Internal pressure coefficient, GC_{pi}, see Section 26.13

Figure 26.1-1. Outline of process for determining wind loads.

Ch. 32 Tornado Load Procedures

Chapter 32: General Requirements. The basic parameters used in determination of tornado loads on both the MWFRS and C&C are

- Tornado speed, V_T, see Section 32.5.1
- Effective plan area, A_e, see Section 32.5.4
- Tornado directionality factor, K_{dT}, see Section 32.6
- Ground elevation factor, K_e, see Section 32.9
- Tornado velocity pressure exposure coefficients, K_{zTor} and K_{hTor}, see Section 32.10
- Tornado gust effect factor, G_T, see Section 32.11
- Tornado enclosure classification, see Section 32.12
- Tornado internal pressure coefficient, GC_{piT}, see Section 32.13
- Tornado pressure coefficient adjustment factor, K_{vT}, see Section 32.14.

Figure 32.1-3. Outline of process for determining tornado loads.

37

37

Tornado Load Procedures

- Based on wind load procedures framework
- Most wind load parameters and equations have been modified to reflect differences between tornadic and non-tornadic wind and wind-structure interaction characteristics
- A few wind parameters have been dropped and new tornado parameters added
- Tornado chapter heavily references wind chapters 26-31, except 28
- Chapter 28 (Envelope Procedure for MWFRS Loads) not applicable to tornadoes
- Explicit provisions permitting the use performance-based tornado design

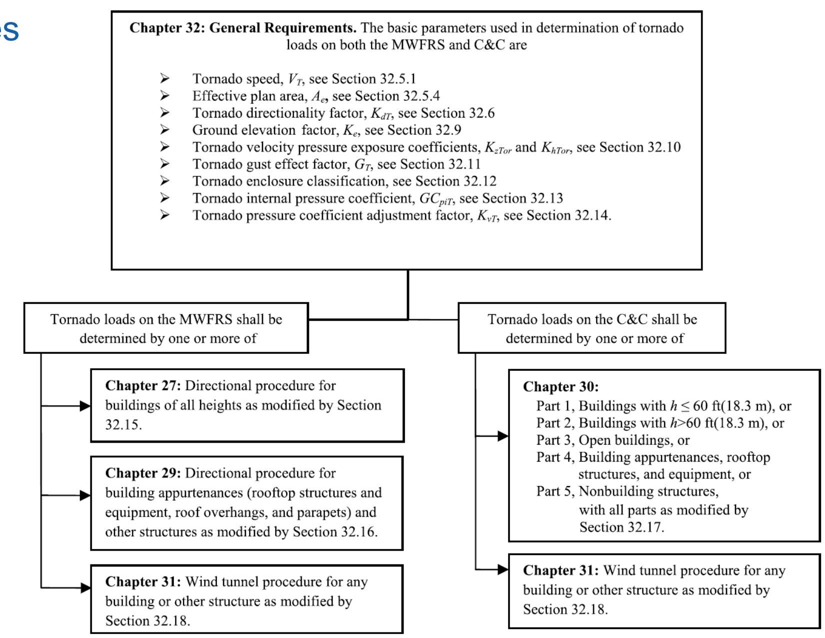


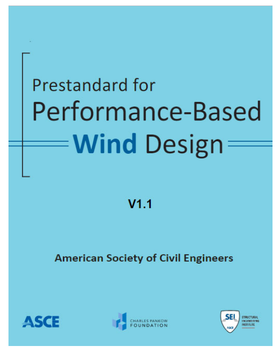
Figure 32.1-3. Outline of process for determining tornado loads.

38

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/10.1061/9780784484739

ASCE | KNOWLEDGE & LEARNING

39

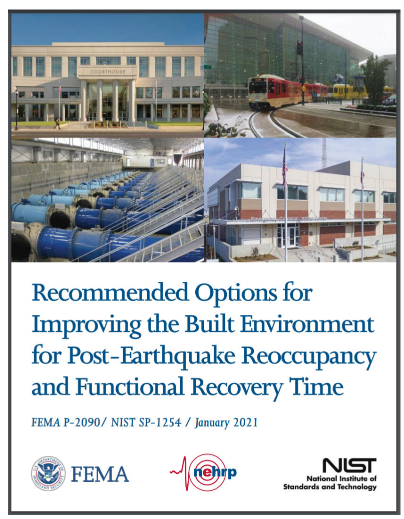
39

Future Directions for Performance-Based Design

ASCE | KNOWLEDGE & LEARNING

Recent publications on:

- Immediate occupancy performance objective
- Improving functional recovery time post-earthquake



https://doi.org/10.6028/NIST.SP.1224

https://doi.org/10.6028/NIST.SP.1254

ASCE | KNOWLEDGE & LEARNING

40

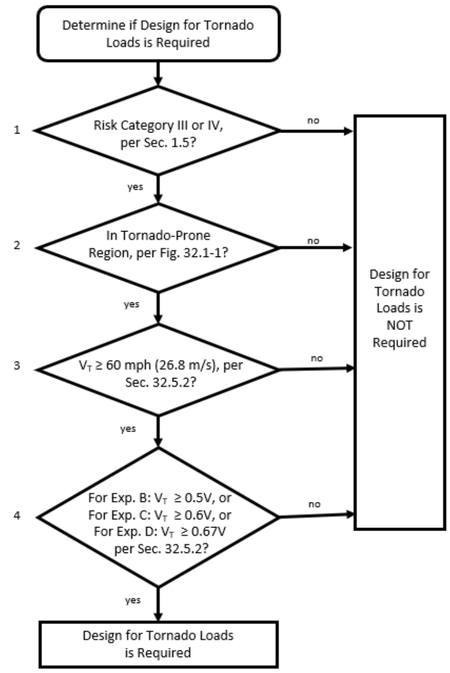
40

Design for Tornado Loads Not Required

A flowchart is provided in a user note in Section 32.1 identifying the process to determine where design for tornado loads is 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

Steps 3 and 4 will be covered in more detail later in Unit 2



ASCE | KNOWLEDGE & LEARNING

41

41

Tornado Load Procedures

Questions / Discussion

marc.l.levitan@gmail.com

42

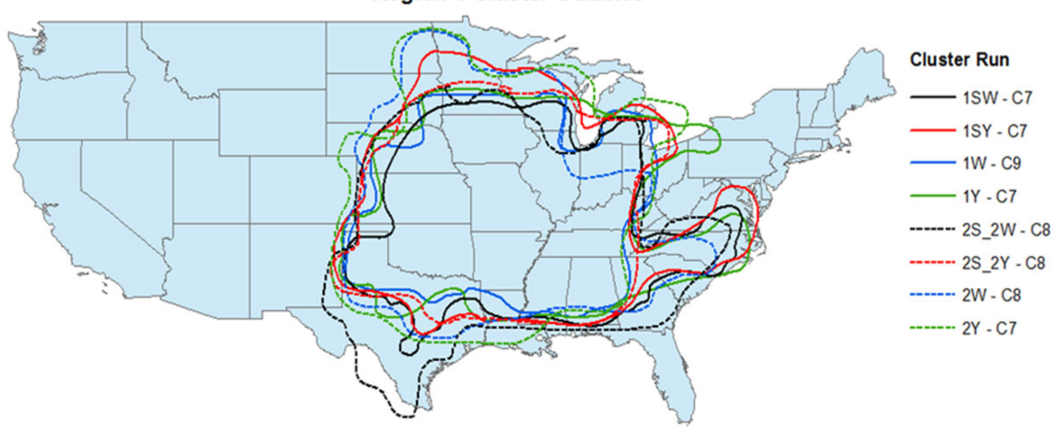
42

Lunch Break

43

43

Region 4 Cluster Outlines



ASCE | KNOWLEDGE & LEARNING

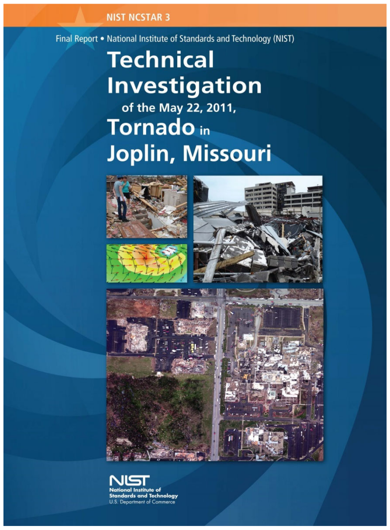
Tornado Hazard Maps

44

44

ASCE | KNOWLEDGE & LEARNING

Genesis of Tornado Maps/Loads for ASCE 7-22



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

NIST conducted 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.

