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Unit 4

Tornado Load Calculations, Combinations, and Impacts on Practice

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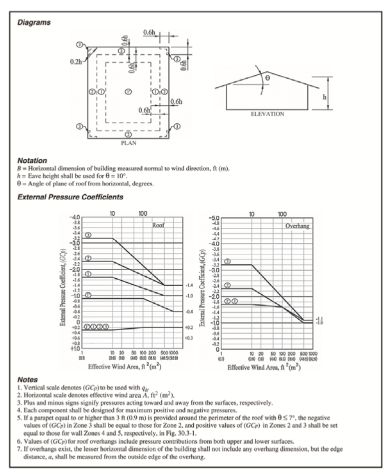
Unit 4 Outline

Tornado Load Calculations, Combinations, and Impacts on Practice

- Tornado Load Cases
- Tornado Load Example Part I - MWFRS
- Tornado Load Example Part II – C&C
- Tornado Load Combinations
- Tornado Load Example Part III – Load Combinations
- Tornado Loads vs Wind Loads – Where Each Controls
- Model Building Codes and Cost Impacts
- Summary



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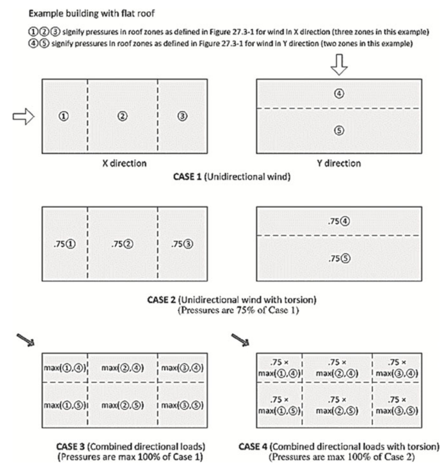
Unit 4: Learning Outcomes

- Upon completion of this unit, you will be able to:
  - Understand the application of MWFRS load cases to tornadoes
  - Evaluate MWFRS and C&C tornado loads for an example building
  - Describe the rationale for how wind and tornado loads are treated in load combinations
  - Determine controlling loads using Strength and ASD load combinations
  - Understand current status for tornado load inclusion in model building codes and local adoptions
- This is important on the job because …
  - Enables inclusion of tornado loads in the wind load design of a building or other structure



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Tornado Load Cases

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Load Cases

- MWFRS Load Cases
  - Review ASCE 7-16 Wind Cases
  - Changes for ASCE 7-22 Wind
  - Changes for ASCE 7-22 Tornado

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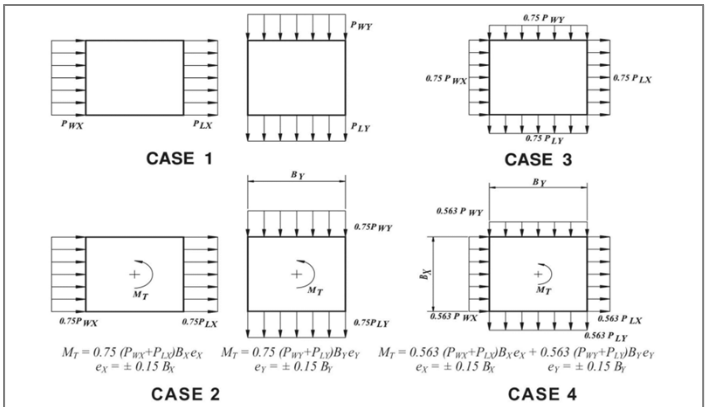
MWFRS Load Cases: Part 1

- Once wind loads have been determined for each principal direction, multiple cases must be considered, including
  - Quartering winds
  - Torsion about vertical axis
  - Exception: Torsion need not be considered for buildings meeting spatial distribution and stiffness requirements of **Appendix D**

27.3.5 Design Wind Load Cases. The MWFRS of buildings of all heights, the wind loads of which have been determined under the provisions of this chapter, shall be designed for the wind load cases as defined in Fig. 27.3-8.

ASCE 7-16 Wind Provisions



Notation

P_{WX}, P_{WY} = Windward face design pressure acting in the *x*, *y* principal axis, respectively.
P_{LX}, P_{LY} = Leeward face design pressure acting in the *x*, *y* principal axis, respectively.
$e(e_X, e_Y)$ = Eccentricity for the *x*, *y* principal axis of the structure, respectively.
M_T = Torsional moment per unit height acting about a vertical axis of the building.

Case 1. Full design wind pressure acting on the projected area perpendicular to each principal axis of the structure, considered separately along each principal axis.
Case 2. Three-quarters of the design wind pressure acting on the projected area perpendicular to each principal axis of the structure in conjunction with a torsional moment as shown, considered separately for each principal axis.
Case 3. Wind loading as defined in Case 1, but considered to act simultaneously at 75% of the specified value.
Case 4. Wind loading as defined in Case 2, but considered to act simultaneously at 75% of the specified value.

Notes

1. Design wind pressures for windward and leeward faces shall be determined in accordance with the provisions of Sections 27.3.1 and 27.3.2 as applicable for buildings of all heights.
2. Diagrams show plan views of buildings.

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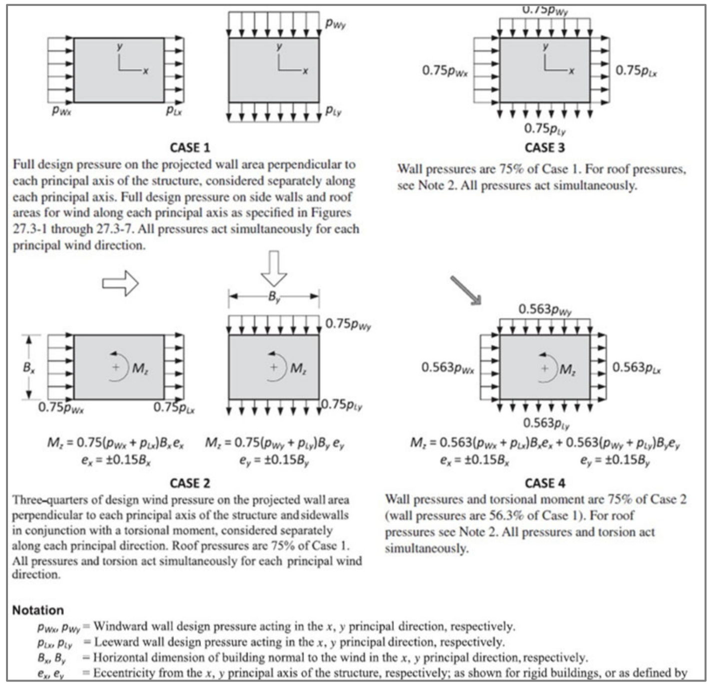
MWFRS Load Cases: Part 2

- ASCE 7-22 Changes Include
  - Improved explanations
  - Revised roof pressures
  - Notes on when torsion applies

Notes

1. Diagrams show plan views of buildings.
2. Pressures on roof are not shown for clarity. For Cases 3 and 4 the resulting pressure on 100% of pressures defined for Cases 1 and 2, respectively.
3. Pressures on side walls for Cases 1 and 2 are not shown for clarity and need not be considered at floors with rigid diaphragms continuous with the sidewalls.
4. M_z shall be applied on rigid diaphragms. On floors with semi-rigid or flexible diaphragms, or without diaphragms, it shall be permitted to apply M_z using an equivalent distributed pressure block on all walls receiving normal wind pressure, applied in the proportion specified for each wall in Figure 27.3-1, or by using other rational methods

ASCE 7-22 Wind Provisions



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MWFRS Load Cases: Part 3

- ASCE 7-22 Changes Include
  - Expanded commentary on application of roof pressures

ASCE 7-22 Wind Provisions

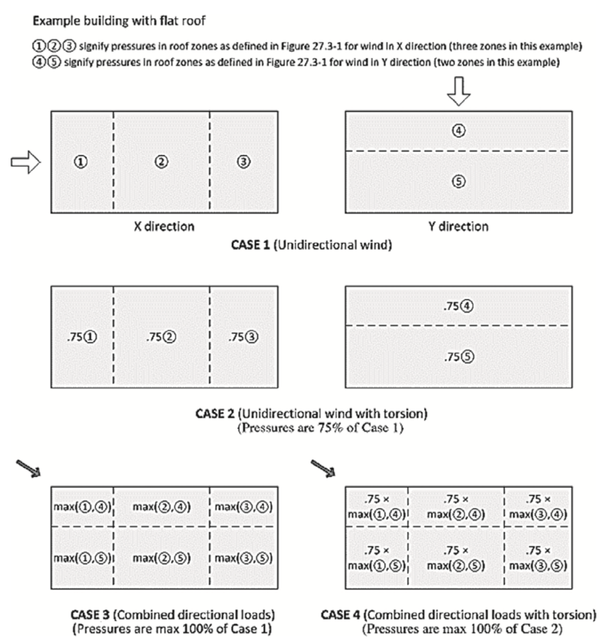

Figure C27.3-4. Roof pressures for load cases of Figure 27.3-8.

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Tornado Load Cases: Part 1

- Use MWFRS load cases from Ch. 27
- No exception for checking torsion loads
  - Asymmetry of wind field tends to increase torsion load
- Accuracy of load cases for tornado loads depends on
  - Size of tornado relative to size of building
  - Position of building relative to tornado track

32.15. Design Load Cases The design load cases shall be determined using Section 27.3.5. The exception for buildings meeting the requirements of Section D1 of Appendix D shall not apply.

C32.15.5 Design Load Cases In cases where a tornado is smaller in plan area than the building or other structure it strikes, the load cases from Figure 27.3-8 are likely to be conservative, since the maximum tornado speed does not extend across the full plan area of the building. The asymmetry of the tornado wind field with respect to the building would tend to increase torsional loads compared to other types of windstorms, hence the removal of the exception in Section 27.3.5 that eliminates the torsional load cases in Figure 27.3-8.

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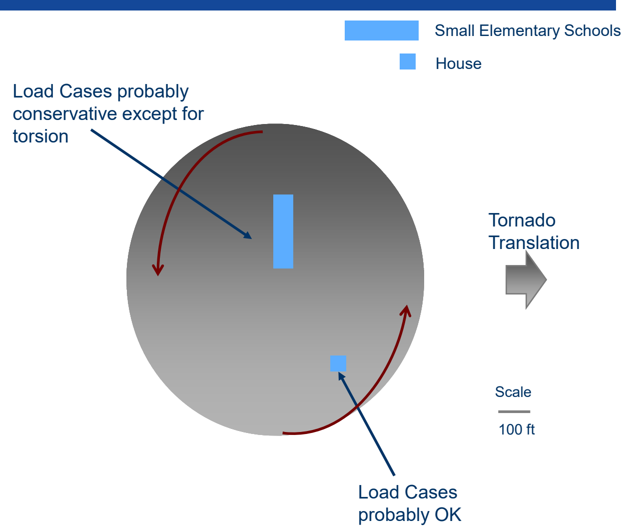
Tornado Load Cases: Part 2

- Tornado width much larger than building
  - Maximum tornado speed may not extend across entire building at any instant in time



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Tornado Load Cases: Part 3

- Joplin MO Tornado, 2011

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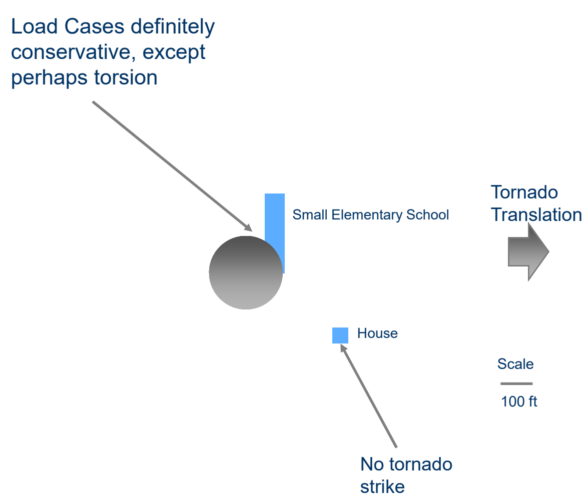
Tornado Load Cases: Part 4

- Tornado width is smaller than building
  - Maximum tornado speed does not impact the whole building at the same instant
  - Winds on different parts of the building coming from different directions simultaneously
  - Base shear will be overestimated



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Tornado Load Cases

Questions / Discussion

marc.l.levitan@gmail.com

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Tornado Load Example Part I - MWFRS

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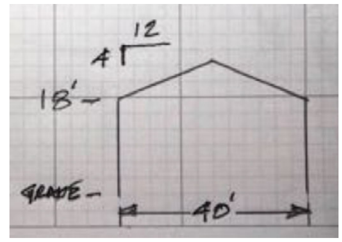
Example – MWFRS Wind and Tornado Loads

Determine the design wind and tornado pressures on MWFRS windward and leeward walls using ASCE 7-22 for the following facility:

- Office of Emergency Services Call Center
  - Metal Building System
  - Single story, 40’ x 75’ x 18’
  - Wichita, Kansas
  - Site Coordinates
    - Lat = 37.755141, Lon = -97.368928
  - Risk Category IV
  - Essential Facility
  - Mean roof height: h=24.7 ft
  - Flat open terrain: Exposure C in all directions
  - Ground elevation: ≈1340 ft MSL



