Calculation of Design Tornado Loads for Structures According to ASCE 7-22 and IBC 2024 Codes

An Online Continuing Education Course for Engineers

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Calculation of Design Tornado Loads for Structures According to ASCE 7-22 and IBC 2024 Codes

Ibrahim M. Metwally, P.E.

Introduction and Background

This instructional course is for design professionals and building officials to help them determine when a building or other structure is required to be designed to minimum tornado loads and how to calculate design tornado forces. This guide is in accordance with the updated requirements of the American Society of Civil Engineers (ASCE) / Structural Engineering Institute (SEI) standard ASCE 7-22, Minimum Design Loads and Associated Criteria for Buildings and Other Structures.

This Design Guide is intended for users with a basic understanding of ASCE 7 and who know how to determine wind loads using ASCE 7 methodology, as presented in Chapters 26 through 31.

Tornadoes have historically killed more people in the United States than hurricanes and earthquakes combined (NWS, 2020; USGS, 2015). According to the Insurance Information Institute, Inc. (2020), the average annual insured catastrophe losses for events involving tornadoes exceeded those for both hurricanes and tropical storms combined from 1997 to 2016. The 2011 Joplin tornado disaster was the deadliest and costliest tornado in the U.S. since 1950 and was one of the primary drivers for the addition of tornado load provisions in ASCE 7 (NIST, 2022). **With the publication of ASCE 7-22 (ASCE, 2021), tornado load requirements are now considered as a minimum design load in conventional building design when buildings are located in tornado-prone areas**. **The new ASCE 7 tornado load provisions do not apply to storm shelters or safe rooms.** The ASCE 7 tornado load requirements will be included in the 2024 International Building Code (IBC), the 2024 National Fire Protection Association (NFPA) 5000 Building Construction and Safety Code, and the 2023 Florida Building Code. The adoption of the ASCE 7 tornado load provisions by the State of Florida is an example of local Authorities Having Jurisdiction incorporating the most current design guidance prior to their inclusion in the model building codes.

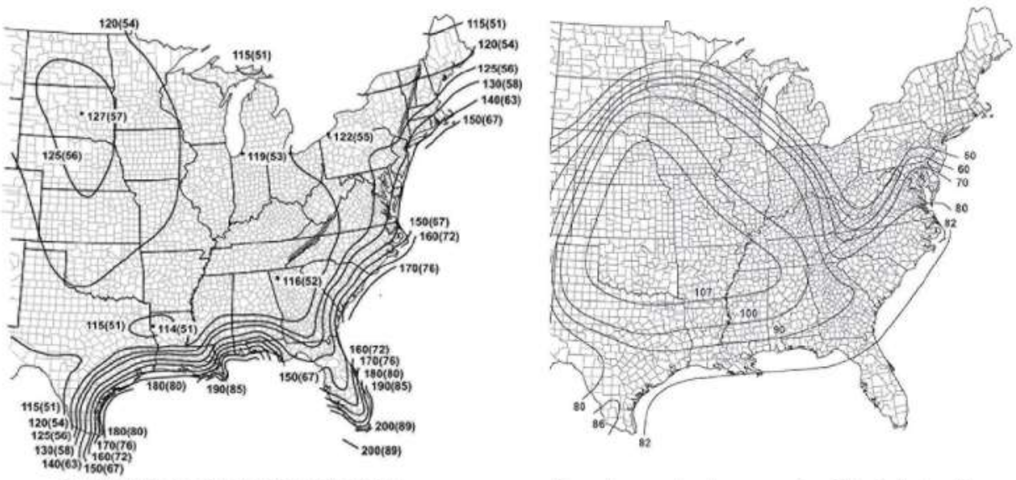
Storm shelters and safe rooms are specifically designed for life safety protection during the most extreme wind events and require more extreme design hazard intensities than conventional buildings. Buildings and other structures designed per Chapter 32 of ASCE 7 do not meet the requirements for storm shelters or safe rooms.

Storm shelters and safe rooms must adhere to the ICC 500, *Standard for the Design and Construction of Storm Shelters* (ICC/NSSA, 2020) specifications, and/or FEMA P-361, *Safe Rooms for Tornadoes and Hurricanes: Guidance for Community and Residential Safe Rooms* (FEMA, 2021), respectively.

