Summary of Progress on Implementation of Recommendations from the World Trade Center Investigation

June 11, 2021
NCST Advisory Committee Meeting

NOTE – Summaries of the recommendations are included in the following slides for context. The complete recommendations are available in the final report of the NIST Technical Investigation, at https://www.nist.gov/el/final-reports-nist-world-trade-center-disaster-investigation

Long Phan
Leader, Structures Group

Progress on Implementation of WTC Recommendations

WTC Disaster Investigation Recommendations	Progress Update
Recommendation 1. NIST recommends that: (1) progressive collapse be prevented in buildings through the development and nationwide adoption of consensus standards and code provisions, along with the tools and guidelines needed for their use in practice; and (2) a standard methodology be developed—supported by analytical design tools and practical design.	• In FY 2012, based on NIST's proposal, a new ASCE/SEI *Disproportionate Collapse Mitigation Standard Committee* was established. • This committee has completed a draft standard on Disproportionate Collapse Mitigation, which is being prepared for release by ASCE for public comments.
Recommendation 2. NIST recommends that nationally accepted performance standards be developed for: (1) conducting wind tunnel testing of prototype structures based on sound technical methods that result in repeatable and reproducible results among testing laboratories; and (2) estimating wind loads and their effects on tall buildings for use in design, based on wind tunnel testing data and directional wind speed data.	NIST's contributions to: • Revision of ASCE 49 Wind Tunnel Testing Standards were approved. ASCE 49 is being prepared for publication in 2021 • Revision to wind velocity profiles in ASCE 7-22, to better reflect the state-of knowledge on atmospheric boundary-layer flows

Summary of Progress on Implementation of Recommendations from the Joplin Tornado Investigation

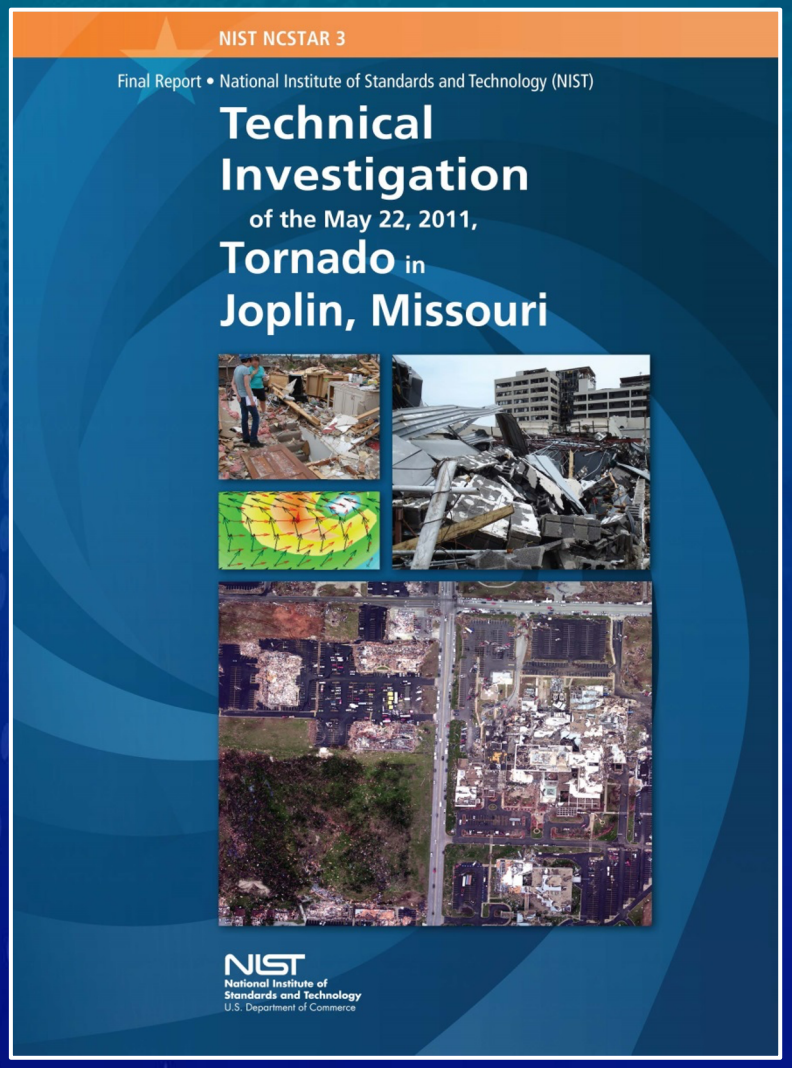
June 11, 2021
NCST Advisory Committee Meeting