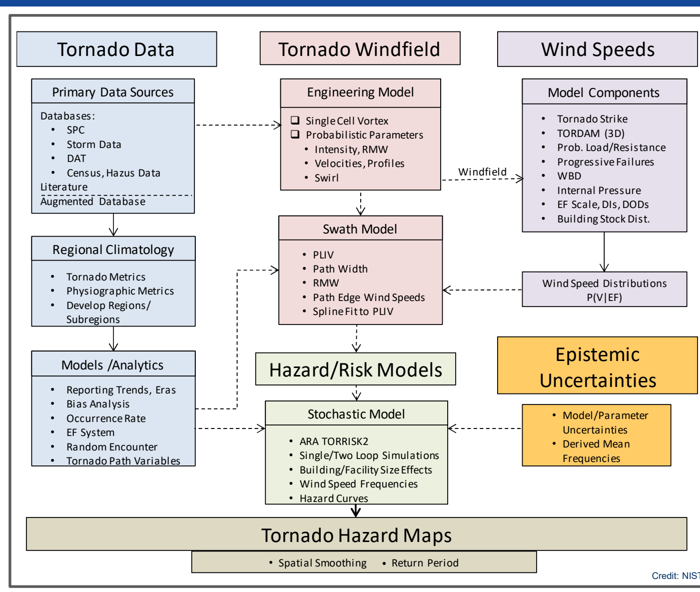
45

45

ASCE | KNOWLEDGE & LEARNING

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 (i.e., modeling) uncertainties



ASCE | KNOWLEDGE & LEARNING

46

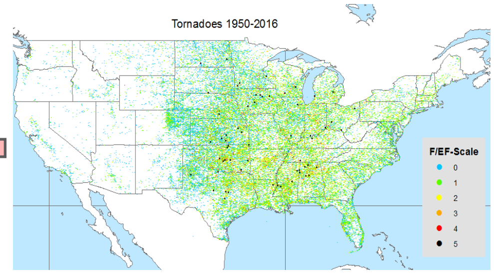
46

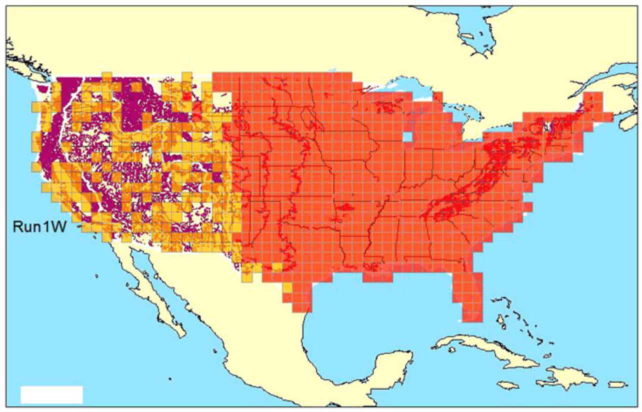
Tornado Risk Regionalization

- Identify broad regions of similar tornado climatology
- Ten climatology metrics evaluated
- Grid based approach
- Multivariate statistical analysis method used to discern areas of similar "climatology"
- Uniform climatology assumed within regions

Variables

Latitude, Longitude	Tornado Days/Yr
Elevation	Path Length
Std Dev Elevation	Occurrence Rates
Land Fraction	Point Strike Probability





Animation of Sequential Cluster Formation – 1° Grid

Credit: NIST

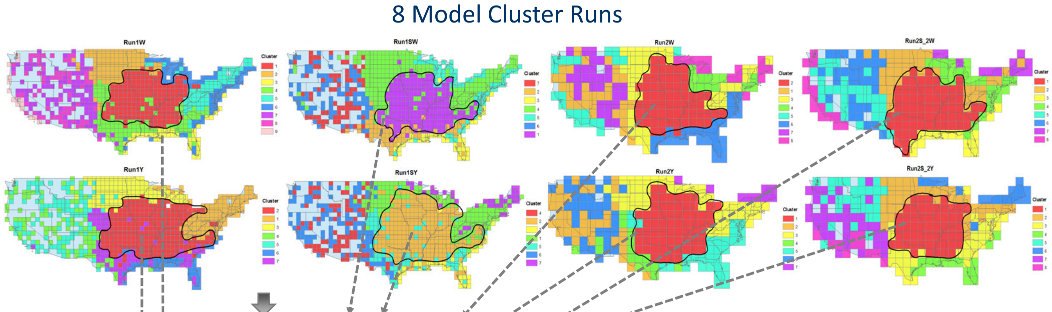
ASCE | KNOWLEDGE & LEARNING

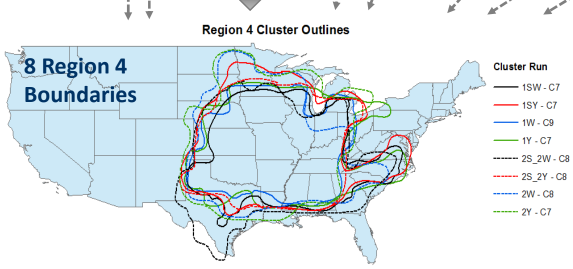
47

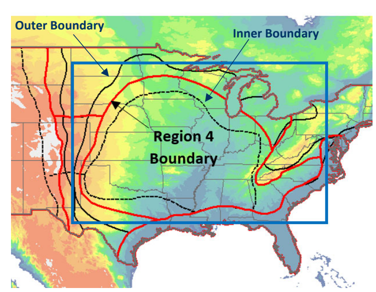
47

Region Boundaries and Uncertainties

8 Model Cluster Runs







Credit: NIST

ASCE | KNOWLEDGE & LEARNING

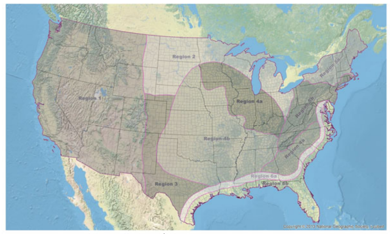
48

48

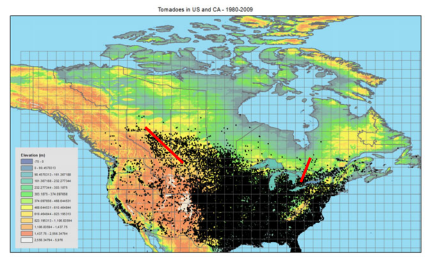
Final Region/ Subregion Boundaries

- Final regional boundaries determined using regions from cluster analysis with modifications, including
  - Smoothing of certain boundaries to improve map contouring near multi-region intersections
  - Adjusted Region 1-2 boundary in Montana-Wyoming to follow tornado trends in combined US-Canadian tornado maps and land elevation

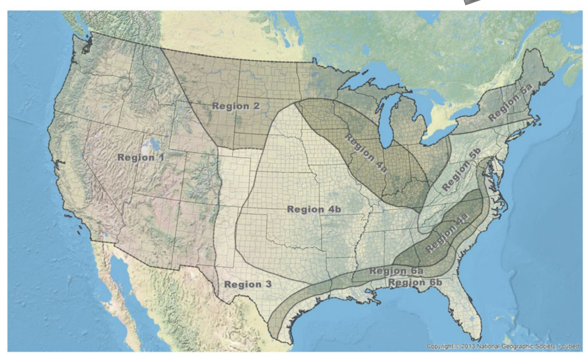
Hazard Regions from Cluster Analysis and Sub-region analysis