Section 423 of the IBC requires that storm shelters are provided for K-12 school buildings with an occupant load of 50 or more people; 911 call stations; fire, rescue, ambulance, and police stations; and emergency operations centers where the design tornado wind speed is 250 mi/h per Figure 304.2(1) in ICC-500.

The new tornado load requirements are based on a decade of research by the National Institute of Standards and Technology (NIST), working with Applied Research Associates, Inc. (ARA), the ASCE 7-22 Tornado Task Committee, and others. Tornado hazard maps were developed to define design tornado speeds for a range of return periods. The mapped tornado speeds represent the 3-second gust tornado speed at 33 feet above the ground. Design tornado speeds use a 1,700- and 3,000-year return period for Risk Category III and IV buildings, respectively. Design tornado speeds are also a function of the plan size and shape of the building, other structures, or facility, as measured by the effective plan area, Ae; the larger the facility, the greater the tornado strike probability. For a given return period, this means that a larger facility has a greater design tornado speed than a smaller facility at the same geographic location. Design tornado speeds are mapped for a wide range of effective plan areas for each Risk Category/return period.

The tornado speed return periods for each risk category are the same mean recurrence intervals (MRIs) used for basic wind speeds in ASCE 7, Chapter 26. They are approximately consistent with the target reliabilities defined in the first row of ASCE 7, Table 1.3-1. Figure 1 presents an example comparison of a basic wind speed map versus a tornado speed map for a Risk Category IV structure (3,000-year return period). Basic wind speeds are greater than the tornado speeds everywhere, for the Ae = 100,000 ft2 map shown. Design tornado speeds range from 60 to 138 mi/h, as a function of Risk Category, effective plan area, and geographic location. This approximately corresponds to tornado intensities of EF0-EF2 on the Enhanced Fujita Scale. In most instances, the design tornado speed will be less than the basic wind speed for a specific structure, However, this does not mean design wind pressures govern over design tornado pressures in most cases for that structure, as will become evident throughout this Design Guide and the design example at the end of this guide.



Basic wind speeds shown are for Risk Category IV buildings and other structures

Basic Wind Speeds
ASCE 7, Figure 26.5-1D

Tornado speeds shown are for Risk Category IV buildings and other structures, for effective plan area of 100,000 ft^2

Tornado Speeds
ASCE 7, Figure 32.5-2E

Figure 1: Basic wind speed map versus tornado speed map. Speeds are in mi/h (m/s) (Source: ASCE 7, used with permission from ASCE)

Building stakeholders may elect to design a more resilient structure for higher tornado speeds based on personal risk management decisions. A more resilient structure can be achieved through performance-based design per ASCE 7, Section 1.3.1.3, using mapped basic wind and tornado speeds for longer return periods (10,000-, 100,000-, 1,000,000-, and 10,000,000-year return periods) provided in ASCE 7, Appendices F and G.

Terminology and Basic Design Parameters in ASCE 7-22

The following design guide and basic design parameter definitions refer to the provisions of Chapters 26 through 32 of ASCE 7. This guide uses general design terms applied throughout Chapters 26 through 32. Basic design parameters are coefficients used in the determination of tornado loads on both the MWFRS and C&C per Chapter 32.

Design Guide Terminology

The design guide terms are listed below in alphabetical order.

♣ ASCE 7 Hazard Tool: Online tool that provides site-specific structural design parameters for wind, seismic, snow, ice, rain, flood, tsunami, and tornado load types: https://asce7hazardtool.online/.

♣ Components and Cladding (C&C): Elements of the building envelope or elements of building appurtenances and rooftop structures, and equipment that do not qualify as part of the MWFRS.

♣ Enhanced Fujita Scale (EF-Scale): Tornado rating scale that rates the intensity of tornadoes based on the severity of damage they cause. A tornado is rated as one of six categories (EF0, EF1, EF2, EF3, EF4, or EF5) on this scale, with EF5 being the most intense.

♣ Impact-Protective System: Construction that has been shown by testing to withstand the impact of test missiles and that is applied, attached, or locked over exterior glazing (Section 26.12.3.2).

♣ Main Wind Force Resisting System (MWFRS): An assemblage of structural elements assigned to provide support and stability for the overall building or other structure. The system generally receives wind loading from more than one surface.

♣ Performance-Based Procedures: An alternative to the prescriptive procedures in ASCE 7 that is characterized by project-specific engineering analysis, optionally supplemented by limited testing, to demonstrate that the design is generally consistent with the target reliabilities stipulated in Section 1.3.1.3 (see also Section 32.1.3).