NOTE – Summaries of the recommendations are included in the following slides for context. The complete recommendations are available in the final report of the NIST Technical Investigation of the Joplin Tornado, at https://dx.doi.org/10.6028/NIST.NCSTAR.3

Long Phan
Leader, Structures Group

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

NIST Joplin Tornado Investigation



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

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

- **16 recommendations for improving:**
  - Tornado hazard characterization
  - Design and construction of buildings and shelters in tornado–prone regions
  - Emergency communications that warn of threats from tornadoes
- Implementation of recommendations began in spring 2014, immediately following publication of final report

List of Joplin Recommendations

	R #	RECOMMENDATION SUMMARY
Hazard Characteristics	1	Development and deployment of technology to measure tornado wind fields
	2	Archival of tornado event data
	3	Development of tornado hazard maps
	4	Improvement of EF Scale; means for continued improvement; adoption by NWS
Buildings, Shelters, Designated Safe Areas, and Lifelines	5	Development of performance-based standards for tornado-resistant design
	6	Development of performance-based tornado design methodologies
	7	a) Development of tornado shelter standard for existing buildings; b) Installation of tornado shelters in more buildings in tornado-prone regions
	8	Development of guidelines for public tornado sheltering strategies
	9	Development of guidelines for selection of best available refuge areas
	10	Prohibition of aggregate roof coverings and ballast in tornado-prone regions
	11	Development of requirements for enclosures of egress systems in critical facilities
	12	a) Development of tornado vulnerability assessment guidelines for critical facilities; b) Performance of vulnerability assessments by critical facilities in tornado-prone
Emergency Communication	13	Development of codes, standards, and guidance for emergency communications; Development of joint plan by emergency managers/media/NWS for consistent alerts
	14	Deployment of “push” technologies for transmission of emergency information
	15	Research to identify factors to enhance public perception of personal risk
	16	Develop technology for real-time, spatially-resolved tornado threat information

List of Joplin Recommendations

	R #	RECOMMENDATION SUMMARY **PROGRESS UPDATES IN THIS BRIEFING**
Hazard Characteristics	1	Development and deployment of technology to measure tornado wind fields
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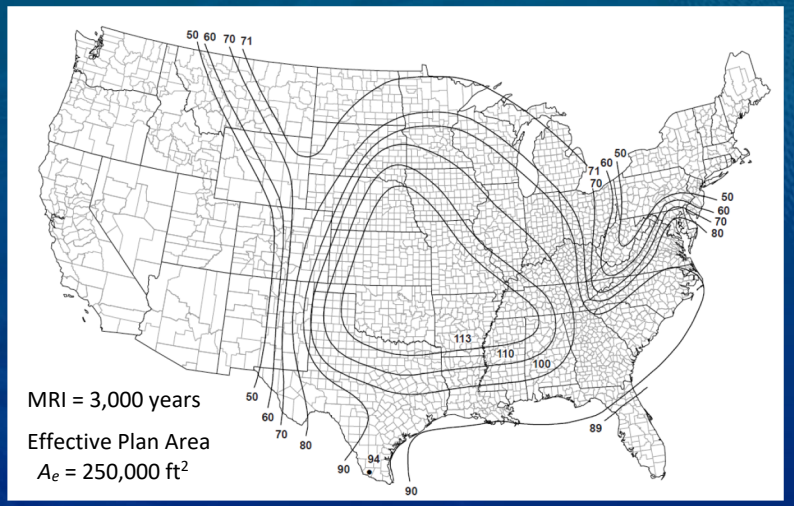
Highlights of Implementation Activities and Successes since last Meeting (1/2)

R3: Tornado hazard maps

- Tornado map changes required by ASCE 7-22 Main Committee completed
- Final map cartography completed
- **Technical report under review**



Example tornado map, speeds in mph

R5/6: Performance-based standards/design methodologies for tornado resistant design