Elevation and Plan Views

Graphics courtesy of Mark Detwiler

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Wind Velocity Pressure

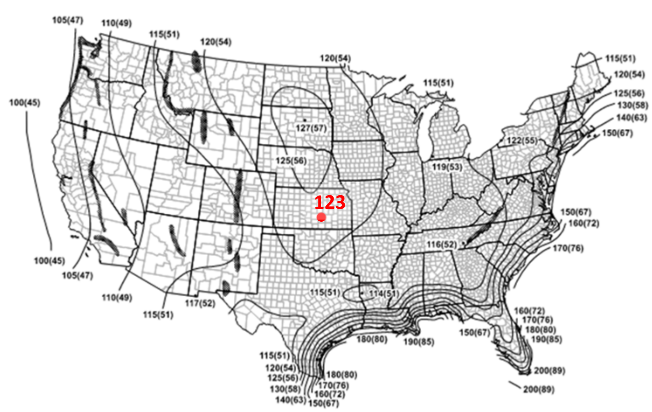
Velocity Pressure

$q_h = 0.00256 * K_h K_{zt} K_e V^2$

$\boldsymbol{q_h = 34.6}$ **psf**

Velocity pressure exposure coefficient at h=24.7 ft, exposure C	K_h = 0.94
Topographic factor	K_{zt} = 1.0
Ground elevation factor	K_e = 0.95
Basic wind speed	V = 123 mph

Reminder - In ASCE 7-22, K_d has been removed from velocity pressure equation and placed into the pressure and force equations, since it is not *purely* a function of the extreme wind climatology (it also depends on the geometry of the building)



ASCE 7-22: FIGURE 26.5-1D Basic Wind Speeds for Risk Category IV Buildings and Other Structures

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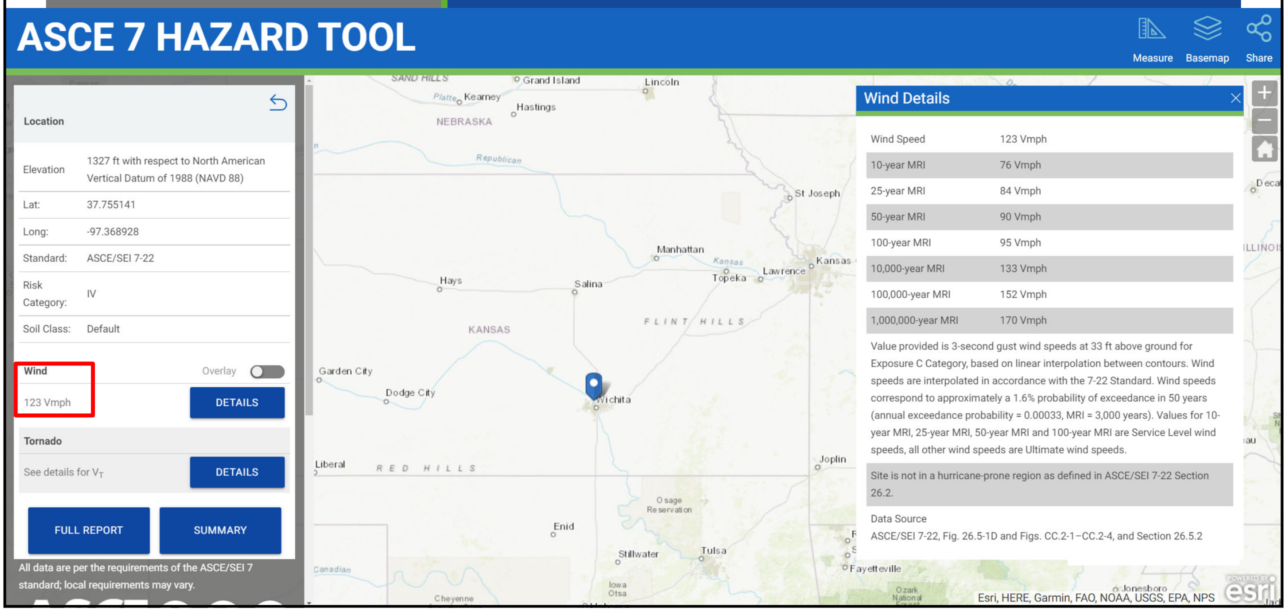
Basic Wind Speed from Hazards Tool



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Design Wind Pressure Equation (Ch 27)

MWFRS Design Wind Pressures

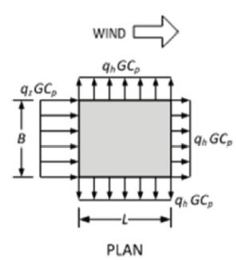
$$p = qK_d GC_p - q_i K_d (GC_{pi})$$

Velocity pressure	q_h = 34.6 psf
Directionality factor	K_d = 0.85
Gust effect factor	G = 0.85
Wall pressure coefficients	
Windward wall	C_p = +0.8
75' leeward wall (L/B=0.53)	= -0.5
40' leeward wall (L/B=1.875)	= -0.325
Internal pressure coefficient	
Enclosed Building	(GC_{pi}) = 0.18, -0.18

Wall Pressure Coefficients, C_p

Surface	L / B	C_p	Use with
Windward wall	All values	0.8	q_z
Leeward wall	0–1	−0.5	q_h
	2	−0.3	q_h
	≥4	−0.2	q_h
Sidewall	All values	−0.7	q_h

interpolate



From ASCE 7-22, FIGURE 27.3-1

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Design Wind Pressures (Ch 27)

MWFRS Wind Design Pressures

$p = qK_dGC_p - q_iK_d(GC_{pi})$

Velocity pressure q_h = 34.6 psf

Directionality factor K_d = 0.85

Gust effect factor G = 0.85

Wall pressure coefficients

Windward wall C_p = +0.8

75' leeward wall (L/B=0.53) = -0.5

40' leeward wall (L/B=1.875) = -0.325

Internal pressure coefficient

Enclosed Building (GC_{pi}) = 0.18, -0.18

WALL DESIGN PRESSURES-WIND

Top of Windward wall (- int pr)

p = +25.3 psf

75' Leeward wall (+ int pr)

p = -17.8 psf

40' Leeward wall (+ int pr)

p = -13.4 psf

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Tornado Velocity Pressure: Part 1

Tornado Velocity Pressure

$q_{hT} = 0.00256 * K_{hTor} K_e V_T^2$

Tornado velocity pressure exposure coefficient at h=24.7 ft K_{hTor} = 1.0

Ground elevation factor K_e = 0.94

Tornado speed V_T = ?

effective plan area = 40' x 75' = 3,000 SF

Table 32.10-1 Tornado Velocity Pressure Exposure Coefficients, K_{zTor} and K_{hTor}

Height above Ground Level, z		K_{zTor} and K_{hTor}
ft	m	
0-200	0-61.0	1.0
250	76.2	0.96
300	91.4	0.92
>328	>100	0.90

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Tornado Speed

Tornado Speed, V_T

- A_e= 3,000 SF
- Select speed using next largest mapped A_e
  - Use A_e = 10,000 SF map
- V_T = 99 mph

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

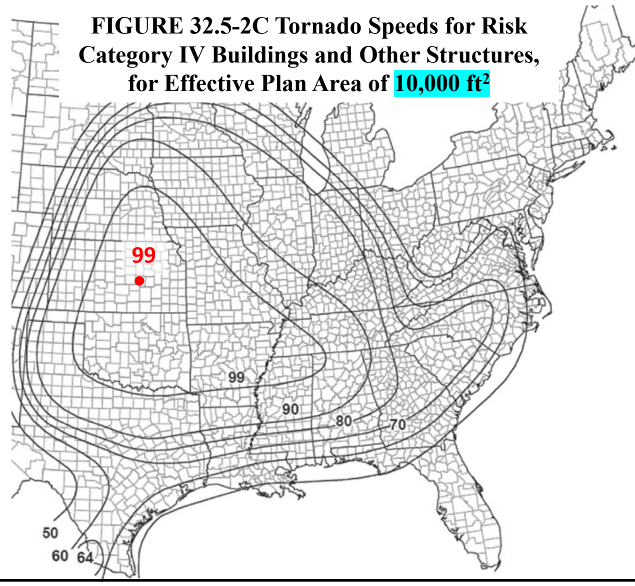

FIGURE 32.5-2C Tornado Speeds for Risk Category IV Buildings and Other Structures, for Effective Plan Area of 10,000 ft^2

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Alternate Interpolated Solution for V_T

- Select speed using next smallest mapped A_e
  - Use A_e = 2,000 SF map
  - V_T = 96 mph
- Use linear interpolation on log (A_e) for A_e = 3,000 SF

A_e (SF)	Log A_e	V_T (mph)
2,000	3.30	96
10,000	4.00	99

- V_T = 97 mph – use this value

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

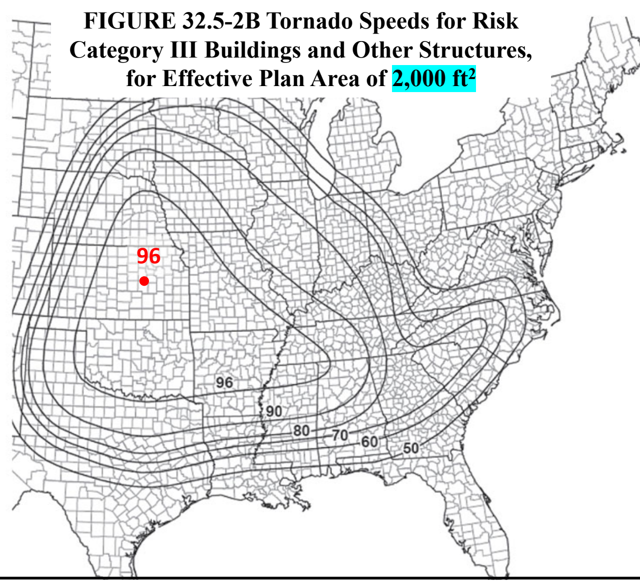

FIGURE 32.5-2B Tornado Speeds for Risk Category III Buildings and Other Structures, for Effective Plan Area of 2,000 ft^2

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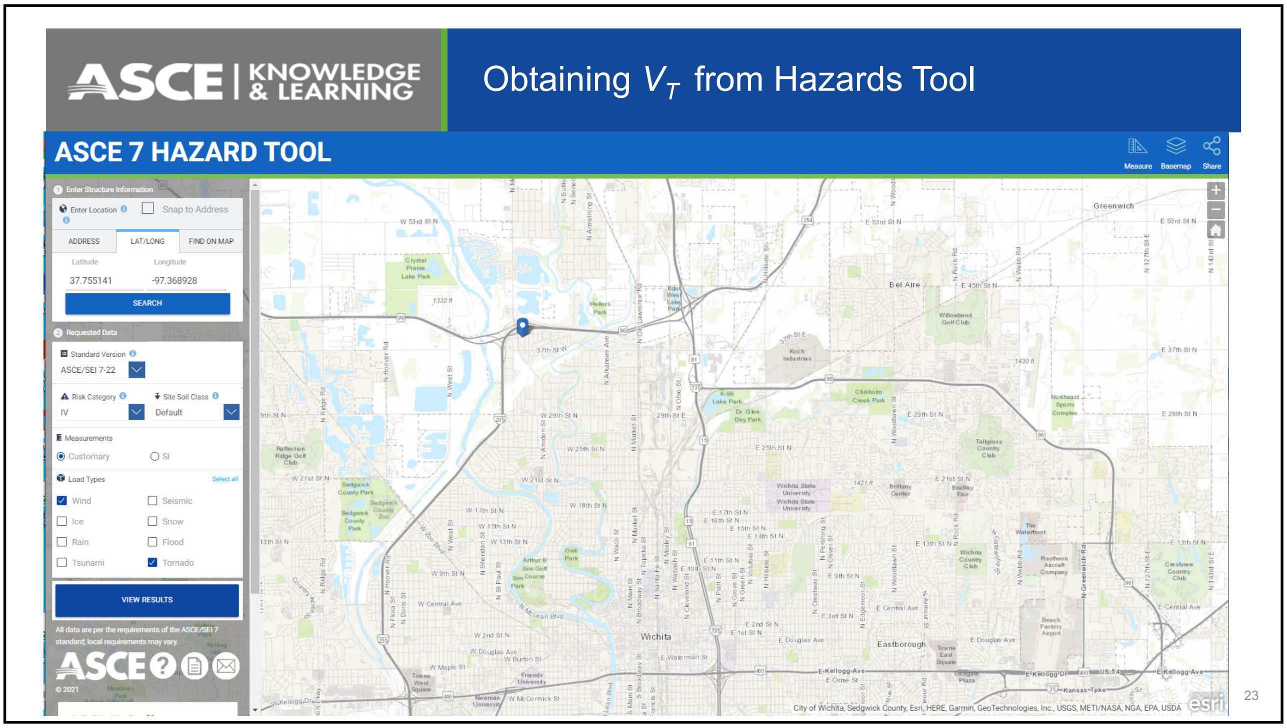
ASCE | KNOWLEDGE & LEARNING
Obtaining V_T from Hazards Tool
ASCE 7 HAZARD TOOL
Enter Structure Information
ADDRESS
LAT/LONG
FIND ON MAP
37.755141
-97.368928
SEARCH
Requested Data
Standard Version
ASCE/SEI 7-22
Risk Category
IV
Site Soil Class
Default
Measurements
Customary
SI
Load Types
Wind
Seismic
Ice
Snow
Rain
Flood
Tsunami
Tornado
VIEW RESULTS
All data are per the requirements of the ASCE/SEI 7 standard; local requirements may vary.
Wichita
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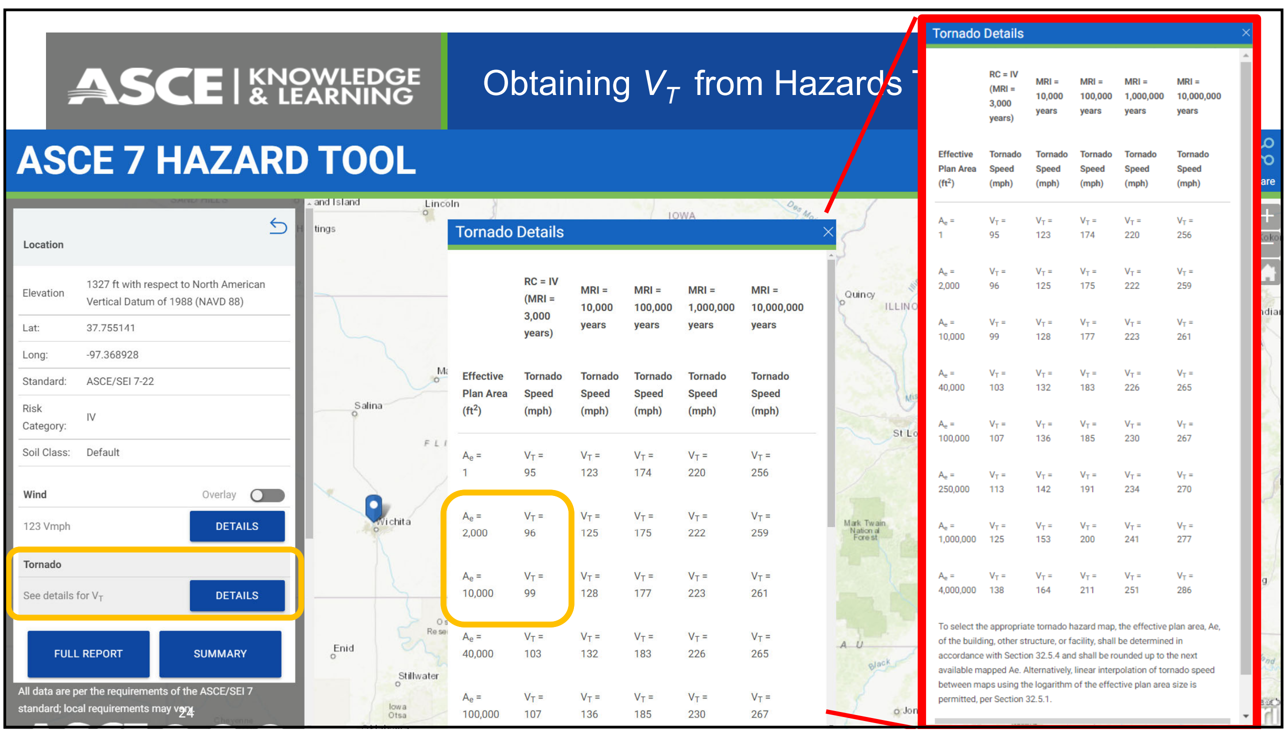
ASCE | KNOWLEDGE & LEARNING
Obtaining V_T from Hazards Tool
ASCE 7 HAZARD TOOL
Location
Elevation 1327 ft with respect to North American Vertical Datum of 1988 (NAVD 88)
Lat: 37.755141
Long: -97.368928
Standard: ASCE/SEI 7-22
Risk Category: IV
Soil Class: Default
Wind
123 Vmph
DETAILS
Tornado
See details for V_T
DETAILS
FULL REPORT
SUMMARY
All data are per the requirements of the ASCE/SEI 7 standard; local requirements may vary.
Tornado Details
RC = IV (MRI = 3,000 years)
MRI = 10,000 years
MRI = 100,000 years
MRI = 1,000,000 years
MRI = 10,000,000 years
Effective Plan Area (ft²)
Tornado Speed (mph)
A_e = 1: V_T = 95, 123, 174, 220, 256
A_e = 2,000: V_T = 96, 125, 175, 222, 259
A_e = 10,000: V_T = 99, 128, 177, 223, 261
A_e = 40,000: V_T = 103, 132, 183, 226, 265
A_e = 100,000: V_T = 107, 136, 185, 230, 267
A_e = 250,000: V_T = 113, 142, 191, 234, 270
A_e = 1,000,000: V_T = 125, 153, 200, 241, 277
A_e = 4,000,000: V_T = 138, 164, 211, 251, 286
To select the appropriate tornado hazard map, the effective plan area, Ae, of the building, other structure, or facility, shall be determined in accordance with Section 32.5.4 and shall be rounded up to the next available mapped Ae. Alternatively, linear interpolation of tornado speed between maps using the logarithm of the effective plan area size is permitted, per Section 32.5.1.
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Tornado Velocity Pressure: Part 2