♣ Tornado-Prone Region: The area of the conterminous United States most vulnerable to tornadoes (Figure 32.1-1, which is reproduced in Figure 2).

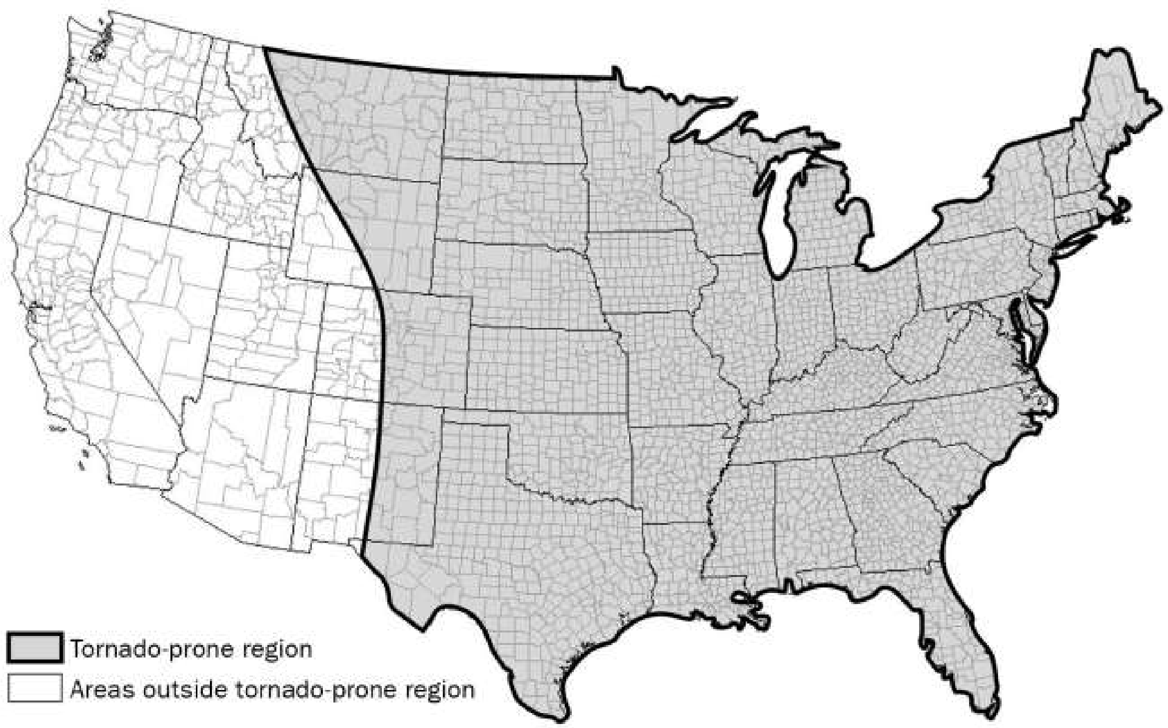


Figure 2: Tornado-prone region (Adapted from ASCE 7, Figure 32.1-1; used with permission from ASCE)

Introduction to Design Parameters Used in the Determination of Tornado Loads

The design parameters are listed below in alphabetical order. Where tornado load parameters are modified versions of corresponding wind load parameters, they are designated with the addition of a subscript T or Tor on the wind load parameter.

♣ **Basic Wind Speed (V):** The area Basic wind speed obtained from Figures 26.5- 1A through 26.5- 1D, mi/h (m/s); the basic wind speed corresponds to a 3-second gust at 33 feet (10 meters) above the ground in Exposure Category C.

♣ **Effective Plan Area (Ae)*:** The area of the smallest convex polygon enclosing the plan of the building, other structure, or facility, used in the determination of VT (Section 32.5.4).

♣ **External Pressure Coefficient (Cp or GCp):** External pressure coefficient for use in determining MWFRS (Cp) or C&C (GCp) loads (Chapters 27, 29, 30, and Section 32.18).

♣ **Ground Elevation Factor (Ke):** Adjustment factor to account for the reduced mass density of air as the height of the local ground level above sea level increases (Section 32.9).

♣ **Tornado Design Pressure (pT)*:** Design tornado pressure to be used in the determination of tornado loads for buildings and for certain other structures (Sections 32.15–32.17).