- Tornado load design methodology changes required by ASCE 7-22 Main Committee completed
- Tornado load provisions approved by ASCE 7-22 Main Committee
- **ASCE 7-22 Draft for Public Comment to be published soon by ASCE**

ASCE 7-22

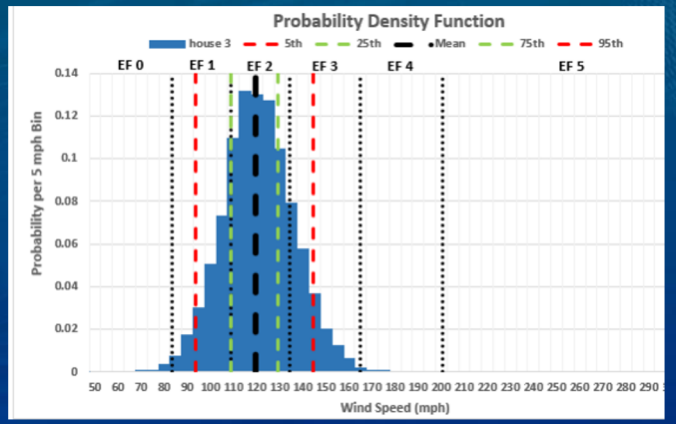
New
CHAPTER 32:
TORNADO LOADS

Highlights of Implementation Activities and Successes since last Meeting (2/2)

R4: Enhanced Fujita Scale

Completed draft engineering-based 'Smart' Damage Indicator for one- and two-family wood frame residences

- In beta-testing w/ National Weather Service
- Final version to be proposed for inclusion in new ASCE/AMS Standard for Wind Speed Estimation in Tornadoes



(1 mph = 0.447 m/s)

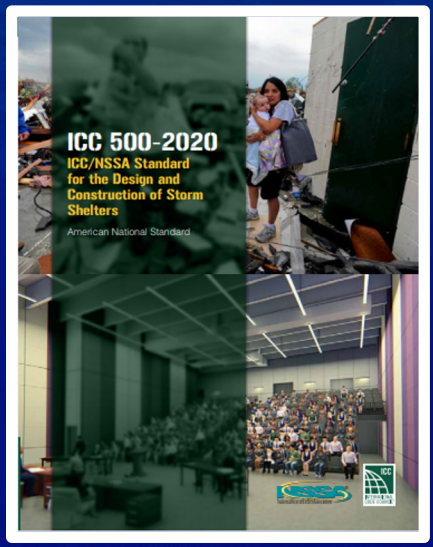
Example tornado speed estimation output from Smart DI tool

R7a: Storm Shelter standard for existing buildings

Expanded scope of International Code Council storm shelter standard to include shelters constructed in existing buildings

ICC 500-2020 Std for Design and Construction of Storm Shelters published in December

- ICC 500-2020 Commentary is in press



Progress on Implementation of Recommendations from the Joplin Tornado Investigation

Tornado Hazard Characteristics

Performance of Buildings, Shelters, Designated Safe Areas, and Lifelines

Marc Levitan, *Research Wind Engineer*
Structures Group

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

Progress – Tornado Wind Measurements

R1: Development & deployment of technology to measure tornado wind fields
R2: Archival of tornado event data

NIST collaborated with NSF in a joint solicitation for the Disaster Resilience Research Grants[1] in 2020 (results pending). Guidance for offerors submitting proposals in the windstorm area continued to include a focus on measurement of surface level winds in tornadoes, hurricanes and other windstorms

2020 Disaster Resilience Grants Program

Specific areas of research currently being solicited through the Disaster Resilience Grant 2020 funding opportunity include the development, advancement, and deployment of new sensors and methods to collect high spatiotemporal resolution data on windstorm phenomena to improve understanding of surface level wind features, extreme rainfall, and storm surge hazard information of relevance to:

- wind and structural engineering risk assessment, analysis, and design and/or
- high resolution meteorological modeling applications, such as embedded mesovortices and tornadoes in landfalling tropical cyclones.