Additional Data on Tornadoes in Canada



Data Sources: NOAA and Environment Canada



Final Climatology Regions for Tornado Maps

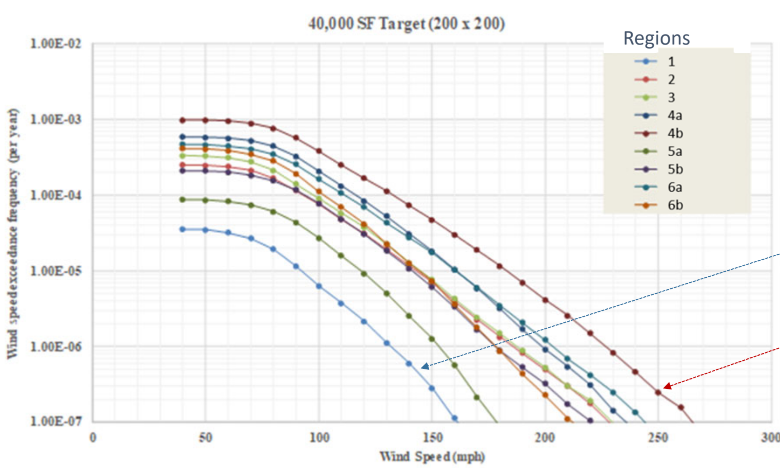
Credit: NIST

ASCE | KNOWLEDGE & LEARNING

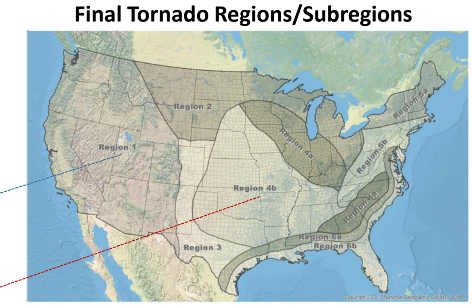
49

Windspeed Exceedance Frequencies (WEFs)

WEFs developed for each region and subregion, for a range of target sizes



Final Tornado Regions/Subregions



Credit: NIST

Note: Return Period (also referred to as mean recurrence interval or MRI) is the inverse of the annual exceedance frequency

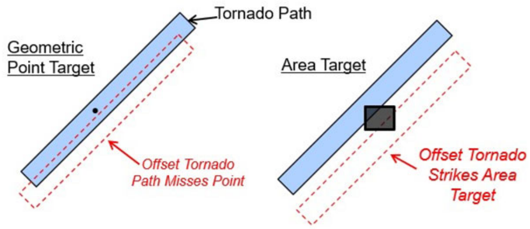
ASCE | KNOWLEDGE & LEARNING

50

Target Size Effects Part 1

- Tornado speeds are dependent on plan size and shape of the building/other structure
  - Tornado strike probabilities increase with increasing plan area of the target building or facility
  - For a fixed return period, tornado speed increases with increasing plan area

In Chapter 32, we use 'Effective Plan Area' as a measure of target size



Credit: NIST

"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

ASCE | KNOWLEDGE & LEARNING

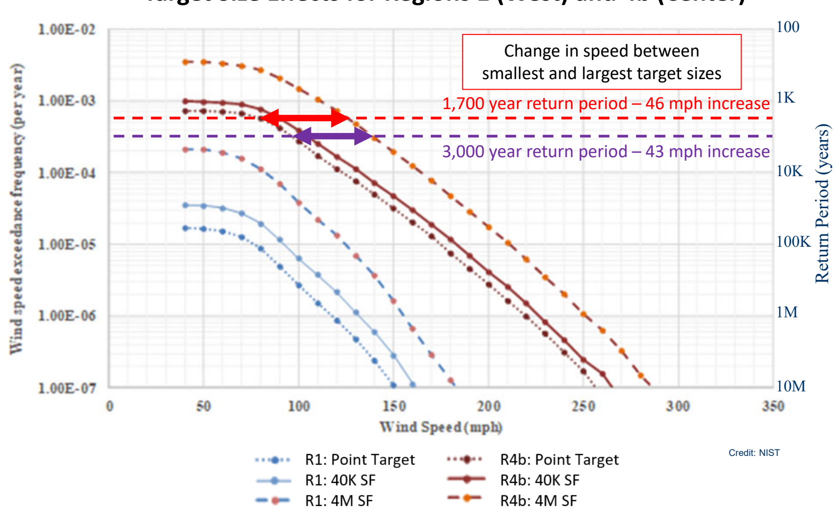
51

51

Target Size Effects Part 2

- The effects of target size depend on the Region and the tornado wind speed
- The effect of target size is reduced for high return periods
- The effects of target size are greater in regions with lower wind hazard, such as Region 1, since the tornadoes are smaller and the impact of increasing target size has a more dominant effect on the resulting risk.

Target Size Effects for Regions 1 (West) and 4b (Center)



Credit: NIST

ASCE | KNOWLEDGE & LEARNING

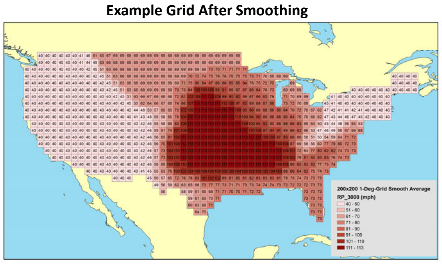
52

52

Map Development Process

- A six step process is used to develop maps.
- The grid wind speeds for a given Return Period and Target Size were smoothed using Gaussian smoothing.
- The Kriging was performed in ArcGIS with default parameters, similar to the current ASCE 7 non-tornadic maps.

Example Grid After Smoothing



1. Hazard Curve WEFs (Given Target Size)
2. Interpolate Windspeeds to Return Periods
3. Input Windspeeds to Region/Subregion Grid Cells
4. Gaussian Smoothing
5. ArcGIS Kriging
6. PAEK Smoothing & Hand Adjustments for Final Maps

Regional Boundary Uncertainties

Region Boundary	Mean Distance (mi)	Approx. Number of 1 Deg. Cell Widths
Region 1- Region 2	166	2.8
Region 1 – Region 3	125	2.1
Region 2 – Region 3	416	6.9
Region 4 – Region 2	217	3.6
Region 4 – Region 3	130	2.2
Region 4 – Region 5 (West of Appalachians)	85	1.4
Region 4 – Region 5 (South and East of Appalachians)	177	3.0
Overall Mean	**188**	**3.1**

Gaussian Smoothing Weights

0.0099	0.0239	0.0320	0.0239	0.0099
0.0239	0.0575	0.0770	0.0575	0.0239
0.0320	0.0770	0.1031	0.0770	0.0320
0.0239	0.0575	0.0770	0.0575	0.0239
0.0099	0.0239	0.0320	0.0239	0.0099