♣ **Tornado Directionality Factor (KdT)*:** Factor to account for the less than 100% probability that the maximum tornado winds impacting the building or structure come from any given direction and that the maximum magnitude of pressure coefficient occurs for any given wind direction (Table 32.6-1).

♣ **Tornado Gust Effect Factor (GT)*:** Factor to account for the decorrelation of wind gusts over the size of the structure (Section 32.11.1).

♣ **Tornado Internal Pressure Coefficient (GCpiT)*:** Pressure coefficient that accounts for the combined effects of wind-induced internal pressure and atmospheric pressure change (Section 32.13).

♣ **Tornado Pressure Coefficient Adjustment Factor (KvT)*:** New modifier on external pressure coefficients to account for effects of vertical components (i.e., strong updrafts) of tornadic wind (Section 32.14), which increase the uplift on roof surfaces.

♣ **Tornado Speed (VT)***: Three-second gust tornado speed at 33 feet above the ground used in the determination of tornado loads on buildings and other structures, obtained from the tornado hazard maps (Figures 32.5- 1A through 32.5- 2H or Appendix G).

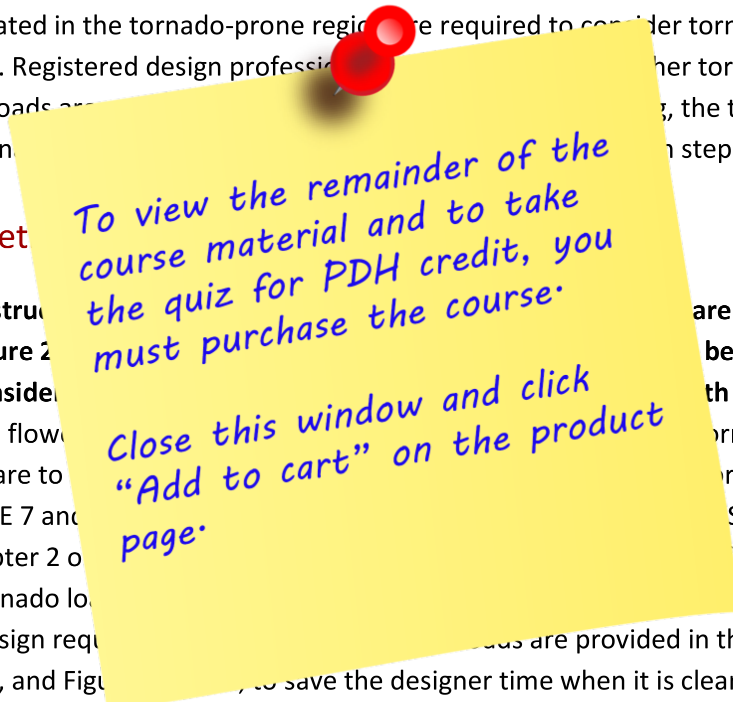
♣ **Tornado Velocity Pressure (qzT or qhT)*:** Velocity pressure evaluated at height z or h above ground (Section 32.10.2).

♣ **Tornado Velocity Pressure Exposure Coefficient (KZTor or KhTor)***: Coefficient to account for the tornado wind loading profile at different heights above ground level (Table 32.10-1).

* New ASCE 7-22 tornado design parameters

Procedure for Determining When Design for Tornado Loads is Required (ASCE 7, Section 32.5.2)

Not all structures located in the tornado-prone regi... re required to con...der tornado loads per Chapter 32 of ASCE 7. Registered design professi... ...her tornado loads are required. If tornado loads ar... ..., the tornado velocity pressure, and the torn... ...n step below.



Determining Whet...

Buildings and other stru... ...are in the tornado-prone region per Figure 2... ...be designed and constructed with conside... ...th Chapter 32 of ASCE 7. Figure 3 provides a flow... ...rnado loads is required. Structures are to ... ...rdance with Chapters 26 through 31 of ASCE 7 and ... ...SCE 7 using the load combinations in Chapter 2 o... ...tornado speed to basic wind speed, tornado lo... ...ional criteria for determining if the design requ... ...ads are provided in the flowchart in Chapter 32 of ASCE 7, and Figu... ...to save the designer time when it is clear tornado loads will not control over wind loads.

Building stakeholders have the option, even if not required per ASCE 7, to consider tornado loads or to use a greater risk category or mean recurrence interval in the building design, in addition to performance-based design procedures. Enhanced performance may be an important option for building stakeholders concerned about maintaining the functionality of their operations during and after a design-level tornado.