NIST held a 2-day workshop (July 30-31) for the mobile windstorm and storm surge measurements community and stakeholders. Workshop goals included

- Sharing information on current and planned mobile measurement capabilities
- Hearing from stakeholders about their windstorm science and data needs
- Defining windstorm science objectives that can be facilitated through a collaborative research network
- Exploring ideas for the next generation of research infrastructure and instrumentation
- Exploring the creation of a new Windstorm Extreme Event Research Network or coordination of future networking activities through one of the existing natural hazard programs

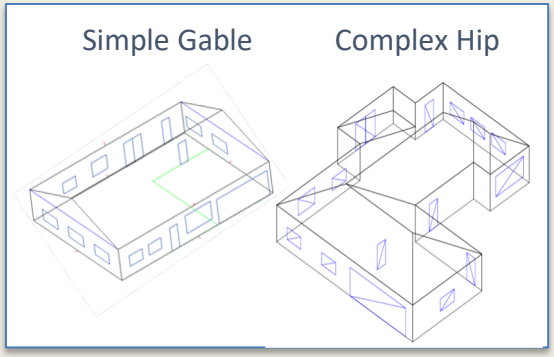
[1] https://www.nist.gov/el/disaster-resilience/disaster-resilience-federal-funding-opportunity-ffo

Progress – Improvement of the EF Scale

R4: Standardize the Enhanced Fujita (EF) scale and improve through addition of scientific/quantifiable damage indicators, particularly those that better distinguish between the most intense tornado events

ASCE/AMS Standard on Wind Speed Estimation in Tornadoes and Other Windstorms *(NOAA and NIST co-chair)*

- Complete drafts for all methods chapters of the standard
  - Radar
  - In Situ
  - **EF Scale Method**
  - Forensic Engineering
  - Forrest Damage/Treefall Pattern
  - Remote Sensing Condition Assessment
- Most chapters have completed at least one round of Main Committee ballots
- Completed development of 'Smart DI'
  - Based on damage modeling conducted for tornado maps
  - v1.9 in beta-testing with NWS Weather Forecast Offices



1. Simulate tornado loads and resistances (w/validated finite element models) for 44 house configurations to estimate probability of damage (d) as a function of wind speed (v), $\mathbf{P(d_i|v_j)}$
2. Correlate modeled damage with Degree of Damage (DOD) from Enhanced Fujita (EF) Scale, $\mathbf{P(DOD_i|v_j)}$
3. Use Bayesian approach to estimate probability of wind speed given a DOD, $\mathbf{P(v_j|DOD_i)}$

Current Operational EF Scale - House Damage Indicator (DI)

2. ONE-AND TWO-FAMILY RESIDENCES (FR12)
(1000 – 5000 sq. ft.)

Typical Construction

- Asphalt shingles, tile, slate or metal roof covering
- Flat, gable, hip, mansard or mono-sloped roof or combinations thereof
- Plywood/OSB or wood plank roof deck
- Prefabricated wood trusses or wood joist and rafter construction
- Brick veneer, wood panels, stucco, EIFS, vinyl or metal siding
- Wood or metal stud walls, concrete blocks or insulating-concrete panels
- Attached single or double garage

DOD*	Damage description	EXP	LB	UB
1	Threshold of visible damage	65	53	80
2	Loss of roof covering material (<20%), gutters and/or awning; loss of vinyl or metal siding	79	63	97
3	Broken glass in doors and windows	96	79	114
4	Uplift of roof deck and loss of significant roof covering material (>20%); collapse of chimney; garage doors collapse inward; failure of porch or carport	97	81	116
5	Entire house shifts off foundation	121	103	141
6	Large sections of roof structure removed; most walls remain standing	122	104	142
7	Exterior walls collapsed	132	113	153
8	Most walls collapsed, except small interior rooms	152	127	178
9	All walls	170	142	198
10	Destruction of engineered and/or well constructed residence; slab swept clean	200	165	220

* DOD is degree of damage

Limitations Include

- Judgement-based wind speeds (expert elicitation)
- No consideration of important variables such as
  - Roof shape
  - Plan shape
  - Connection details
- No consideration of uncertainty

Notes

- Estimated wind speeds in mph
- EXP = Expected
- LB = Lower Bound
- UB = Upper Bound
- User adjusts between EXP/LB/UB based on minimally described construction type/quality