Tornado Velocity Pressure

$q_{hT} = 0.00256 * K_{hTor} K_e V_T^2$

$q_{hT} = 22.9$ psf

Tornado velocity pressure exposure coefficient at h=24.7 ft $K_{hTor} = 1.0$

Ground elevation factor $K_e = 0.94$

Tornado speed $V_T = 97$ mph

effective plan area = 40' x 75' = 3,000 SF (interpolated)

Table 32.10-1 Tornado Velocity Pressure Exposure Coefficients, K_{zTor} and K_{hTor}

Height above Ground Level, z		K_{zTor} and K_{hTor}
ft	m	
0-200	0-61.0	1.0
250	76.2	0.96
300	91.4	0.92
>328	>100	0.90

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Design Tornado Pressure Equation: Part 1

MWFRS Design Tornado Pressures

$p_T = q_T G_T K_{dT} K_{vT} C_p - q_{iT}(GC_{piT})$

Tornado velocity pressure $q_{hT} = 22.9$ psf

Tornado gust effect factor $G_T = 0.85$

Tornado directionality factor $K_{dT} = 0.80$

Table 32.6-1 Tornado Directionality Factor, K_{dT}

Structure Type	Tornado Directionality Factor K_{dT}
Buildings	
Main Wind Force Resisting System	0.80
Components and Cladding	
For Essential Facilities and for buildings and other structures required to maintain the functionality of Essential Facilities	1.0
Roof Zone 1' as shown on Figure 30.3-2A	0.90
All other cases	0.75
Arched Roofs, Circular Domes, and All Other Structures	Use value from Table 26.6-1

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Design Tornado Pressure Equation: Part 2

MWFRS Design Tornado Pressures

$$p_T = q_T G_T K_{dT} K_{vT} C_p - q_{iT}(GC_{piT})$$

Tornado velocity pressure q_{hT} = 22.9 psf

Tornado gust effect factor G_T = 0.85

Tornado directionality factor K_{dT} = 0.80

Tor pr coeff adjustmnt factor K_{vT} = 1.0

Wall pressure coefficients

Windward wall C_p = +0.8

75' leeward wall (L/B=0.53) = -0.5

40' leeward wall (L/B=1.875) = -0.325

STRUCTURE TYPE	K_{vT}
Buildings	
Negative (Uplift) Pressures on Roofs	
Main Wind Force Resisting System	1.1
Components and Cladding	
Roof Slope <=7 degrees	
Zone 1	1.2
Zone 2	1.05
Zone 3	1.05
Roof Slope > 7 degrees	
Zone 1	1.2
Zone 2	1.2
Zone 3	1.3
Positive Pressures (Downward acting) on Roofs	1.0
Wall Pressures	1.0
All Other Cases	1.0

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Design Tornado Pressure Equation: Part 3

MWFRS Tornado Design Pressures

$$p_T = q_T G_T K_{dT} K_{vT} C_p - q_{iT}(GC_{piT})$$

Tornado velocity pressure q_{hT} = 22.9 psf

Tornado gust effect factor G_T = 0.85

Tornado directionality factor K_{dT} = 0.8

Tor pr coeff adjustmnt factor K_{vT} = 1.0

Wall pressure coefficients

Windward wall C_p = +0.8

75' leeward wall (L/B=0.53) = -0.5

40' leeward wall (L/B=1.875) = -0.325

Tornado internal pressure coefficient

Essential Facility –enclosed (GC_{pi}) = +0.55, -0.18

Table 32.13-1 MWFRS and C&C Tornado Internal Pressure Coefficient, (GC_{piT}), for Enclosed, Partially Enclosed, Partially Open, and Open Buildings and Sealed Other Structures

Enclosure Classification	Tornado Internal Pressure Coefficient, (GC_{piT})
Sealed Other Structures	+1.0
Enclosed buildings	+0.55
	- 0.18
Partially enclosed buildings	+0.55
	- 0.55
Partially open buildings	+0.18
	- 0.18
Open buildings	0.00

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Design Tornado Pressure Equation: Part 4

MWFRS Design Tornado Pressures

$$p_T = q_T G_T K_{dT} K_{vT} C_p - q_{iT}(GC_{piT})$$

Tornado velocity pressure q_{hT} = 22.9 psf

Tornado gust effect factor G_T = 0.85

Tornado directionality factor K_{dT} = 0.8

Tor pr coeff adjustmnt factor K_{vT} = 1.0

Wall pressure coefficients

Windward wall C_p = +0.8

75' leeward wall (L/B=0.53) = -0.5

40' leeward wall (L/B=1.875) = -0.325

Tornado internal pressure coefficient

Essential Facility –enclosed (GC_{pi}) = +0.55, -0.18

WALL DESIGN PRESSURES-TORNADO

Top of Windward wall (- int pr)
p = +16.6 psf

75' Leeward wall (+ int pr)
p = -20.4 psf

40' Leeward wall (+ int pr)
p = -17.6 psf

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Wind Loads vs Tornado Loads

WALL DESIGN PRESSURES – WIND: EXPOSURE C

Top of Windward wall (- int pr)
p = +25.3 psf

75' Leeward wall (+ int pr)
p = -17.8 psf

40' Leeward wall (+ int pr)
p = -13.4 psf

WALL DESIGN PRESSURES - TORNADO

Top of Windward wall (- int pr)
p = +16.6 psf

75' Leeward wall (+ int pr)
p = -20.4 psf

40' Leeward wall (+ int pr)
p = -17.6 psf

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Wind Loads vs Tornado Loads: Part 2

- What if the building would have been in Exposure B?

WALL DESIGN PRESSURES – WIND: EXPOSURE B

Top of Windward wall (- int pr)
p = +17.8 psf

75' Leeward wall (+ int pr)
p = -12.5 psf

40' Leeward wall (+ int pr)
p = -9.4 psf

WALL DESIGN PRESSURES - TORNADO

Top of Windward wall (- int pr)
p = +16.6 psf

75' Leeward wall (+ int pr)
p = -20.4 psf

40' Leeward wall (+ int pr)
p = -17.6 psf

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Tornado Load Example Part I - MWFRS

Questions / Discussion

marc.l.levitan@gmail.com

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Tornado Load Example Part II – C&C

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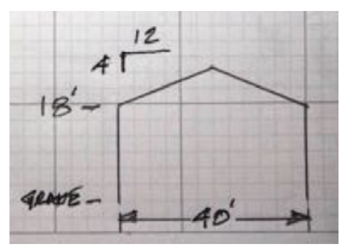
Example – C&C Wind and Tornado Loads

Determine the design wind and tornado pressures for the roof edge purlin shown, using ASCE 7-22

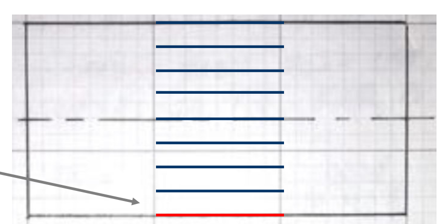
- Office of Emergency Services Call Center
  - Metal Building System
  - Single story, 40’ x 75’ x 18’
  - Wichita, Kansas
  - Site Coordinates
    - Lat = 37.755141, Lon = -97.368928
  - Risk Category IV
  - Essential Facility
  - Mean roof height: h=24.7 ft
  - Flat open terrain: Exposure C in all directions
  - Ground elevation: ≈1340 ft MSL

4/12 roof pitch = 18.4°



Purlins are 25 ft long @ 5 ft o.c.

Edge purlin



Elevation and Plan Views

Graphics courtesy of Mark Detwiler

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Design Wind Pressure Equation (Ch 30): Part 1

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C&C Design Wind Pressure (h<60')

$p = q_h K_d[(GC_p) - (GC_{pi})]$

Velocity pressure q_h = 34.6 psf (from before)

Directionality factor K_d = 0.85

Table 26.6-1 Wind Directionality Factor, K_d

Structure Type	Directionality Factor K_d
Buildings	
Main Wind Force Resisting System	0.85
Components and Cladding	0.85
Arched Roofs	0.85
Circular Domes	1.0[a]
Chimneys, Tanks, and Similar Structures	
Square	0.90
Hexagonal	0.95
Octagonal	1.0[a]
Round	1.0[a]
Solid Freestanding Walls, Roof Top Equipment, and Solid Freestanding and Attached Signs	0.85
Open Signs and Single-Plane Open Frames	0.85
Trussed Towers	
Triangular, square, or rectangular	0.85
All other cross sections	0.95

[a]Directionality factor K_d =0.95 shall be permitted for round or octagonal structures with nonaxisymmetric structural systems.

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Design Wind Pressure Equation (Ch 30): Part 2

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C&C Design Wind Pressure (h<60')

$p = q_h K_d[(GC_p) - (GC_{pi})]$

Velocity pressure q_h = 34.6 psf

Directionality factor K_d = 0.85

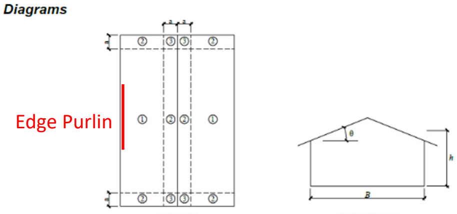
Roof pressure coefficients

Gable Roof with θ = 18.4°

Use Fig. 30.3-2B

Roof zone 1, by inspection

Diagrams



Notation

a = 10% of the least horizontal dimension or $0.4h$, whichever is smaller, but not less than either 4% of the least horizontal dimension or 3 ft (0.9 m). If an overhang exists, the edge distance shall be measured from the outside edge of the overhang. The horizontal dimensions used to compute the edge distance shall not include any overhang dimensions.
B = Horizontal dimension of building measured normal to wind direction, in ft (m).
h = Mean roof height, in ft (m), except that eave height shall be used for $\theta \leq 10°$.
θ = Angle of plane of roof from horizontal, in degrees.