Credit: NIST

ASCE | KNOWLEDGE & LEARNING

53

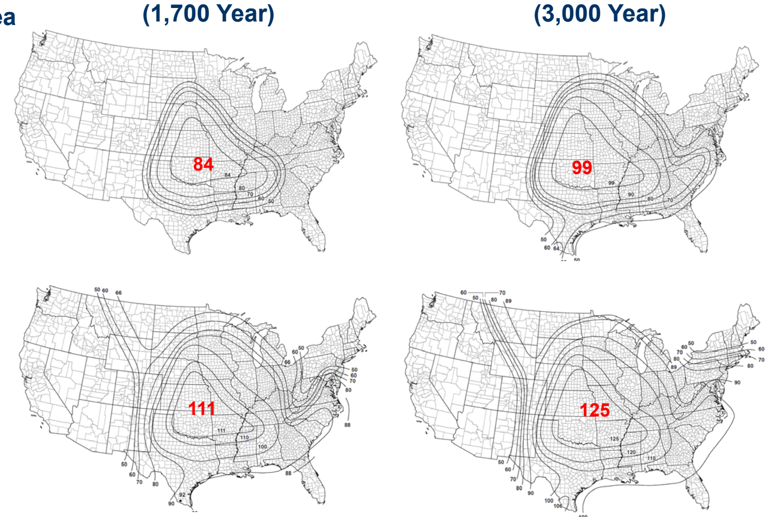
53

Example Tornado Hazard Maps

ASCE | KNOWLEDGE & LEARNING

Effective Plan Area A_e (ft^2) — **10K**, **1M**

Risk Category III (1,700 Year) — **Risk Category IV (3,000 Year)**



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

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

Mapped tornado speeds for longer return periods at each of the 8 sizes are provided in Appendix G
- 10,000 years
- 100,000 years
- 1,000,000 years
- 10,000,000 years

ASCE 7-22 also includes a new Appendix F with longer return period *wind speed* maps

54

54

Tornado Hazard Maps

Questions / Discussion

marc.l.levitan@gmail.com

55

55

ASCE | KNOWLEDGE & LEARNING

Effective Plan Area

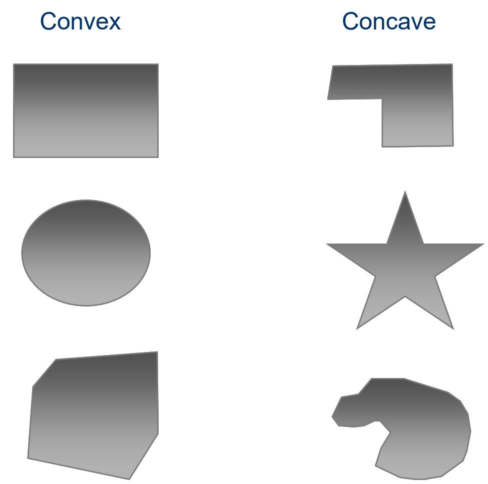
56

56

ASCE | KNOWLEDGE & LEARNING

Effective Plan Area, A_e

- As discussed in the previous lecture, the 'Target size' of the building or other structure has a significant effect on the tornado speed at a given return period
- In ASCE 7-22, the Effective Plan Area, A_e, is used as the measure for target size
- Effective Plan Area
  - = plan area for convex plan shapes
  - = area of the smallest convex polygon enclosing the plan shape for non-convex (concave) plan shapes



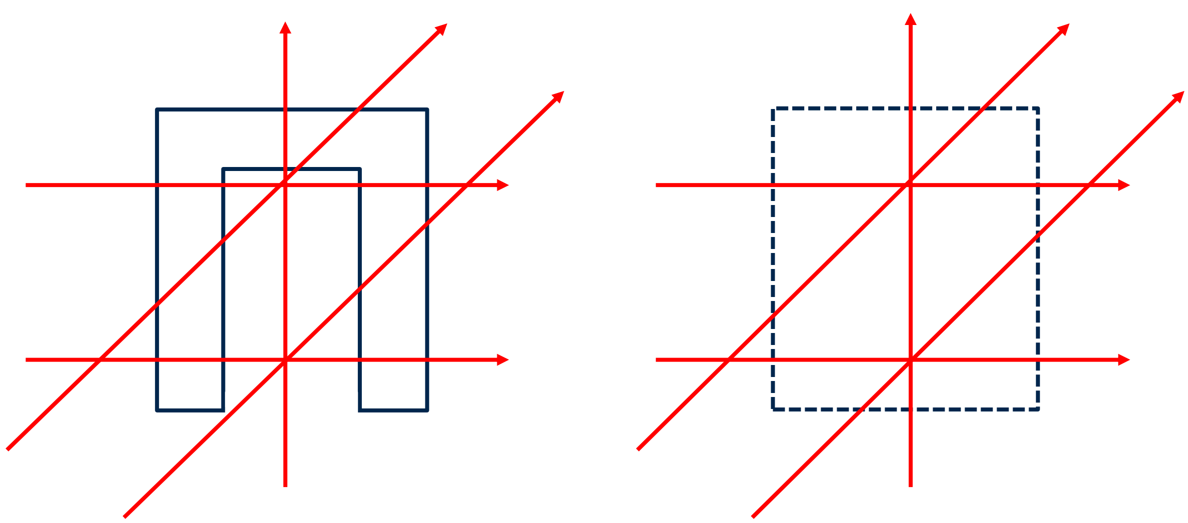
ASCE | KNOWLEDGE & LEARNING

57

57

ASCE | KNOWLEDGE & LEARNING

Why Use Smallest Convex Polygon?



58

58

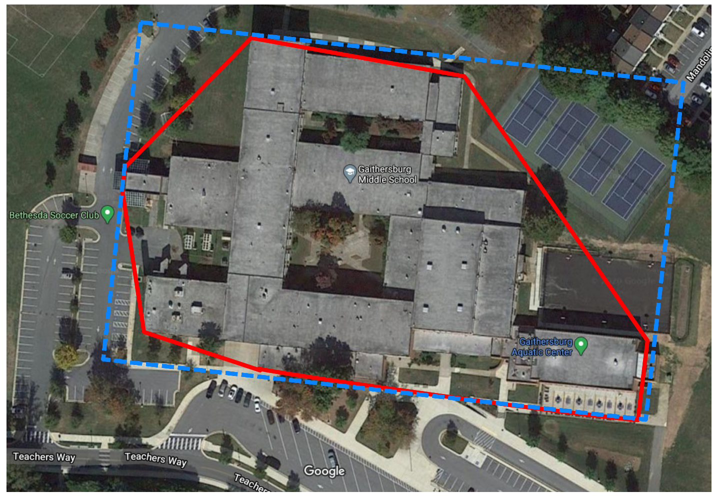
Effective Plan Area Example

Standard

- The effective plan area A_e shall be equal to the area of the smallest convex polygon enclosing the plan of the building, other structure, or facility.

Commentary

- Alternatively, A_e can simply and conservatively be calculated as the area of the smallest rectangle that encloses the maximum plan area



59

59

A_e for Essential Facilities

32.5.4.1 Essential Facilities. For Essential Facilities and buildings and other structures required to maintain the functionality of Essential Facilities, the effective plan area shall be equal to the area of the smallest convex polygon enclosing both the Essential Facility and all of the buildings and other structures that maintain the functionality of the Essential Facility.

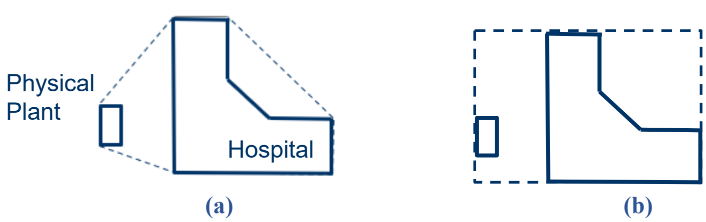


FIGURE C32.5-2. Effective plan area for a hospital and its central utility plant determined using (a) the smallest convex polygon enclosing the facility, and (b) rectangle enclosing the facility.

60

60

ASCE | KNOWLEDGE & LEARNING

A_e for other Facilities

32.5.4.2 Other than Essential Facilities. For buildings and structures that are not designated as Essential Facilities and are not required to maintain the functionality of Essential Facilities … It is permitted to reduce the effective plan area to that of the effective plan area of the largest structurally independent building or other structure, which has no shared structural components with adjacent buildings or other structures.