Source: NOAA/NWS/Storm Prediction Center

Progress – Improvement of the EF Scale, cont'd

Individual DI Input/Output

1. Location Information

Location Number:	
Location:	
Location Latitude:	
Location Longitude:	
City or County:	
State:	

2. Damage Indicator

Type:	FR12
Type Description:	One/Two Family Residences
DI Name:	
Street Address:	
City:	
County:	
State:	
DI Latitude:	
DI Longitude:	

3a. Input DI Physical Characteristics

Year Built Era:	
Basic Strength Group:	

Selection Characteristics

Roof Shape:	
House Shape:	
Roof Deck:	
Foundation:	

3b. Summary of INPUT Characteristics

Year Built Era:	
Roof Shape:	
House Shape:	
Roof Deck:	
Roof Wall:	
Wall Sheathing:	
Stud to Base Plate:	
Foundation:	

4. DOD Damage Observations

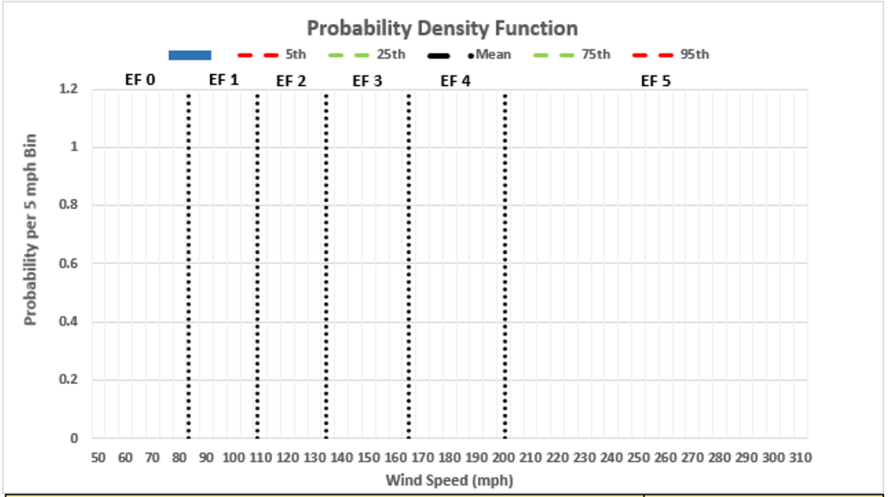
Observed DoD:	

Evaluate

DOD Description

No Visible Damage

5. Complute Wind Speed Probability Density Function (PDF)



Wind Speed (mph) Statistics							
Mean	SD	Mode	5th	25th	50th	75th	95th

Warning Box

6. EF Scale Category Wind Speed Probabilities

EF Category	Below EF0	EF0	EF1	EF2	EF3	EF4	EF5	Mean EF	EF with Mean V
Wind Speed (mph)	<65	65-85	86-110	111-135	136-165	166-200	>200		
EF Category Probability									

7. Notes:

Save to Location Tab | Clear DI | Clear Location and DI

Note: NIST funded development of v1.0 (initial demonstration version). ARA funded development of v1.9 (shown here).

Progress – Improvement of the EF Scale, cont'd

Individual DI Input/Output

1. Location Information

Location Number:	L1
Location:	Kansas city
Location Latitude:	39.1
Location Longitude:	-94.6
City or County:	Clay County
State:	MO

2. Damage Indicator

Type:	FR12
Type Description:	One/Two Family Residences
DI Name:	house 3
Street Address:	123 Main St
City:	Kansas City
County:	Clay County
State:	MO
DI Latitude:	
DI Longitude:	

3a. Input DI Physical Characteristics

Year Built Era:	1966-2002
Basic Strength Group:	Mid
Selection Characteristics	
Roof Shape:	non-Hip
House Shape:	Complex
Roof Deck:	6d @ 6-12
Foundation:	Unknown

3b. Summary of INPUT Characteristics

Year Built Era:	1966-2002
Roof Shape:	non-Hip
House Shape:	Complex
Roof Deck:	6d @ 6-12
Roof Wall:	16d TN
Wall Sheathing:	Sheathed
Stud to Base Plate:	Toe Nails
Foundation:	Unknown

4. DOD Damage Observations

Observed DoD:	4

Evaluate

DOD Description

Roof deck damage exceeds 10% or roof cover damage greater than 20%; or non-high-wind-rated and non-braced garage door failure. May also see collapse of chimneys, or failure of gable ends. DoD 4 may or may not have failure of unprotected glazed openings.