FIGURE 30.3-2B Components and Cladding [h ≤ 60 ft (h ≤ 18.3 m)]: External Pressure Coefficients, (GC_p), for Enclosed, Partially Enclosed, & Partially Open Buildings Gable Roofs, 7° < θ ≤ 20°

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Design Wind Pressure Equation (Ch 30): Part 3

C&C Design Wind Pressure (h<60')

$p = q_h K_d[(GC_p) - (GC_{pi})]$

Velocity pressure q_h = 34.6 psf

Directionality factor K_d = 0.85

Roof pressure coefficients

Effective Wind Area = 25' x 5/2' = 62.5 sq ft

need not be smaller than $L^2/3$ = 208 sq ft

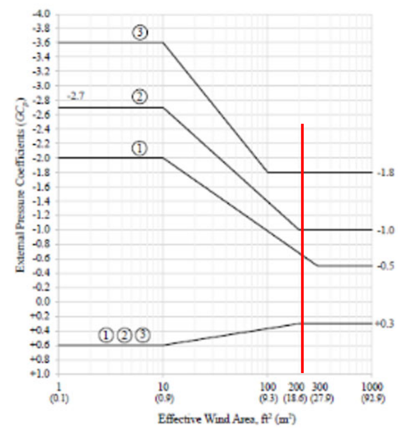
Upward acting (GC_p) = -0.63

Downward acting = +0.3

Internal pressure coefficient

Enclosed Building (GC_{pi}) = 0.18, -0.18

(Table 26.13-1)



Notes
1. Vertical scale denotes (GC_p) to be used with q_h.
2. Horizontal scale denotes effective wind area (EWA), in ft² (m²).
3. Plus and minus signs signify pressures acting toward and away from the surfaces, respectively.
4. Each component shall be designed for maximum positive and negative pressures.
5. Values of (GC_p) for roof overhangs to be determined in accordance with Section 30.7 Roof Overhang

FIGURE 30.3-2B Components and Cladding [h ≤ 60 ft (h ≤ 18.3 m)]: External Pressure Coefficients, (GC_p), for Enclosed, Partially Enclosed, & Partially Open Buildings Gable Roofs, 7° < θ ≤ 20°

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Design Wind Pressure Equation (Ch 30): Part 4

C&C Design Wind Pressure (h<60')

$p = q_h K_d[(GC_p) - (GC_{pi})]$

Velocity pressure q_h = 34.6 psf

Directionality factor K_d = 0.85

Roof pressure coefficients

Effective Wind Area = 25' x 5/2' = 62.5 sq ft

need not be smaller than $L^2/3$ = 208 sq ft

Negative (upward) (GC_p) = -0.63

Positive (downward) = +0.3

Internal pressure coefficient

Enclosed Building (GC_{pi}) = 0.18, -0.18

(Table 26.13-1)

ZONE 1 ROOF PURLIN DESIGN PRESSURES-WIND

Negative, (GC_p) = -0.63, (GC_{pi}) = 0.18

p = -23.8 psf

Positive, (GC_p) = 0.3, (GC_{pi}) = -0.18

~~***p = +14.1 psf***~~

p = +16 psf

Minimum +/- 16 psf per Section 30.2.2

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Design Tornado Pressure Equation: Part 1

C&C Design Tornado Pressures

$$p_T = q_{hT}[K_{dT}K_{vT}(GC_p) - (GC_{piT})]$$

Tor velocity pr (from before) q_{hT} = 22.9 psf

Tor directionality factor K_{dT} = 1.0

Table 32.6-1 Tornado Directionality Factor, K_{dT}

Structure Type	Tornado Directionality Factor K_{dT}
Buildings	
Main Wind Force Resisting System	0.80
Components and Cladding	
For Essential Facilities and for buildings and other structures required to maintain the functionality of Essential Facilities	1.0
Roof Zone 1′ as shown on Figure 30.3-2A	0.90
All other cases	0.75
Arched Roofs, Circular Domes, and All Other Structures	Use value from Table 26.6-1

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Design Tornado Pressure Equation: Part 2

C&C Design Tornado Pressures

$$p_T = q_{hT}[K_{dT}K_{vT}(GC_p) - (GC_{piT})]$$

Tor velocity pr (from before) q_{hT} = 22.9 psf

Tor directionality factor K_{dT} = 1.0

Tor pr coeff adjustment factor

Negative (upward) K_{vT} = 1.2

Positive (downward) = 1.0

Roof pressure coefficients

Negative (upward) (GC_p) = -0.63

Positive (downward) = +0.3

Tornado internal pressure coefficient

Essential Facility –enclosed (GC_{pi}) = +0.55, -0.18

STRUCTURE TYPE	K_{vT}
Buildings	
Negative (Uplift) Pressures on Roofs	
Main Wind Force Resisting System	1.1
Components and Cladding	
Roof Slope <=7 degrees	
Zone 1	1.2
Zone 2	1.05
Zone 3	1.05
Roof Slope > 7 degrees	
Zone 1	1.2
Zone 2	1.2
Zone 3	1.3
Positive Pressures (Downward acting) on Roofs	1.0
Wall Pressures	1.0
All Other Cases	1.0

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Design Tornado Pressure Equation: Part 3

C&C Design Tornado Pressures

$$p_T = q_{hT}[K_{dT}K_{vT}(GC_p) - (GC_{piT})]$$

Tor velocity pr (from before) q_{hT} = 22.9 psf

Tor directionality factor K_{dT} = 1.0

Tor pr coeff adjustment factor

Negative (upward) K_{vT} = 1.2

Positive (downward) = 1.0

Roof pressure coefficients

Negative (upward) (GC_p) = -0.63

Positive (downward) = +0.3

Tornado internal pressure coefficient

Essential Facility –enclosed (GC_{pi}) = +0.55, -0.18

ZONE 1 ROOF PURLIN DESIGN PRESSURES-TORNADO

Negative

K_{vT} = 1.2, (GC_p) = -0.63, (GC_{pi}) = 0.55

p = -29.9 psf

Positive

K_{vT} = 1.0, (GC_p) = 0.3, (GC_{pi}) = -0.18

p = +11.0 psf

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Wind Loads vs Tornado Loads

- Building in Exposure C

ZONE 1 ROOF PURLIN DESIGN PRESSURES-WIND

Negative

p = -23.8 psf

Positive

p = +16 psf

ZONE 1 ROOF PURLIN DESIGN PRESSURES-TORNADO

Negative

p = -29.9 psf

Positive

p = +11.0 psf

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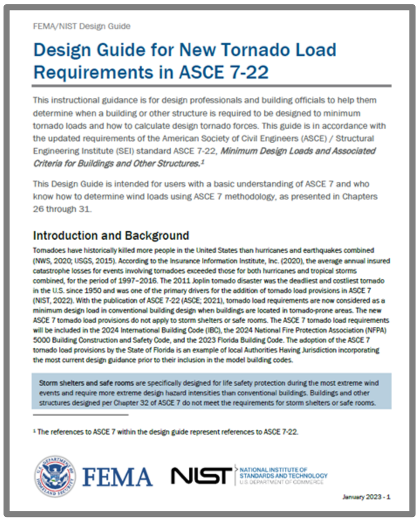
More Example Load Calculations



FEMA/NIST Design Guide

Design Guide for New Tornado Load Requirements in ASCE 7-22

This instructional guidance 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.***[1]

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.

Introduction and Background

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, for the period of 1997–2016. 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.

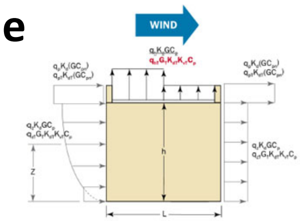
[1] The references to ASCE 7 within the design guide represent references to ASCE 7-22.

FEMA NIST NATIONAL INSTITUTE OF STANDARDS AND TECHNOLOGY U.S. DEPARTMENT OF COMMERCE

January 2023 - 1

FEMA/NIST Design Guide

- Overview of tornado load provisions
- Differences between tornado loads and wind loads
- Example calculations, including comparisons to wind loads



Elevation

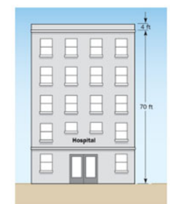


Figure 9: Elevation view of example hospital

NCSEA Resources – Worked Example Problems

Tornado Loads – Schools

Tornado Loads - Hospital

https://tsapps.nist.gov/publication/get_pdf.cfm?pub_id=935883

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Tornado Load Example Part II – C&C

Questions / Discussion

marc.l.levitan@gmail.com

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ASCE | KNOWLEDGE & LEARNING

Tornado Load Combinations

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Load Combinations

- Load Combination Equations
  - Review ASCE 7-16 Wind equations
  - Changes for ASCE 7-22 Wind
  - Changes for ASCE 7-22 Tornado

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ASCE | KNOWLEDGE & LEARNING — ASCE 7-16 Load Combinations: Part 1

Chapter 2: COMBINATIONS OF LOADS

2.2 SYMBOLS

	Roof Loads
D = Dead Load	L_r = Roof Live Load
L = Live Load	S = Snow Load
W = Wind Load	R = Rain Load

2.3 LOAD COMBINATIONS FOR STRENGTH DESIGN
2.3.1 Basic Combinations

1a. 1.4D
2a. 1.2D + 1.6L + 0.5(L_r or S or R)
3a. 1.2D + 1.6(L_r or S or R) + (L or 0.5W)
4a. 1.2D + 1.0W + L + 0.5(L_r or S or R)
} Maximize loads in gravity direction

5a. 0.9D + 1.0W } Maximize uplift loads

ASCE 7-16 Wind Provisions

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ASCE | KNOWLEDGE & LEARNING — ASCE 7-16 Load Combinations: Part 2

Chapter 2: COMBINATIONS OF LOADS

2.2 SYMBOLS

	Roof Loads
D = Dead Load	L_r = Roof Live Load
L = Live Load	S = Snow Load
W = Wind Load	R = Rain Load

XX Principal Load - Maximum lifetime value

YY Arbitrary point-in-time value

Effects of one or more loads not acting shall also be considered

2.3 LOAD COMBINATIONS FOR STRENGTH DESIGN
2.3.1 Basic Combinations

1a. 1.4D
2a. 1.2D + 1.6L + 0.5(L_r or S or R)
3a. 1.2D + 1.6(L_r or S or R) + (L or 0.5W)
4a. 1.2D + 1.0W + L + 0.5(L_r or S or R)
} Maximize loads in gravity direction

5a. 0.9D + 1.0W } Maximize uplift loads

ASCE 7-16 Wind Provisions

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ASCE 7-22 Load Combinations: SNOW

Chapter 2: COMBINATIONS OF LOADS

2.2 SYMBOLS

D = Dead Load
L = Live Load
W = Wind Load

Roof Loads
Lr = Roof Live Load
S = Snow Load
R = Rain Load

Snow loads moved to strength-level in ASCE 7-22, with corresponding changes to load factors

(Tornado Load Changes not shown here)

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 + 1.0W + L + (0.5L_r or 0.3S or 0.5R)
5a. 0.9D + 1.0W

(1a–4a) Maximize loads in gravity direction

(5a) Maximize uplift loads

ASCE 7-22 Wind Provisions

Tornado Load Combinations: Part 1

Chapter 2: COMBINATIONS OF LOADS

Snow loads moved to strength-level w/ corresponding changes to load factors

Tornado loads are completely separate from wind loads, not a subset of wind

2.2 SYMBOLS

…
W = Wind Load
W_T = Tornado Load determined in accordance with Chapter 32

Tornado loads are only applicable to combinations *maximizing* wind loads (4a and 5a)
- No 'arbitrary point-in-time' tornado loads

2.3 LOAD COMBINATIONS FOR STRENGTH DESIGN
2.3.1 Basic Combinations

No (W or W_T) here

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)

(1a–4a) Maximize loads in gravity direction

(5a) Maximize uplift loads

Similar changes to ASD combinations that maximize wind loads, replace "W" with "(W or W_T)" in combos 5, 6, and 7

Tornado Load Combinations: Part 2

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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)

EXCEPTIONS

3. Where using W_T in combination 4a, (0.5Lr or 0.3S or 0.5R) is permitted to be replaced with 0.5(L_r or R).

W_T is not used with load combinations including snow and ice, since tornadoes are overwhelmingly a warm-weather phenomenon

W_T is not used with load combinations including flooding, since the spatio-temporal correlation between tornadoes and flooding is much less than hurricanes / other windstorms and flooding

The most unfavorable effects from wind loads, tornado loads, and earthquake loads shall be considered, where appropriate, but they need not be assumed to act simultaneously

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Tornado Load Combinations: Part 3

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2.4 LOAD COMBINATIONS FOR ALLOWABLE STRESS DESIGN
2.4.1 Basic Combinations

1a. D

2a. D + L

3a. D + (L_r or 0.7S or R)

4a. D + 0.75L + 0.75(L_r or 0.7S or R)

5a. D + 0.6 (W or W_T)

6a. D + 0.75L + 0.75(0.6 (W or W_T)) +0.75(L_r or 0.7S or R)

(1a–6a: Maximize loads in gravity direction)

7a. 0.6D + 0.6 (W or W_T)

(7a: Maximize uplift loads)

EXCEPTIONS

3. Where using W_T in combination 6a, 0.75(Lr or 0.7S or R) is permitted to be replaced with 0.75(L_r or R).

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Tornado Load Combinations

Questions / Discussion

marc.l.levitan@gmail.com

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NWS Flagstaff SKYWARN Storm Spotter Program

Dust devil in the Valley on a clear and hot day. Note the lack of clouds.	Funnel clouds **do not** connect with the ground and remain only attached to a cloud.	Tornado in the Little Colorado River valley. Note the cloud to ground funnel needed for a tornado.