Independent Structural Systems

- Building 3 is the largest structurally independent
- Buildings 1-6 can be designed for tornado speed associated with A_e for Building 3

61

61

ASCE | KNOWLEDGE & LEARNING

A_e for Ground-Mounted Solar

32.5.4.3 Ground-Mounted Photovoltaic Panel Systems. The effective plan area, A_e, of ground-mounted photovoltaic panel systems shall be equal to the effective plan area of the largest structurally independent photovoltaic support structure that has no shared structural components with other adjacent structures.

Credit: NASA

Credit: NASA

ASCE | KNOWLEDGE & LEARNING

62

62

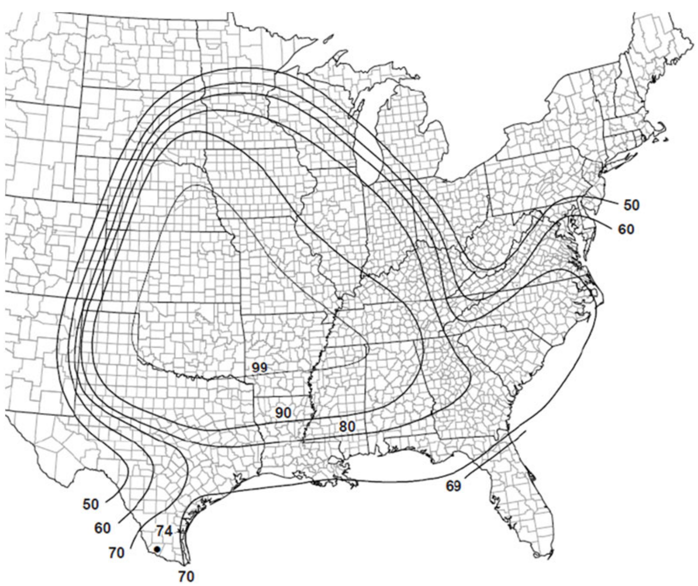
Effective Plan Area

Questions / Discussion

marc.l.levitan@gmail.com

63

63



ASCE | KNOWLEDGE & LEARNING

Tornado Speed and Determination of When Tornado Loads are Not Required

64

64

ASCE | KNOWLEDGE & LEARNING

Tornado Speed, V_T

32.5.1 Tornado Speed. The tornado speed, V_T, used in the determination of tornado loads on buildings and other structures shall be determined from Figures 32.5-1 and 32.5-2 as follows:

1. For Risk Category III buildings and structures, use Figures 32.5-1A through 32.5-1H. ← 1,700 year return period
2. For Risk Category IV buildings and structures, use Figures 32.5-2A through 32.5-2H. ← 3,000 year return period

To select the appropriate tornado hazard map to use for the assigned risk category, the effective plan area, A_e, of the building, other structure, or facility, shall be determined in accordance with Section 32.5.4 and shall be rounded up to next available mapped A_e, including 1, 2,000, 10,000, 40,000, 100,000, 250,000, 1,000,000, and 4,000,000 ft^2 (0.1, 186, 929, 3,716, 9,290, 23,226, 92,903, and 371,612 m^2). Alternatively, linear interpolation of tornado speed between maps using the logarithm of the effective plan area size is permitted.

← Select smallest map size that is greater than or equal to A_e

← Interpolation for A_e is permitted

Alternatively, it shall be permitted to use the tornado speeds from the ASCE Tornado Design Geodatabase. The ASCE Tornado Design Geodatabase is available at the ASCE 7 Hazard Tool (https://asce7hazardtool.online/), or approved equivalent.

← Allows use of ASCE 7 hazards Tool instead of static maps in standard

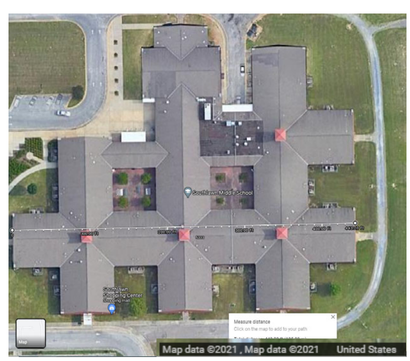
65

65

ASCE | KNOWLEDGE & LEARNING

Example – Determination of V_T

- Middle School
- Little Rock, Arkansas
- Risk Category III



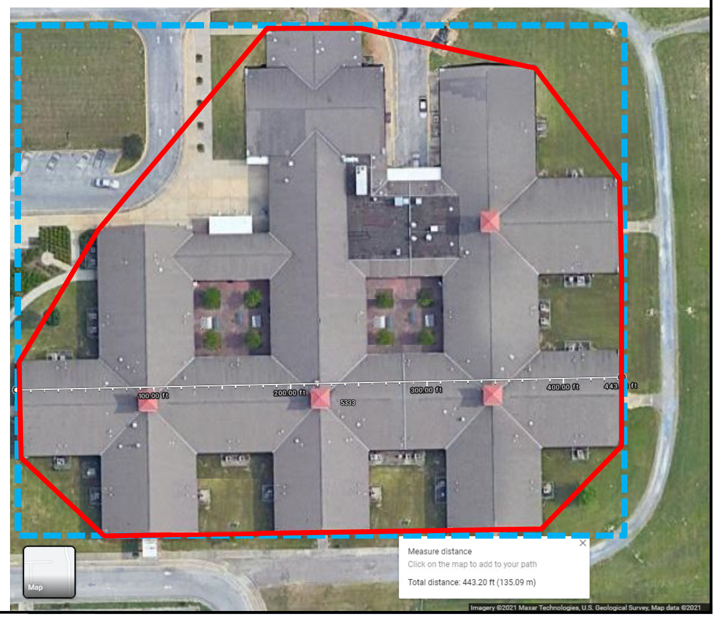
66

66

Example – Effective Plan Area, A_e

Effective Plan Area

- Area smallest convex polygon enclosing the plan of the building
  - A_e = 132,000 SF
- Alternative (simplified) solution
  - A_e = 443' x 368' = 163,000 SF
- Recall, since this is not an Essential Facility, it is permitted to use the A_e value for largest structurally independent building (if school is comprised of more than one)
  - Reduction in A_e not used in this example



Convex polygon
Smallest rectangle

ASCE | KNOWLEDGE & LEARNING

67

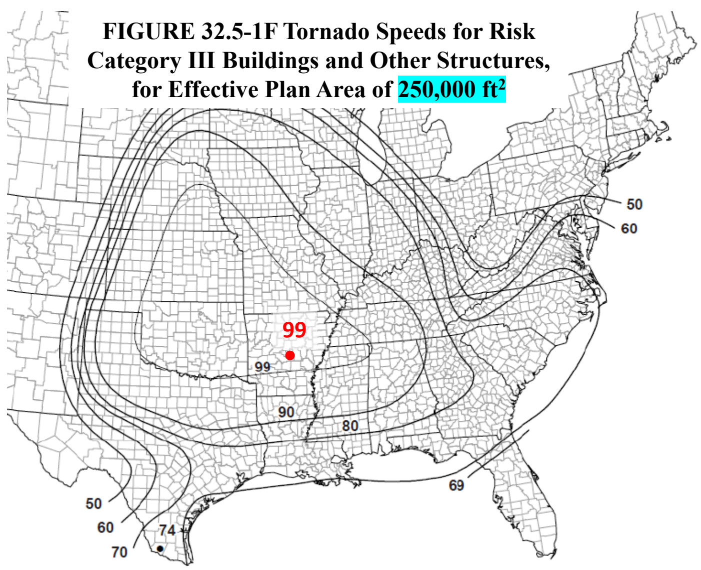
Example – Determination of V_T

ASCE | KNOWLEDGE & LEARNING

Tornado Speed, V_T

- A_e = 132,000 SF
- Select speed using next largest mapped A_e
  - Use A_e = 250,000 SF map
- V_T = 99 mph