Physical Characteristic Inputs

- Several choices for each physical characteristic, including unknown
- Context-sensitive
- Housing stock data variation with geographic region + year built era used to weight parameter values when unknown is selected

Table 1. 44 Basic Strength Groups (FR12) and Selection Options

	Characteristics	Basic Groups			Additional Groups	
		Weak	Mid	Strong	Weak-Plank	Super Strong
Load Path	1. Roof-Wall	8d-TN	16d-TN	Clip	8d-TN	Double Wrap
	2. Wall Sheathing	Minimal	Sheathed	Sheathed	Minimal	≥Sheathed
	3. Stud-Bottom Plate	Str. Nail	TN	Clip	Str. Nail	Double Strap
	4. Foundation	Nails	Pin or Bolt	Bolt	Nail or Bolt	Bolt
Selection Options	A. Roof Shape	Select	Select	Select	Select	Select
	B. House Shape	Select	Select	Select	Select	Select
	C. Roof Deck	Select	Select	Select	(Plank Nail)	(8d-RS @6-6)
	D. Foundation	(Nails)	Select	(Bolt)	Select	(Bolt)
	E. No. of Options	8	16	8	8	4

Clearer, more quantitative DoD descriptions

DOD	Table 2. Engineering-Based Damage Description
0	No Visible Damage
1	Threshold of visible damage such as one or more of the following: (a) roof cover damage less than 5%; (b) threshold damage to exterior attachments (such as house trim, lights, decorative shutters, awnings); (c) metal carports ; (d) torn or damaged light- weight wall/ soffit siding (e.g., vinyl); (e) bent TV antennas or loss of chimney cap; (f) OR multiple wall impact dings from asphalt shingles, tree branches, or other light-weight WBD.
2	Greater than threshold damage (DoD 1) with notably broader damage, such as roof cover loss greater than DoD 1, but less than 20%: more damage to DoD 1 items (b-f), including failures with some exterior attachments broken loose and displaced; toppling of poorly attached brick masonry (≤25%).
3	Failure of one or more glazed openings.
4	Roof deck damage exceeds 10% or roof cover damage greater than 20%; or non-high-wind-rated and non-braced garage door failure. May also see collapse of chimneys, or failure of gable ends. DoD 4 may or may not have failure of unprotected glazed openings.
5	House rigid body sliding failure
6	Roof deck damage greater than 80%; OR one or more major roof structure sections fail (which includes whole roof failure).
7	Exterior wall collapse exceeds 25%.
8	Exterior wall failures exceed 85% with some interior room walls standing.
9	Exterior wall failure ≥ DoD 8 and failure of all interior room walls.
10	Complete destruction of building with debris swept away (with exception of properly bolted floor plates which may remain in place).

Progress – Improvement of the EF Scale, cont'd

Individual DI Input/Output

1. Location Information

Location Number:	L1
Location:	Kansas city
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3a. Input DI Physical Characteristics

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Selection Characteristics	
Roof Shape:	non-Hip
House Shape:	Complex
Roof Deck:	6d @ 6-12
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3b. Summary of INPUT Characteristics

Year Built Era:	1966-2002
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Roof Wall:	16d TN
Wall Sheathing:	Sheathed
Stud to Base Plate:	Toe Nails
Foundation:	Unknown