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Tornado Load Example Part III – Load Combinations

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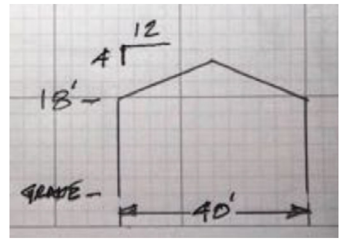
Example – Load Combinations

Determine the controlling loads for the roof edge purlin using Strength and ASD load combinations

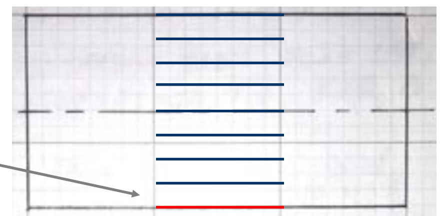
- Office of Emergency Services Call Center
  - Metal Building System
  - Single story, 40' x 75' x 18'
  - Wichita, Kansas
  - Site Coordinates
    - Lat = 37.755141, Lon = -97.368928
  - Risk Category IV
  - Essential Facility
  - Mean roof height: h=24.7 ft
  - Flat open terrain: Exposure C in all directions
  - Ground elevation: ≈1340 ft MSL

4/12 roof pitch = 18.4°



Purlins are 25 ft long @ 5 ft o.c.

Edge purlin



Elevation and Plan Views

Graphics courtesy of Mark Detwiler

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Strength Load Combinations

Chapter 2: COMBINATIONS OF LOADS

2.2 SYMBOLS

D = Dead Load
L = Live Load
W = Wind Load
W_T = Tornado Load

Roof Loads
L_r = Roof Live Load
S = Snow Load
R = Rain Load

EXCEPTIONS

3. Where using W_T in combination 4a, (0.5Lr or 0.3S or 0.5R) is permitted to be replaced with $0.5(L_r$ or R).

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)

Maximize loads in gravity direction

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

Maximize uplift loads

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Emergency Services Call Center Roof Loads

LOADS (in psf)

D = 15
L = 0 (for roof)
W = -23.8 and + 16.0
W_T = -29.9 and +11.0

Roof Loads
L_r = 20
S = 0
R = 0

Snow Load

Ground snow load from Hazard tool
p_g = 28 psf

New in ASCE 7-22

7.2 The snow load provisions of this chapter need not be considered for roofs or roof members with no potential for drift accumulation or unbalanced snow loading where the ground snow load, p_g, is less than the factored roof live load used in design

Factored roof live load:

*1.6 L_r = 1.6*20 = 32 psf, which is > p_g*

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Purlin Design Loads – Strength Design

LOADS (PSF)

D = 15
L = 0
W = -23.8 and + 16.0
W_T = -29.9 and +11.0

Roof Loads
L_r = 20
S = 0
R = 0

Strength Design Loads
+58.0 psf (controlled by L_r)
-16.4 psf (controlled by W_T)

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)

1a. 1.4 (15) = 21.0
2a. -
3a. 1.2(15) + 1.6(20)+ 0.5(16) = 58.0
4a. 1.2(15) + 1.0(16)+ 0.5(20) = 44.0
5a. 0.9(15) + 1.0(-29.9) = -16.4

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Purlin Design Loads – ASD

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LOADS (PSF)

D = 15
L = 0
W = -23.8 and + 16.0
W_T = -29.9 and +11.0

Roof Loads
L_r = 20
S = 0
R = 0

ASD Loads
+37.2 psf (controlled by W)
-8.9 psf (controlled by W_T)

2.4 LOAD COMBINATIONS FOR ASD

1a. D	1a. 15 = 15.0
~~2a. D + L~~	2a. -
3a. D + (L_r)	3a. 15 + 20 = 35.0
~~4a. D + 0.75L + 0.75(L_r)~~	4a. -
5a. D + 0.6 (W or W_T)	5a. 15 + 0.6 (16) = 24.6
6a. D + 0.75L + 0.75(0.6 (W or W_T)) +0.75(L_r)	6a. 15 + 0.75(0.6 (16)) +0.75(20) = 37.2
7a. 0.6D + 0.6 (W or W_T)	7a. 0.6(15) + 0.6 (-29.9) = -8.9

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Tornado Load Example Part III – Load Combinations

Questions / Discussion

marc.l.levitan@gmail.com

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Tornado Loads vs Wind Loads – Where Each Controls

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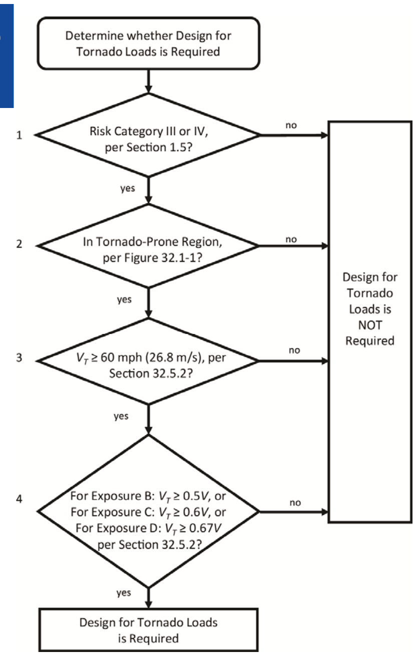
Where Design for Tornado Loads is Not Required

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



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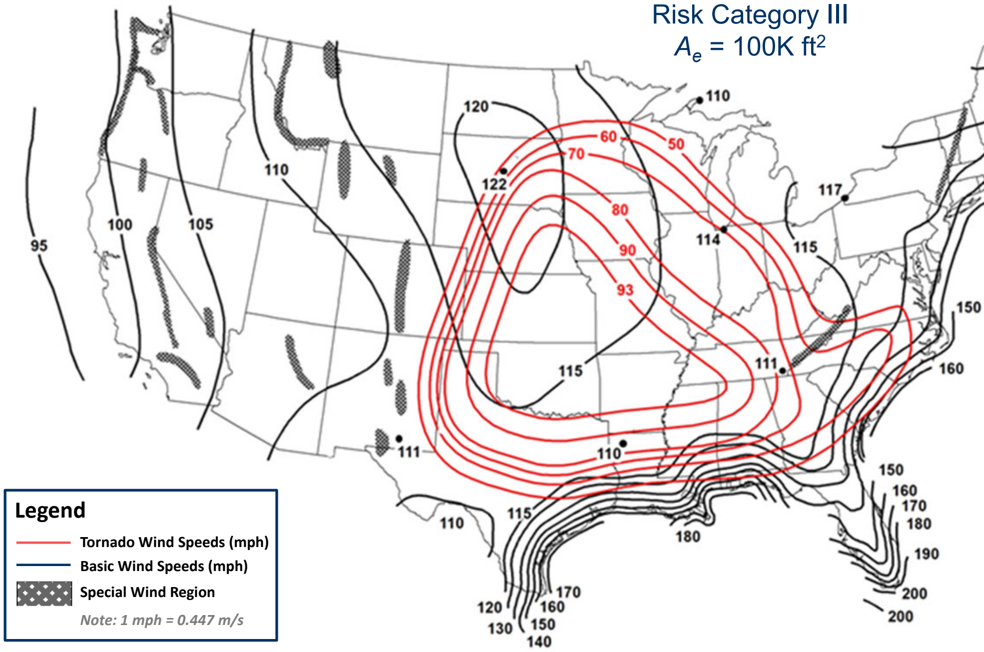
Comparing Design Tornado Speeds and Basic Wind Speeds

Risk Category III

A_e = 100K ft^2



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

Credit: NIST

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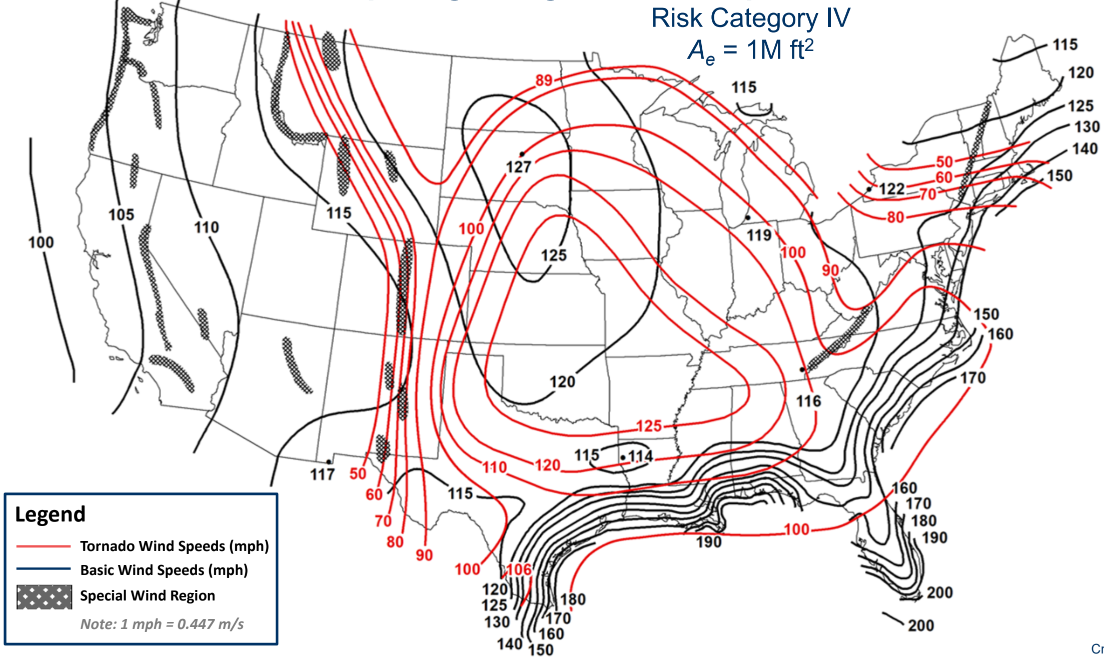
Comparing Design Tornado Speeds and Basic Wind Speeds