Mapped A_e Sizes, ft^2
1
2K
10K
40K
100K
250K
1M
4M



68

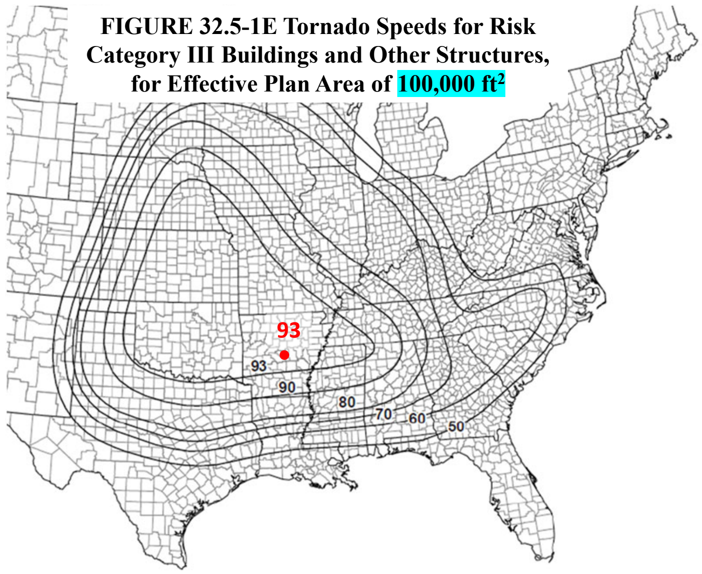
ASCE | KNOWLEDGE & LEARNING

Example – Interpolation for V_T

Interpolation for A_e is permitted

- Select speed using next smallest mapped A_e
  - Use A_e = 100,000 SF map
  - $V_{T,100}$ = 93 mph
- Interpolate between speeds determined from 100K SF and 250K SF

Mapped A_e Sizes, ft^2
1
2K
10K
40K
100K
250K
1M
4M



69

ASCE | KNOWLEDGE & LEARNING

Example – Interpolation for V_T

Interpolate linearly using (log A_e) instead of A_e

$$V_{T,132} = V_{T,100} + (\log(132)-\log(100)) \frac{(V_{T,250} - V_{T,100})}{(\log(250)-\log(100))}$$

$$V_{T,132} = 93 + (\log(132)-\log(100)) \frac{(99-93)}{(\log(250)-\log(100))}$$

$V_{T,132}$ = 95 mph Interpolated Tornado Speed

$V_{T,250}$ = 99 mph Single map solution Tornado Speed

A_e (thousands of SF)	Map Figure	V_T (mph)
100	32.5-1E	93
132	-	?
250	32.5-1F	99

Section 32.5.1 states:

"linear interpolation of tornado speed between maps using the logarithm of the effective plan area size is permitted."

70

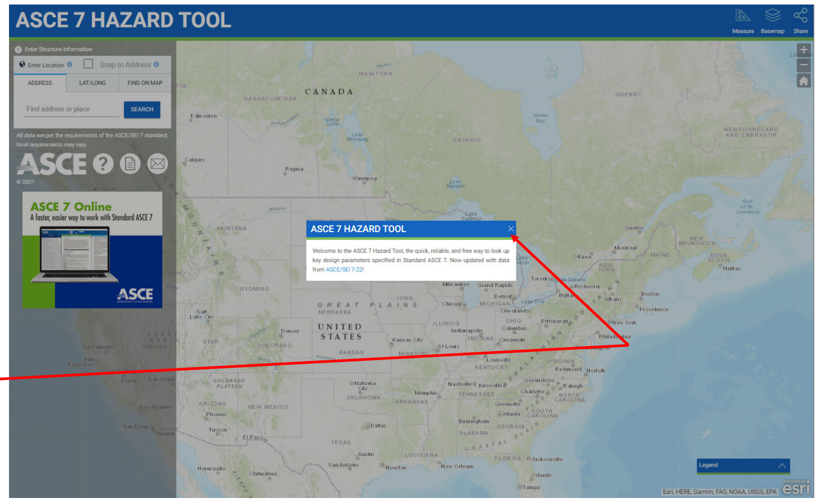
70

ASCE | KNOWLEDGE & LEARNING

ASCE 7 Hazard Tool

https://asce7hazardtool.online/

- Mapped values for all hazards in ASCE 7-22
- App opens with a welcome message and any service alerts
- Close the “Welcome” box to get started



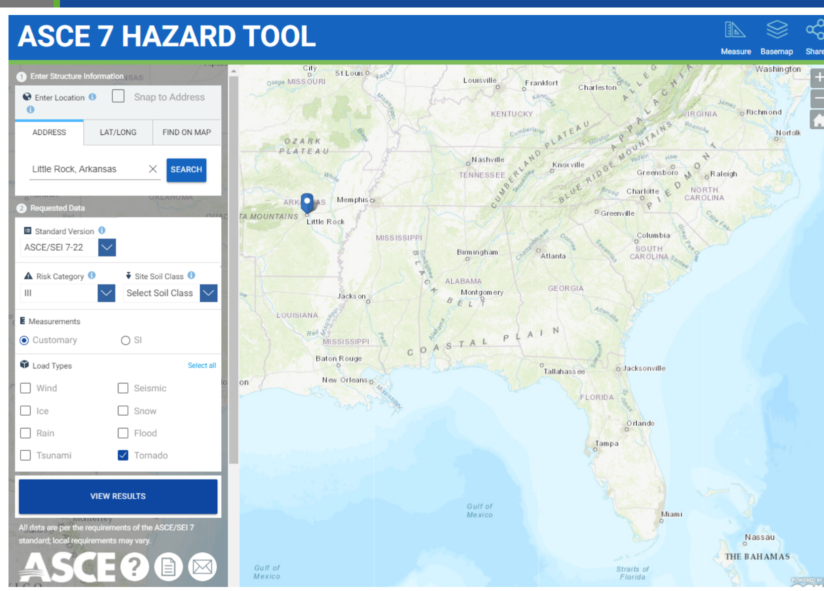
71

71

ASCE | KNOWLEDGE & LEARNING

Obtaining V_T from ASCE 7 Hazard Tool

1. Enter Location
2. Select Risk Category
3. Select Soil Class (seismic only)
4. Select Units
5. Select Load Types
6. Click “View Results”