4. DOD Damage Observations

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Evaluate

DOD Description

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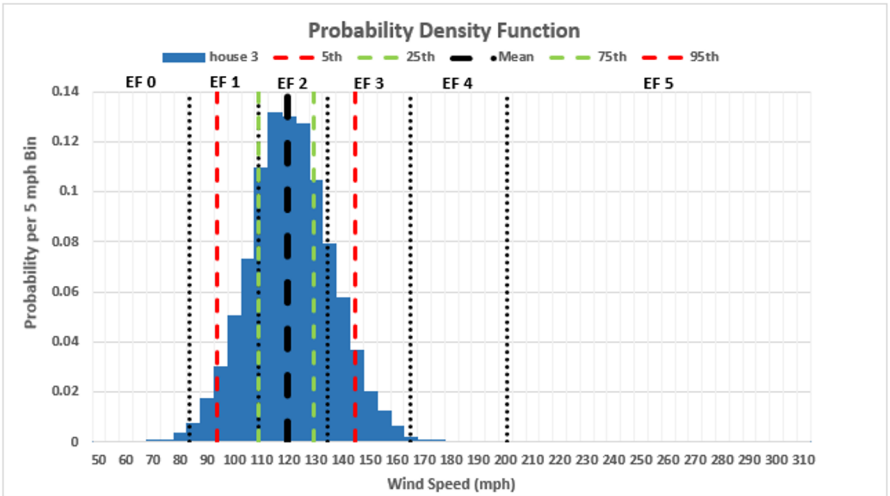


Wind Speed (mph) Statistics							
Mean	SD	Mode	5th	25th	50th	75th	95th
120.7	15.1	115	95	110	120	130	145

Warning Box

Wind speeds reflect the INPUT selections.

6. EF Scale Category Wind Speed Probabilities

EF Category	Below EF0	EF0	EF1	EF2	EF3	EF4	EF5	Mean EF	EF with Mean V
Wind Speed (mph)	<65	65-85	86-110	111-135	136-165	166-200	>200		
EF Category Probability	0.00	0.01	0.28	0.57	0.13	0.00	0.00	1.83	2

7. Notes:

Probabilistic estimate of EF Rating based on this single DI

Other software features provide rating guidance for multiple DIs in same location (not shown here)

Estimated tornado wind speed at DI location, including uncertainty

Save to Location Tab | Clear DI | Clear Location and DI

(1 mph = 0.447 m/s)

Progress – Tornado Hazard Maps

R3: Development of tornado hazard maps for use in design of buildings and infrastructure, considering spatially based estimates of the tornado hazard

Map Production

Final Cartography of all 51 maps

- Manually added lower bound contours/point values for interpolation, in response to comments by ASCE 7 Committee
- Hand placement of wind speed value labels for improved readability

GIS map package/documentation provided to ASCE for use in developing online Hazards Tool

Maps Produced

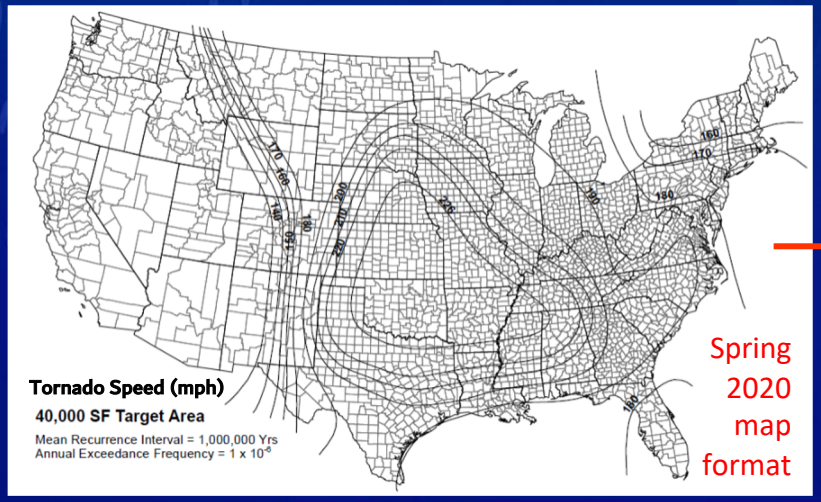
A. Target Sizes, ft^2 (Square targets)

1. Geometrical Point
2. 2,000 (45' x 45')
3. 10,000 (100'x100')
4. 40,000 (200' x200')
5. 100,000 (316'x316')
6. 250,000 (500' x 500')
7. 1,000,000 (1,000' x 1,000')
8. 4,000,000 (2,000' x 2,000')