Risk Category IV

A_e = 1M ft^2



Credit: NIST

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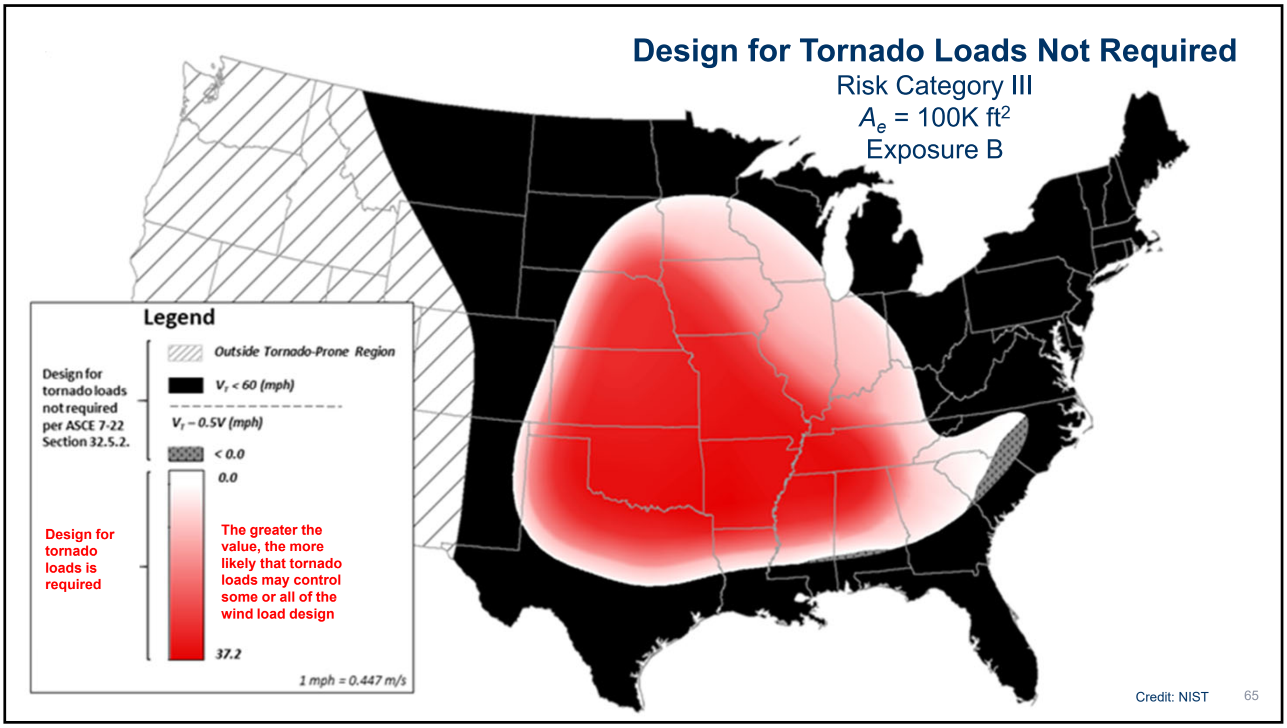
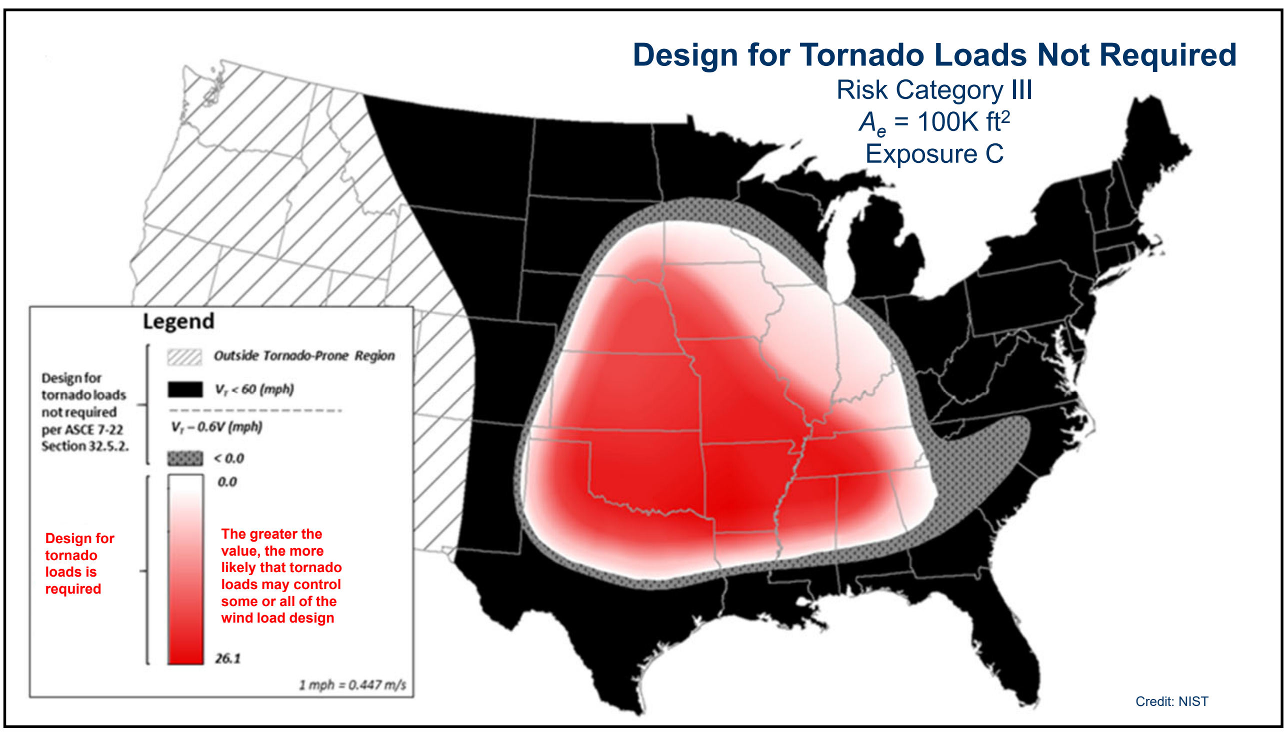
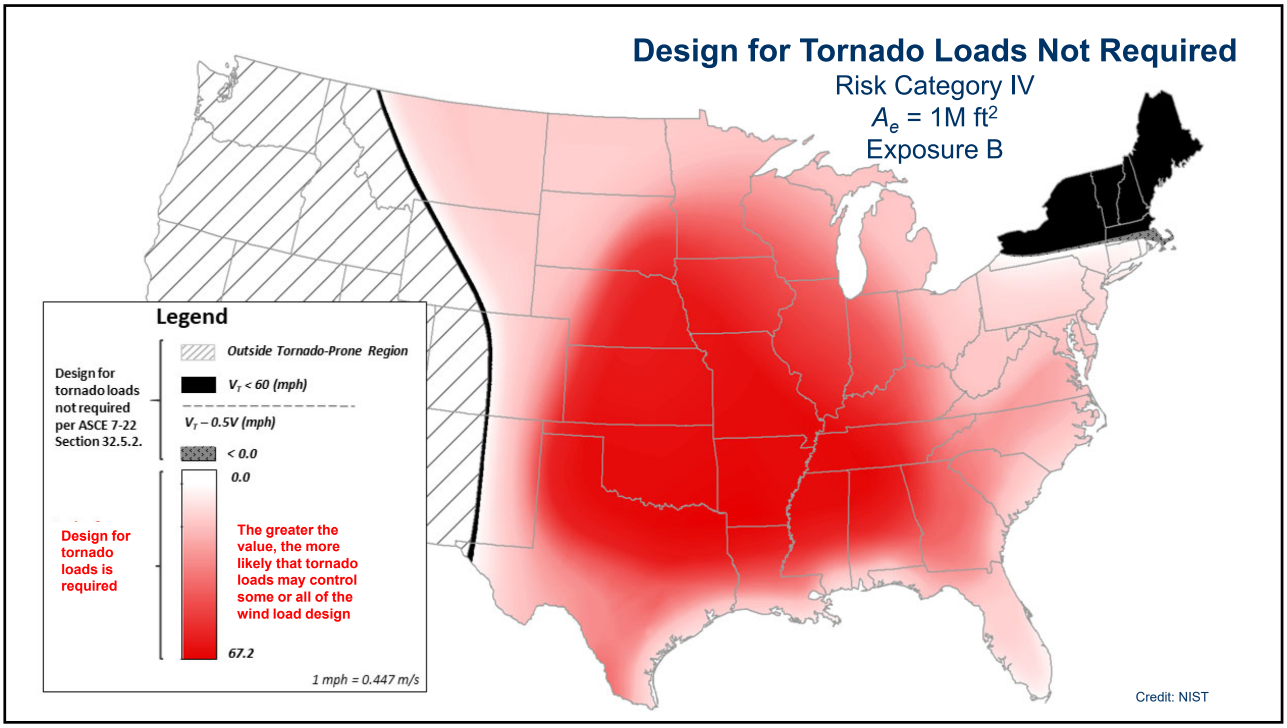

Design for Tornado Loads Not Required
Risk Category III
A_e = 100K ft^2
Exposure B
Legend
Outside Tornado-Prone Region
$V_T < 60$ (mph)
$V_T - 0.5V$ (mph)
< 0.0
0.0
37.2
Design for tornado loads not required per ASCE 7-22 Section 32.5.2.
Design for tornado loads is required
The greater the value, the more likely that tornado loads may control some or all of the wind load design
1 mph = 0.447 m/s
Credit: NIST
65

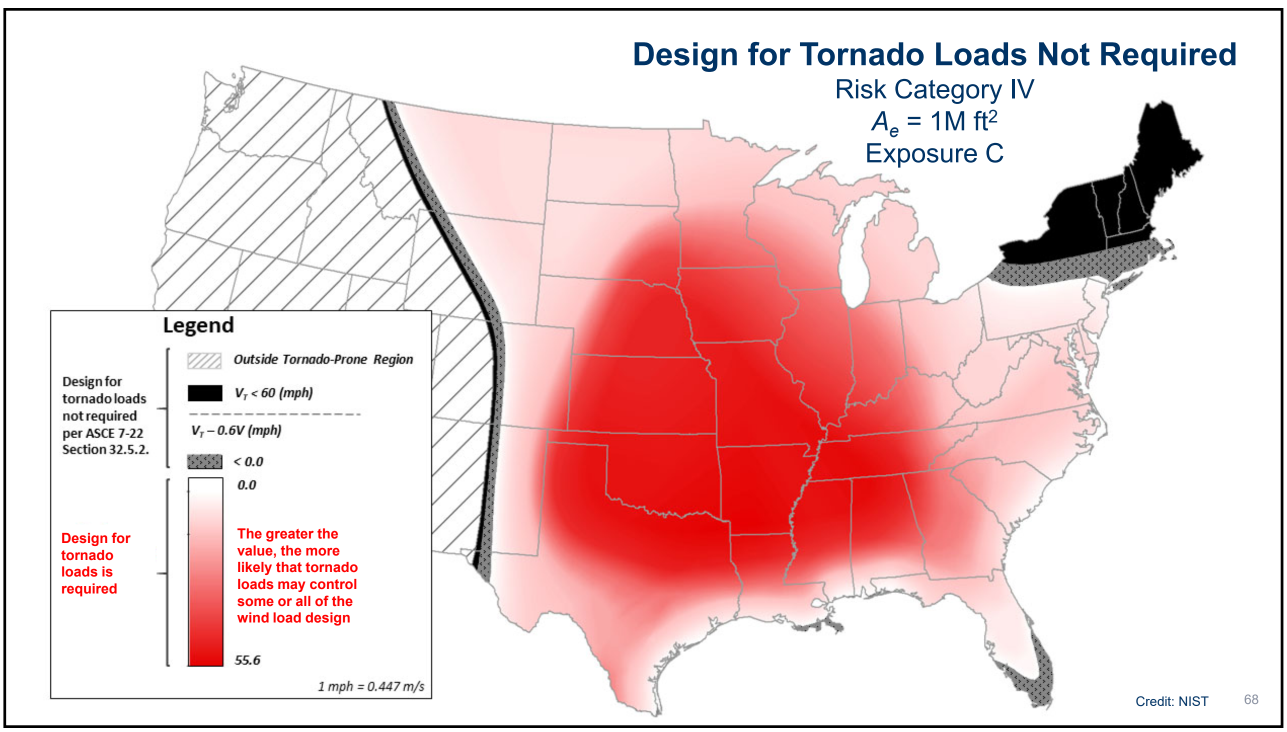
65


Design for Tornado Loads Not Required
Risk Category III
A_e = 100K ft^2
Exposure C
Legend
Outside Tornado-Prone Region
$V_T < 60$ (mph)
$V_T - 0.6V$ (mph)
< 0.0
0.0
26.1
Design for tornado loads not required per ASCE 7-22 Section 32.5.2.
Design for tornado loads is required
The greater the value, the more likely that tornado loads may control some or all of the wind load design
1 mph = 0.447 m/s
Credit: NIST

66


Design for Tornado Loads Not Required
Risk Category IV
A_e = 1M ft^2
Exposure B
Legend
Outside Tornado-Prone Region
V_T < 60 (mph)
V_T – 0.5V (mph)
< 0.0
0.0
67.2
Design for tornado loads not required per ASCE 7-22 Section 32.5.2.
Design for tornado loads is required
The greater the value, the more likely that tornado loads may control some or all of the wind load design
1 mph = 0.447 m/s
Credit: NIST