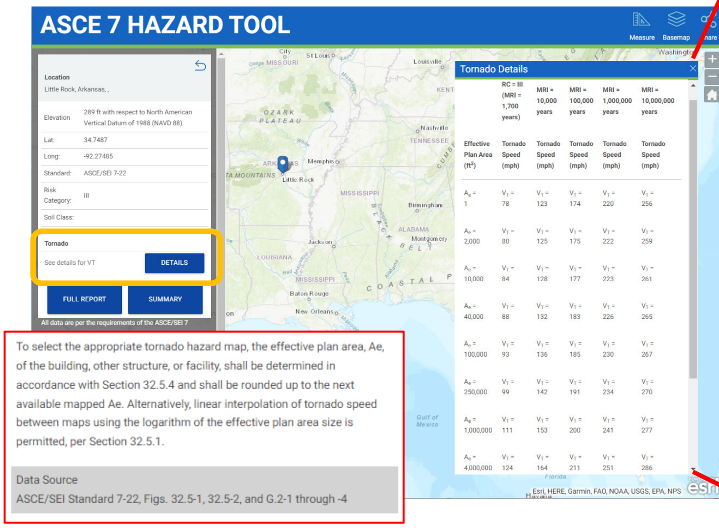
72

72

ASCE | KNOWLEDGE & LEARNING

Obtaining V_T

Example for Risk Category III in Little Rock



Tornado Details

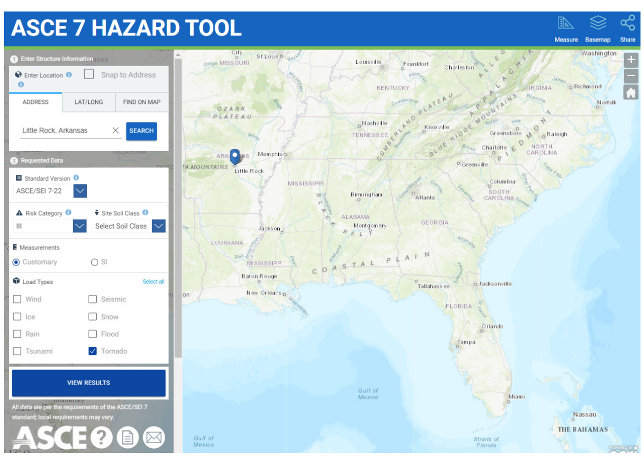
Effective Plan Area (ft²)	RC = III (MRI = 1,700 years) Tornado Speed (mph)	MRI = 10,000 years Tornado Speed (mph)	MRI = 100,000 years Tornado Speed (mph)	MRI = 1,000,000 years Tornado Speed (mph)	MRI = 10,000,000 years Tornado Speed (mph)
A_e = 1	V_T = 78	V_T = 123	V_T = 174	V_T = 220	V_T = 256
A_e = 2,000	V_T = 80	V_T = 125	V_T = 175	V_T = 222	V_T = 259
A_e = 10,000	V_T = 84	V_T = 128	V_T = 177	V_T = 223	V_T = 261
A_e = 40,000	V_T = 88	V_T = 132	V_T = 183	V_T = 226	V_T = 265
A_e = 100,000	V_T = 93	V_T = 136	V_T = 185	V_T = 230	V_T = 267
A_e = 250,000	V_T = 99	V_T = 142	V_T = 191	V_T = 234	V_T = 270
A_e = 1,000,000	V_T = 111	V_T = 153	V_T = 200	V_T = 241	V_T = 277
A_e = 4,000,000	V_T = 124	V_T = 164	V_T = 211	V_T = 251	V_T = 286

73

73

ASCE | KNOWLEDGE & LEARNING

ASCE 7 Hazard Tool Demo



https://asce7hazardtool.online/

74

74

ASCE | KNOWLEDGE & LEARNING

Determination When Tornado Loads are not Required

32.5.2 Where Design for Tornado Loads is Not Required. For Risk Category III and IV buildings and other structures determined to have tornado speeds $V_T < 60$ mi/h (26.8 m/s), design for tornado loads shall not be required. Where $V_T \geq 60$ mi/h (26.8 m/s) but is less than the following threshold speeds then design for tornado loads shall not be required:

1. For Exposure B: $V_T < 0.5V$, or
2. For Exposure C: $V_T < 0.6V$, or
3. For Exposure D: $V_T < 0.67V$,

where V is the basic wind speed determined in accordance with Section 26.5 and the exposure category is determined in accordance with Section 26.7.3, based on the exposure resulting in the greatest wind loads for any wind direction at the site.

Design for Tornado Loads not Required when

← $V_T < 60$ mph

← $V_T < aV$, where a is some fraction of the basic design wind speed V, dependent on wind exposure

← Must use the most open exposure form any direction at the site

75

75

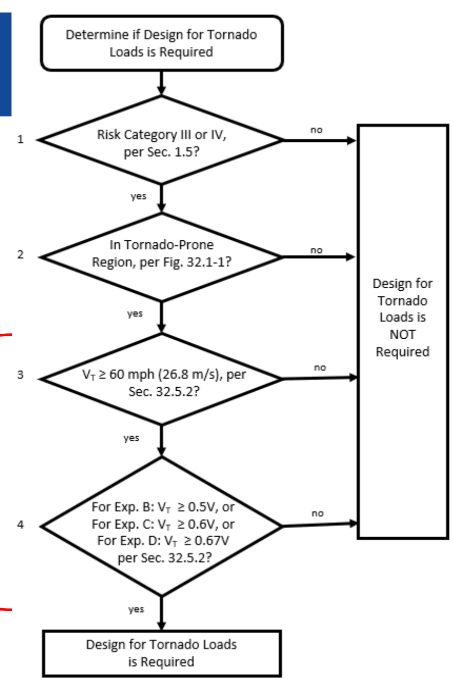
ASCE | KNOWLEDGE & LEARNING

Flowchart

Error in ASCE 7-22 section 32.5.2 and Flowchart

Steps 3 and 4 are potentially unconservative for buildings where the MWFRS wind load design is per Chapter 28 Envelope Method

FIX – when using Ch 28 for Wind Loads, skip steps 3 and 4 when determining if design for tornado loads is required



76

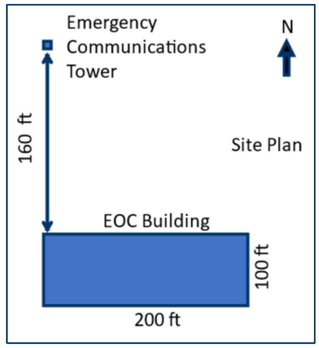
76

ASCE | KNOWLEDGE & LEARNING

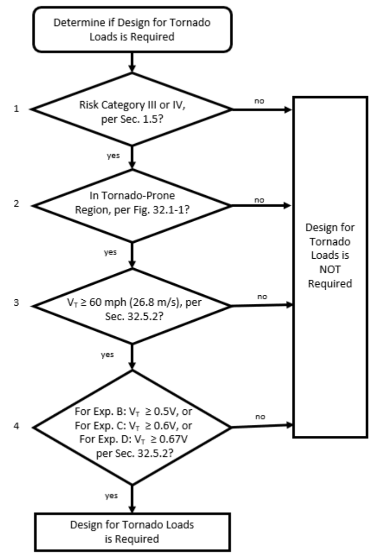
Is Design for Tornado Loads Required?

Practice Your Knowledge

Problem Statement:
Determine if design for tornado loads is required or not, per the flowchart at right



A new county emergency operations center (EOC) is planned for Burlington, Colorado. The facility includes a new building and 130 ft tall, freestanding emergency communications tower, which is located 160 ft due north of the northwest corner of the EOC building, as shown. The facility is located in the middle of town, with suburban exposure in all directions.



77

77

ASCE | KNOWLEDGE & LEARNING

Solution Steps 1 and 2

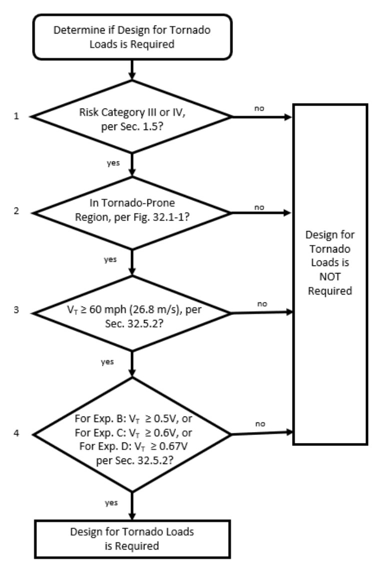
Practice Your Knowledge

Solution

1. Risk Category = ____
2. In tornado-prone region? ____

Problem Statement:
Determine if design for tornado loads is required or not, per the flowchart at right

A new county emergency operations center (EOC) is planned for Burlington, Colorado. The facility includes a new building and 130 ft tall, freestanding emergency communications tower, which is located 160 ft due north of the northwest corner of the EOC building, as shown. The facility is located in the middle of town, with suburban exposure in all directions.



78

78

ASCE | KNOWLEDGE & LEARNING

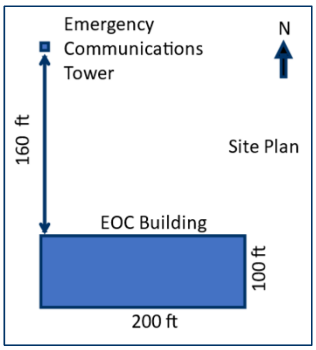
Solution - Effective Pan Area

Practice Your Knowledge

Solution

Effective Plan Area, A_e = ________ sq ft
determined using the smallest convex polygon

Effective Plan Area A_e = ________ sq ft
determined using the smallest rectangle
(simplified approximation)



79

79

ASCE | KNOWLEDGE & LEARNING

Solution – Design Tornado Speed

Practice Your Knowledge

Solution

For A_e = _______ sq ft (convex polygon-from previous step),

V_T = ____ mph

Use Hazards Tool or map in Standard

80

80

ASCE | KNOWLEDGE & LEARNING

Solution Steps 3 and 4

Practice Your Knowledge

Solution

3. Is $V_T \geq 60$ mph? ____

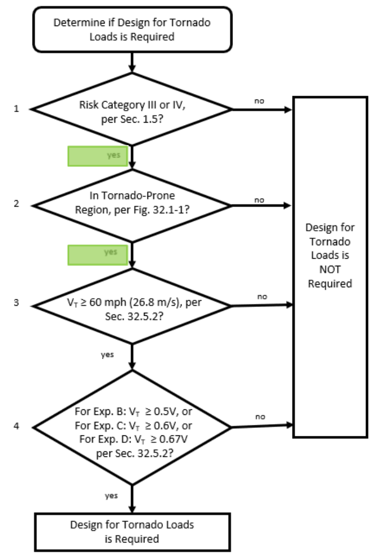
4. What is the wind exposure category? ___

What is the Basic wind speed? ___ mph
(hazards tool or map in standard)

Is $V_T \geq$ ___ V? ____

Answer:

A new county emergency operations center (EOC) is planned for Burlington, Colorado. The facility includes a new building and 130 ft tall, freestanding emergency communications tower, which is located 160 ft due north of the northwest corner of the EOC building, as shown. The facility is located in the middle of town, with suburban exposure in all directions.



81

81

Tornado Speed and Determination of When Tornado Loads are Not Required

Questions / Discussion

marc.l.levitan@gmail.com

82

82

ASCE | KNOWLEDGE & LEARNING

Summary

83

83

ASCE | KNOWLEDGE & LEARNING

Unit 2: Summary Part 1

- Tornado Provisions in ASCE 7-22
  - Chapters 1, 2, 26, 32 and Appendix G
- Chapter 1 General
  - Risk Categories and target reliabilities for tornado loads are the same as for wind loads
  - Essential facilities definition includes tornadoes
- Chapter 2 Load Combinations
  - Tornado Loads W_T added to both Strength and ASD Load Combinations
- Chapter 26 Wind Loads
  - Added pointer to also require Tornado Loads per Chapter 32

ESSENTIAL FACILITIES: Buildings and other structures that are intended to remain operational in the event of extreme environmental loading from flood, wind, tornado, snow, or earthquakes.

2.3 LOAD COMBINATIONS FOR STRENGTH DESIGN

1a. $1.4D$
2a. $1.2D + 1.6L + (0.5L_r \text{ or } 0.3S \text{ or } 0.5R)$
3a. $1.2D + (1.6L_r \text{ or } 1.0S \text{ or } 1.6R) + (L \text{ or } 0.5W)$
4a. $1.2D + 1.0(W \text{ or } W_T) + L + (0.5L_r \text{ or } 0.3S \text{ or } 0.5R)$
5a. $0.9D + 1.0(W \text{ or } W_T)$

ASCE | KNOWLEDGE & LEARNING

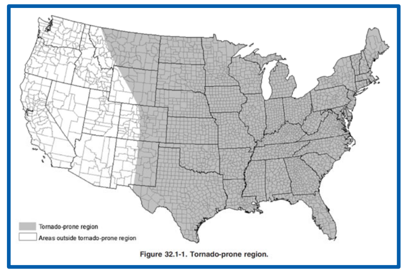
84

84

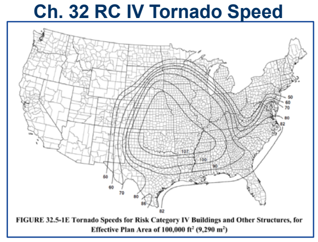
ASCE | KNOWLEDGE & LEARNING

Unit 2: Summary Part 2

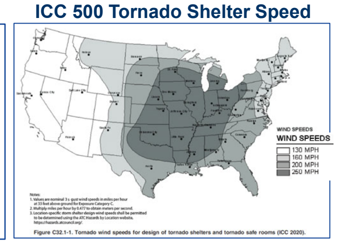
- Chapter 32 Scope
  - Risk Category III and IV buildings and other structures in the tornado-prone region
  - MWFRS and C&C
- Chapter 32 'Limitations'
  - Can NOT design a tornado shelter based solely on Chapter 32
  - Tornado shelter requirements governed by the I-Codes and the ICC 500 Storm Shelter Standard
- Reliability for MWFRS provides reasonable consistency with wind load provisions
- Return periods same as for wind loads



Ch. 32 RC IV Tornado Speed



ICC 500 Tornado Shelter Speed



ASCE | KNOWLEDGE & LEARNING

85

85

ASCE | KNOWLEDGE & LEARNING

Unit 2: Summary Part 3

- Tornado load procedures adapted from wind load procedures
  - Chapter 32 follows wind load chapter organization
  - Tornado versions of symbols add a subscript $_T$ to wind load symbols
- Performance-based design for tornadoes is explicitly permitted

Ch. 32 Tornado Load Procedures

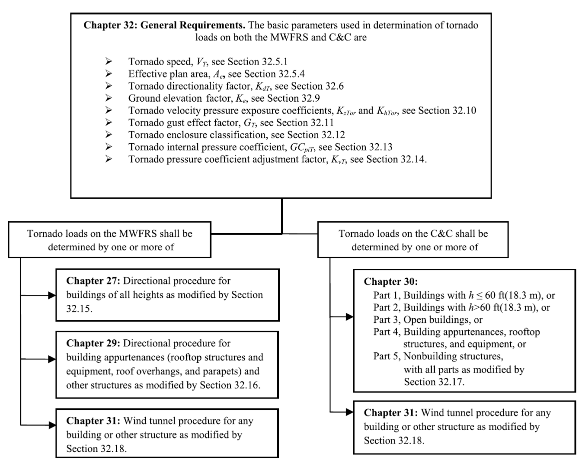


Figure 32.1-3. Outline of process for determining tornado loads.

ASCE | KNOWLEDGE & LEARNING

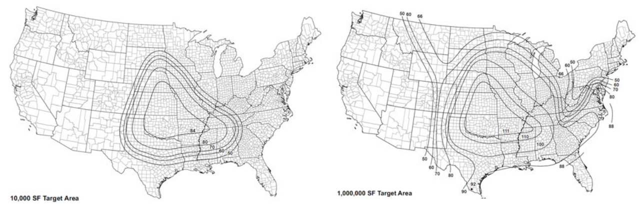
86

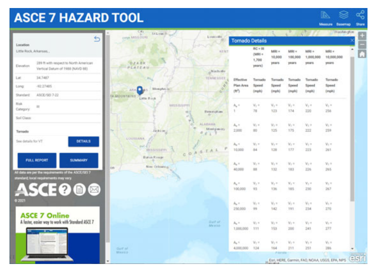
86

Unit 2: Summary Part 4

- Tornado speeds are a function of the plan size and shape of the building or facility
  - Target size is measured using effective plan area, A_e
  - Tornado speed increases with increasing, A_e
- Tornado hazard maps are provided for 8 sizes, from 1 to 4M SF
  - Interpolation between mapped A_e sizes is permitted
- ASCE provided a free online, web-GIS tool to determine tornado speeds and other hazard values as well
  - https://asce7hazardtool.online/
- Checks for when tornado loads are not required

Risk Category III (1,700 Year)





87

87

Break

88

88