67


Design for Tornado Loads Not Required
Risk Category IV
A_e = 1M ft^2
Exposure C
Legend
Outside Tornado-Prone Region
V_T < 60 (mph)
V_T – 0.6V (mph)
< 0.0
0.0
55.6
Design for tornado loads not required per ASCE 7-22 Section 32.5.2.
Design for tornado loads is required
The greater the value, the more likely that tornado loads may control some or all of the wind load design
1 mph = 0.447 m/s
Credit: NIST
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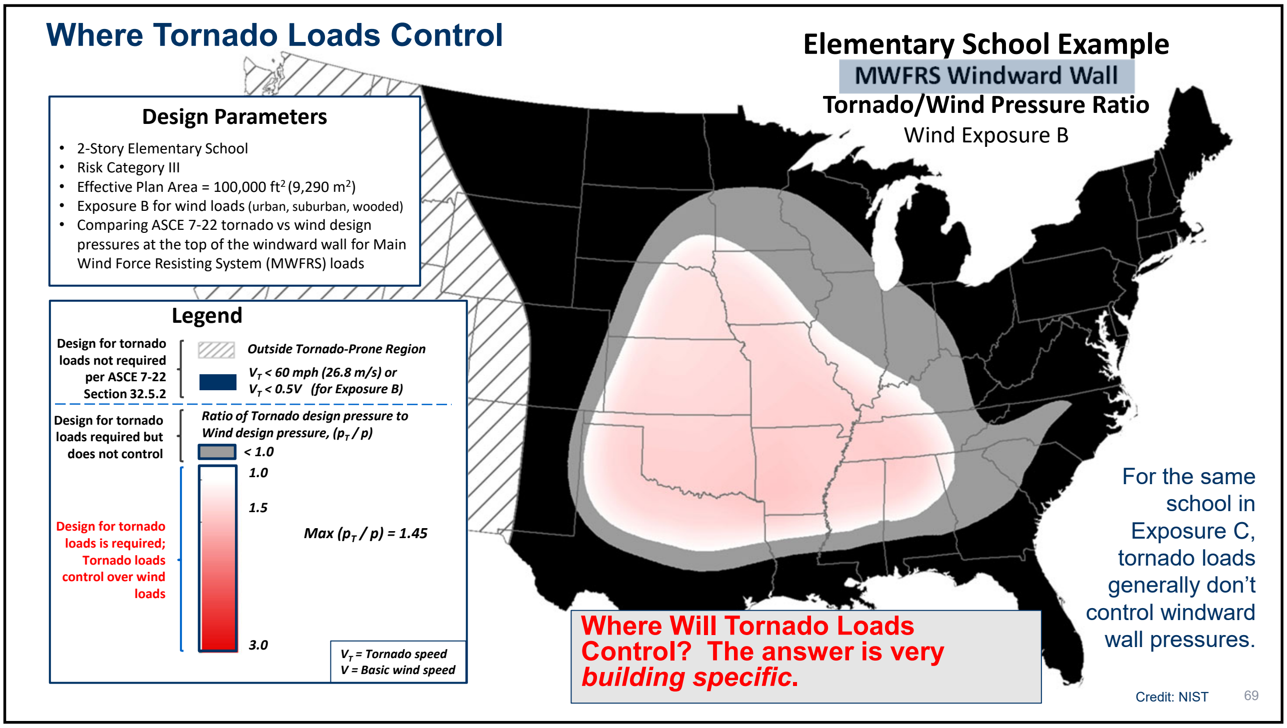
Where Tornado Loads Control
Design Parameters
• 2-Story Elementary School
• Risk Category III
• Effective Plan Area = 100,000 ft² (9,290 m²)
• Exposure B for wind loads (urban, suburban, wooded)
• Comparing ASCE 7-22 tornado vs wind design pressures at the top of the windward wall for Main Wind Force Resisting System (MWFRS) loads
Legend
Design for tornado loads not required per ASCE 7-22 Section 32.5.2
Outside Tornado-Prone Region
V_T < 60 mph (26.8 m/s) or V_T < 0.5V (for Exposure B)
Design for tornado loads required but does not control
Ratio of Tornado design pressure to Wind design pressure, (p_T / p)
< 1.0
1.0
1.5
3.0
Design for tornado loads is required; Tornado loads control over wind loads
Max (p_T / p) = 1.45
V_T = Tornado speed
V = Basic wind speed
Elementary School Example
MWFRS Windward Wall
Tornado/Wind Pressure Ratio
Wind Exposure B
For the same school in Exposure C, tornado loads generally don't control windward wall pressures.
Where Will Tornado Loads Control? The answer is very building specific.
Credit: NIST
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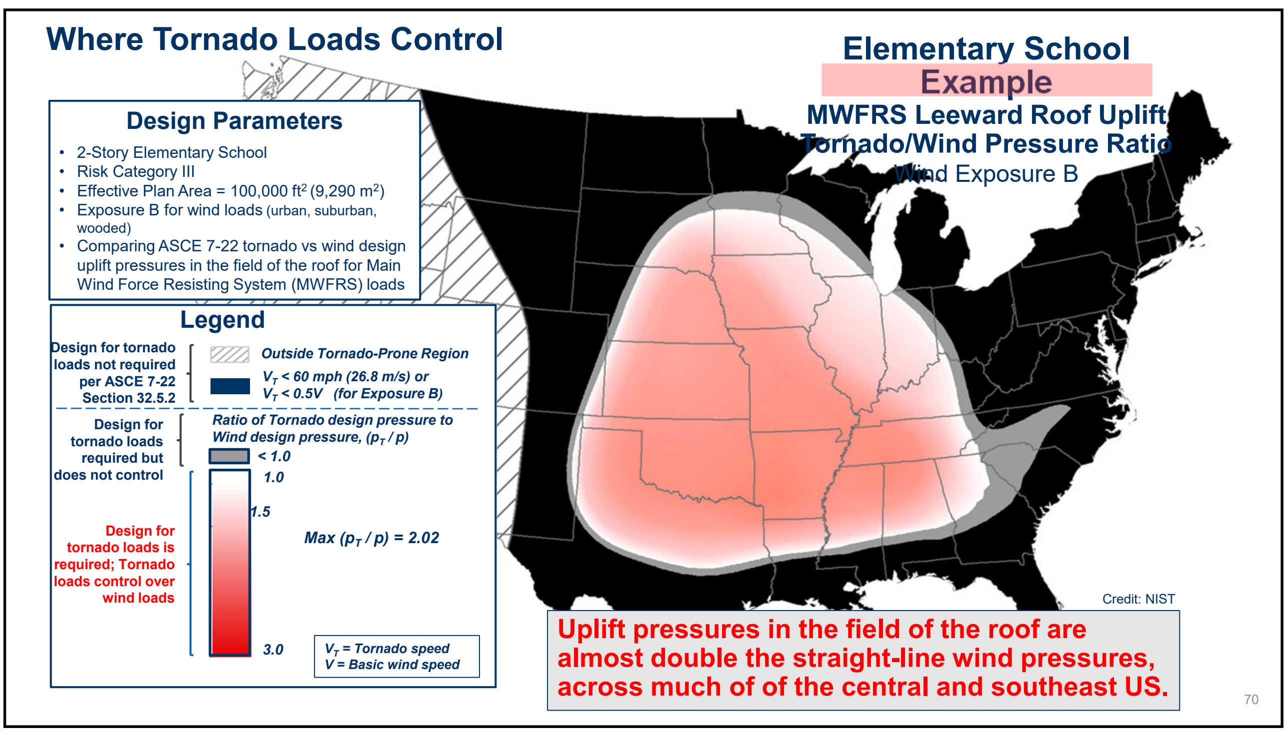
Where Tornado Loads Control
Design Parameters
• 2-Story Elementary School
• Risk Category III
• Effective Plan Area = 100,000 ft² (9,290 m²)
• Exposure B for wind loads (urban, suburban, wooded)
• Comparing ASCE 7-22 tornado vs wind design uplift pressures in the field of the roof for Main Wind Force Resisting System (MWFRS) loads
Legend
Design for tornado loads not required per ASCE 7-22 Section 32.5.2
Outside Tornado-Prone Region
V_T < 60 mph (26.8 m/s) or V_T < 0.5V (for Exposure B)
Design for tornado loads required but does not control
Ratio of Tornado design pressure to Wind design pressure, (p_T / p)
< 1.0
1.0
1.5
3.0
Design for tornado loads is required; Tornado loads control over wind loads
Max (p_T / p) = 2.02
V_T = Tornado speed
V = Basic wind speed
Elementary School Example
MWFRS Leeward Roof Uplift
Tornado/Wind Pressure Ratio
Wind Exposure B
Credit: NIST
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.
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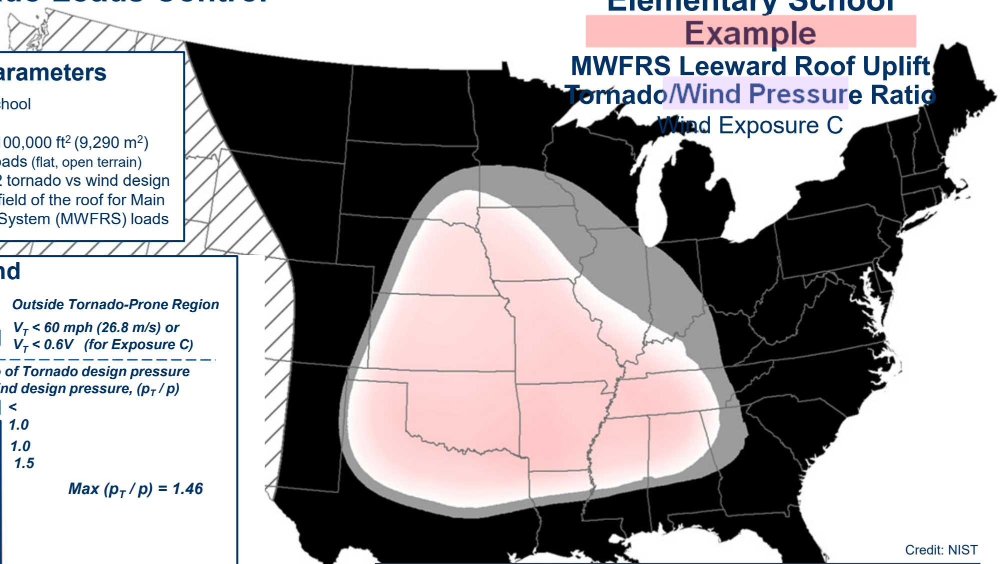
Where Tornado Loads Control

Elementary School Example
MWFRS Leeward Roof Uplift
Tornado/Wind Pressure Ratio
Wind Exposure C

Design Parameters
- 2-Story Elementary School
- Risk Category III
- Effective Plan Area = 100,000 ft^2 (9,290 m^2)
- Exposure C for wind loads (flat, open terrain)
- Comparing ASCE 7-22 tornado vs wind design uplift pressures in the field of the roof for Main Wind Force Resisting System (MWFRS) loads



Legend
Design for tornado loads not required per ASCE 7-22 Section 32.5.2
- *Outside Tornado-Prone Region*
- *V_T < 60 mph (26.8 m/s) or V_T < 0.6V (for Exposure C)*

Design for tornado loads required but does not control
Ratio of Tornado design pressure to Wind design pressure, (p_T / p)
- < 1.0

Design for tornado loads is required; Tornado loads control over wind loads
- 1.0
- 1.5
- 3.0

Max (p_T / p) = 1.46

V_T = Tornado speed
V = Basic wind speed

Credit: NIST

The relative increase in tornado uplift pressure compared to wind pressure for Exposure C is about half of Exposure B value.

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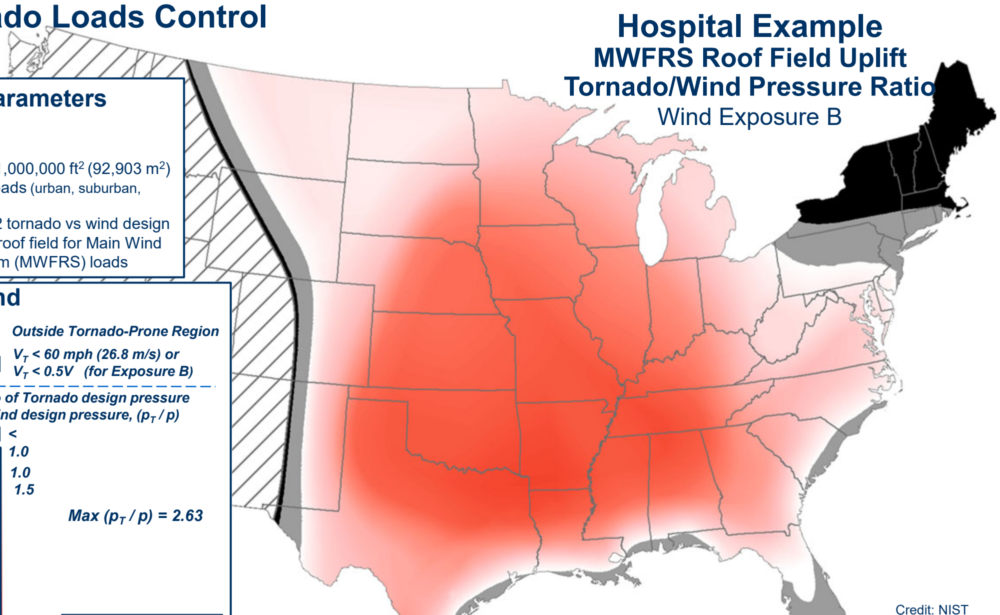
Where Tornado Loads Control

Hospital Example
MWFRS Roof Field Uplift
Tornado/Wind Pressure Ratio
Wind Exposure B

Design Parameters
- 5-Story Hospital
- Risk Category IV
- Effective Plan Area = 1,000,000 ft^2 (92,903 m^2)
- Exposure B for wind loads (urban, suburban, wooded)
- Comparing ASCE 7-22 tornado vs wind design uplift pressures in the roof field for Main Wind Force Resisting System (MWFRS) loads



Legend
Design for tornado loads not required per ASCE 7-22 Section 32.5.2
- *Outside Tornado-Prone Region*
- *V_T < 60 mph (26.8 m/s) or V_T < 0.5V (for Exposure B)*

Design for tornado loads required but does not control
Ratio of Tornado design pressure to Wind design pressure, (p_T / p)
- < 1.0

Design for tornado loads is required; Tornado loads control over wind loads
- 1.0
- 1.5
- 3.0

Max (p_T / p) = 2.63

V_T = Tornado speed
V = Basic wind speed

Credit: NIST

Tornadoes will control uplift in the field of the roof over most of the eastern 2/3 of the US, for this specific hospital building.

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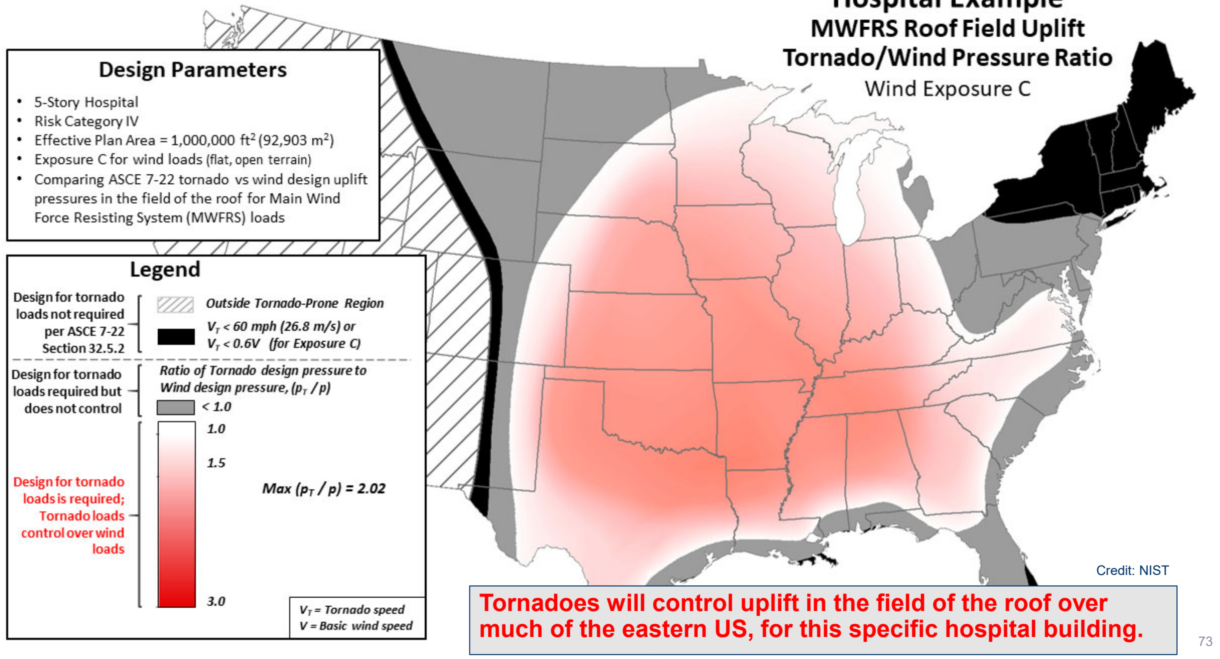
Where Tornado Loads Control



Tornadoes will control uplift in the field of the roof over much of the eastern US, for this specific hospital building.

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Where Tornado Loads are Likely to Control

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- 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

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

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Tornado Loads vs Wind Loads – Where Each Controls

Questions / Discussion

marc.l.levitan@gmail.com

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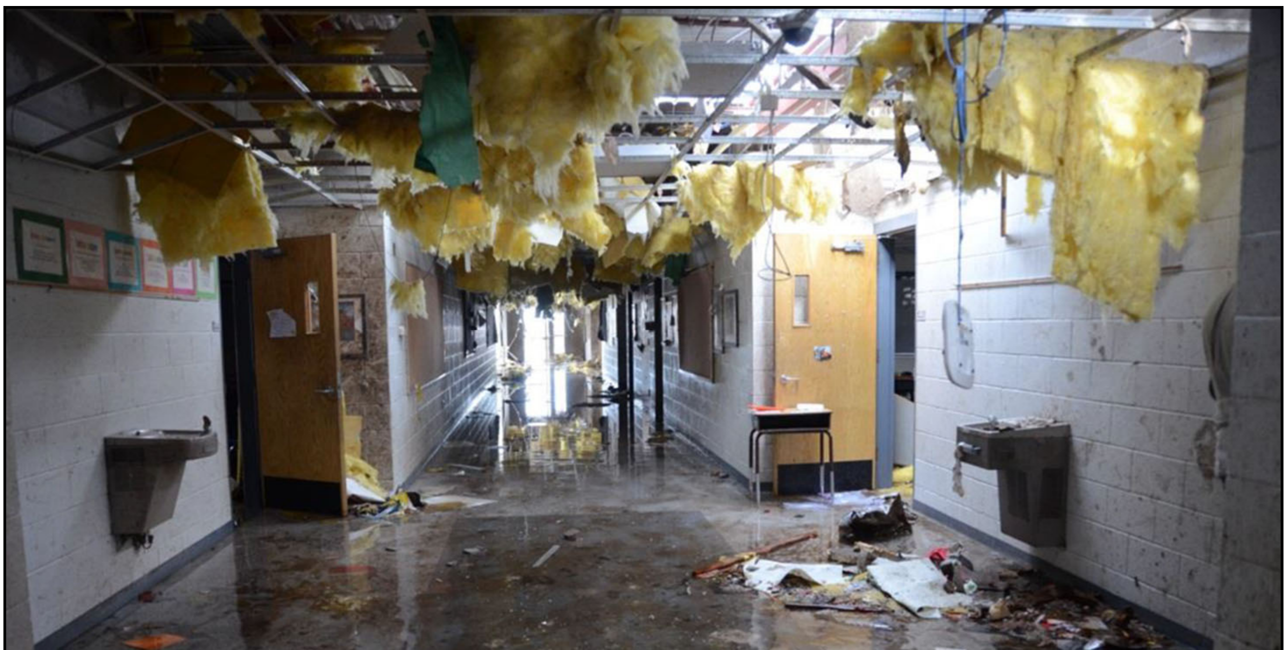

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Model Building Codes and Cost Impacts

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Incorporation in Model Codes

Credit: NOAA/OAR/ERL/NSSL

- **2024 International Building Code**
  - Proposal S63 (pp S175-191) in Structural Monograph
    - Hearing video
    - IBC Structural Committee voted 14-0 to approve
    - No public comments submitted
    - Publication in fall of 2023
  - ASCE 7-22 tornado loads incorporated by reference
  - Additional provisions for tornado loads on roof tiles
  - Limitations on application of certain simplified IBC wind provisions to tornado loads
- **2024 NFPA 5000 Building Construction and Safety Code**
  - ASCE 7-22 tornado loads incorporated by reference
  - Extremely limited adoption in the US

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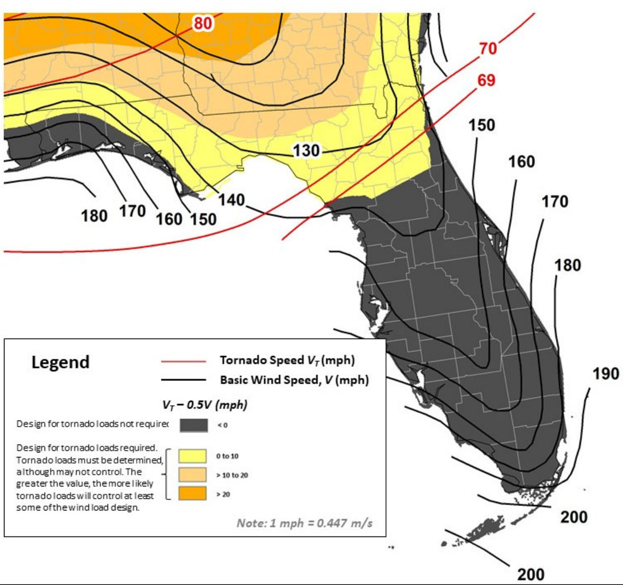
First State/Local Adoption



Comparison of ASCE 7-22 Tornado Speeds and Wind Speeds, and Where Tornado Loads are Required, for

- Risk Category III Building or Structure
- Effective Plan Area = 250,000 ft^2
- Exposure B

2023 Florida Building Code

- Tornado loads approved by the Florida Building Commission in December 2022
- Comparatively limited impacts due to combination of high hurricane speeds and low tornado speeds

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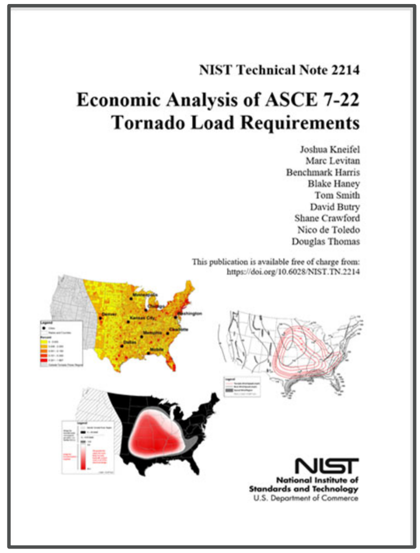
- **Estimated % of new buildings impacted by tornado load requirements**
- **Comparisons of tornado loads vs wind loads**
  - Elementary and high school, fire station, hospital examples
  - Tornado loads can increase wind loads by >100%, particularly in Exposure B and where wind pressures are smallest magnitude – field of the roof, leeward wall
- **Impacts on Roof System Design**
  - Typically modest increases in fasteners, adhesives, pressure ratings
- **Estimated cost increases for tornado loads**
  - Typically <0.15% of total construction costs

Estimated Cost Impacts from Tornado Loads – High School

Cost Item	Charl.	Chicago	Minn.	DFW		Kansas City		Memphis	
	B	B	B	B	C	B	C	B	C
Roof Fasteners	$0	$0	$0	$300	$0	$11 943	$0	$8294	$0
Diaph.	$0	$0	$0	$0	$0	$0	$0	$0	$0
Joists & WF	$0	$165 023	$0	$139 778	$8495	$137 401	$8350	$140 616	$8546
Wall Frame	$0	$0	$0	$90 000	$0	$70 020	$0	$87 480	$0
Found. Anchor.	$2391	$20 835	$12 675	$20 000	$15 574	$16 160	$13 738	$19 140	$19 140
Total	**$2391**	**$185 857**	**$12 675**	**$250 077**	**$24 069**	**$235 525**	**$22 088**	**$255 530**	**$27 686**
Budget ($million)	$200.45	$280.68	$248.64	$200.00	$200.00	$198.64	$198.64	$222.73	$222.73
Pct of Budget	**0.001 %**	**0.07 %**	**0.005 %**	**0.13 %**	**0.01 %**	**0.12 %**	**0.01 %**	**0.11 %**	**0.01 %**
Note: Exposures not displayed had zero cost impacts from tornado loads									


NIST Technical Note 2214

Economic Analysis of ASCE 7-22 Tornado Load Requirements

Joshua Kneifel
Marc Levitan
Benchmark Harris
Blake Haney
Tom Smith
David Butry
Shane Crawford
Nico de Toledo
Douglas Thomas

This publication is available free of charge from: https://doi.org/10.6028/NIST.TN.2214

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

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Tornado Load Impacts on Studied Roofing System Construction, by Location and Exposure

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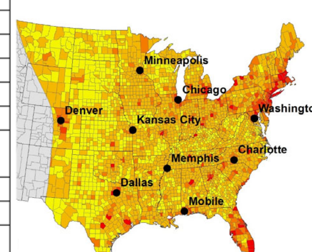
Building Type	Roof Construction	Cities	Exposure (Zones)	Construction Design Change
High School	steel roof deck, mechanically attached membrane	Memphis, Kansas City	B (2 & 3)	Additional membrane fasteners
		DFW	B	Additional membrane fasteners
Fire Station	structural standing seam metal panel system	Memphis, Kansas City, & DFW	B (all zones)	panel rib spacing is reduced
Hospital	steel roof deck, adhered roof system	Memphis, Kansas City, & DFW	B (all zones)	Additional insulation board fasteners
			B (1, 2)	Additional foam ribbon adhesive
			C (all zones)	Additional insulation board fasteners
			C (Zone 1)	Additional foam ribbon adhesive
		Chicago	B (Zone 1-3)	Additional insulation board fasteners
			B (Zone 1 & 2)	additional foam ribbon adhesive
			C (zone 1)	Additional insulation board fasteners & foam ribbon adhesive
		Minneapolis	B (Zone 1-3)	Additional insulation board fasteners
			B (Zone 2)	additional foam ribbon adhesive
		Charlotte	B (zone 1)	Additional insulation board fasteners & foam ribbon adhesive
Note 1: No impact for any location or exposure for elementary school (fully adhered membrane over steel roof deck) or hospital with concrete roof deck (adhered roof system). Note 2: No impact for all other locations, exposures, and zones for high school, fire station or hospital with steel roof deck.				

Compared Loads and Impacts to Roof System Design at 9 cities in the Tornado Prone Region



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Model Building Codes and Cost Impacts

Questions / Discussion

marc.l.levitan@gmail.com

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Summary

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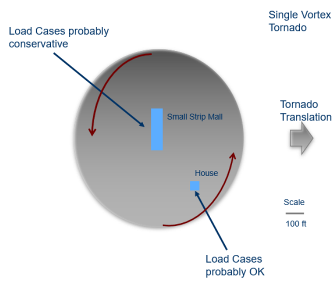
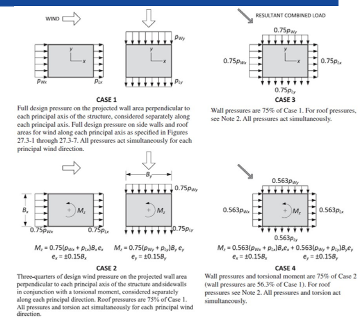
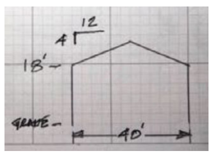
Unit 4: Summary Part 1

- MWFRS Load Cases
  - Same as for Chapter 27, except
    - No exception to skip torsion loads
  - Likely conservative, especially combination of large building and small tornado
- Examples of determination of wind pressure for
  - MWFRS
  - C&C







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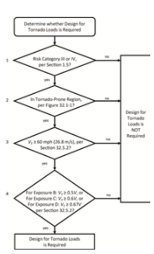
Unit 4: Summary Part 2

- Load Combinations
  - Combos that maximize wind load replace "*W*" with "(*W* or W_T)"
  - W_T not used in combinations where
    - W is an arbitrary point-in-time load
    - In combinations with snow and ice loads
    - In combinations with flood load
- Examples for applications of load combinations
- Where Tornado Loads Control



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)
} Maximize loads in gravity direction

5a. 0.9D + 1.0(W or W_T)
} Maximize uplift loads

2.4 LOAD COMBINATIONS FOR ALLOWABLE STRESS DESIGN
2.4.1 Basic Combinations

1a. D
2a. D + L
3a. D + (L_r or 0.7S or R)
4a. D + 0.75L + 0.75(L_r or 0.7S or R)
5a. D + 0.6 (W or W_T)
6a. D + 0.75L + 0.75(0.6 (W or W_T)) +0.75(L_r or 0.7S or R)
} Maximize loads in gravity direction

7a. D + 0.6 (W or W_T)
} Maximize uplift loads

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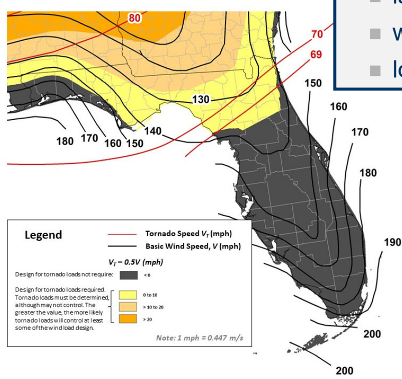
Unit 4: Summary Part 3

Movement of Tornado Loads into Practice

- Model Codes
  - 2024 IBC
  - 2024 NFPA 5000
- State/Local Adoptions
  - 2023 FBC
- Modest cost impacts

- Tornado loads more likely to control
  - locations in central/southeast US
  - Risk Category IV
  - Essential Facilities
  - large effective plan areas
  - wind Exposure B
  - low mean roof height



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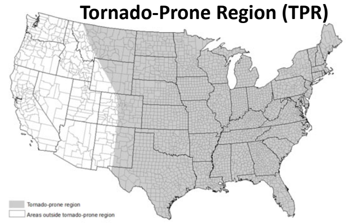
Units 1-4: Summary

IMPACTS SUMMARY

- Risk Category III/IV buildings in TPR
  - Assembly occupancies, schools, nursing homes, hospitals, fire, police, etc.
- Tornado design speeds ≈ EF0-EF2
  - 60-138 mph, depending on Risk Category, location and plan size
- **Designing for most common tornadoes, not the most intense**
- Loads can increase significantly, sometimes >100%
- Construction costs not estimated to increase much, generally < 0.15%

Tornado-Prone Region (TPR)



Enhanced Fujita (EF) Tornado Intensity Scale

EF #	Gust Speed (mph)	% U.S. Tornadoes[1]
0	65-85	61.3
1	86-110	27.8
2	111-135	8.0
3	136-165	2.3
4	166-200	0.52
5	Over 200	0.05

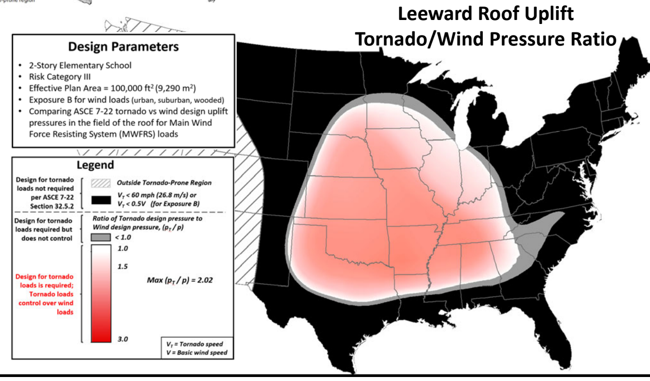
97.1% (EF0–EF2)

[1] 1995-2016. Source: NIST, using NOAA data.

Elementary School Example

Leeward Roof Uplift

Tornado/Wind Pressure Ratio



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Lunch Break

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