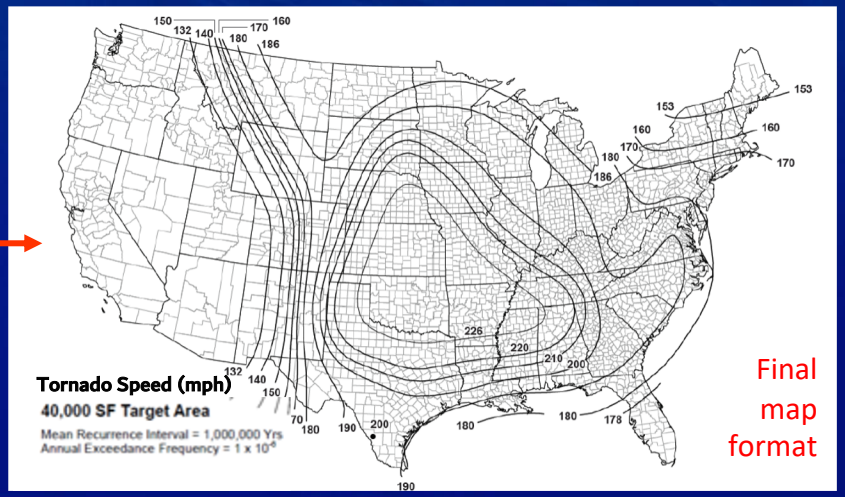
B. Return Periods (Years)

1. 300*
2. 700*
3. 1,700
4. 3,000
5. 10,000
6. 100,000
7. 1,000,000
8. 10,000,000

* not included in ASCE 7-22



Spring 2020 map format



Final map format

Metric Conversions

1 ft = 0.3048 m

1 ft^2 = 0.0929 m^2

1 mph = 0.447 m/s

Progress – Tornado Load Methodology/Standard

R5: Develop PBD standards for tornado-resistant design

R6: Develop risk–balanced, performance–based tornado design methodologies

ASCE 7-22 *Tornado Loads*

Finalized all 26 proposals comprising the new Tornado Load provisions

- New Chapter 32 Tornado Loads
- Necessary additions to other chapters
  - Chapter 1 General
  - Chapter 2 Load Combinations
  - Chapter 26 Wind Loads
- 120+ pages of standards provisions and commentary
- Additional supporting documentation
- Multiple revisions for each proposal to satisfy ballot comments

Current Status: All Tornado Load proposals have now passed the ASCE 7-22

- Tornado Task Committee
- Wind Load Subcommittee
- Main Committee

ASCE 7-22 Draft for Public Comment pending

Set of Tornado Load Proposals

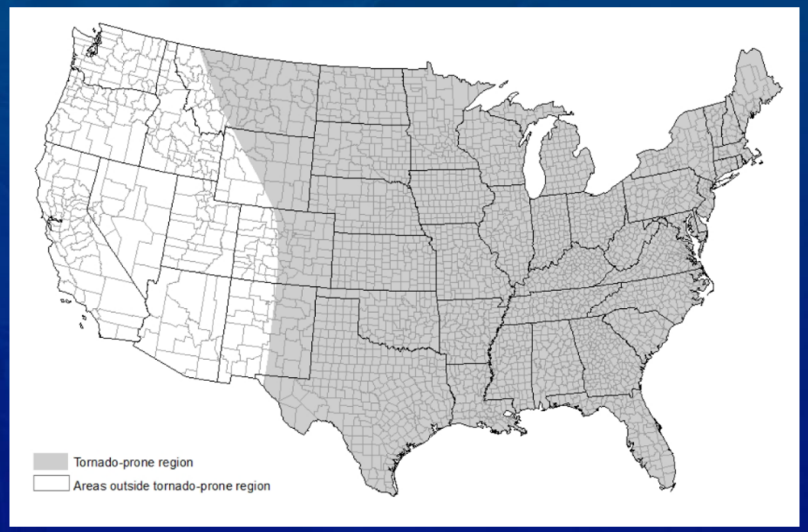
1. WL-CHTN-01r04_New Section 32.1 Procedures
2. WL-CHTN-02r02_New Section 32.2 Definitions
3. WL-CHTN-03r03_New Section 32.3 Symbols-Notation
4. WL-CHTN-04r02_New Section 32.4 General
5. WL-CHTN-05r04_New Section 32.5 Tornado Hazard Maps
6. WL-CHTN-06r03_New Section 32.6 Tornado Directionality Factor
7. WL-CHTN-07r03_New Section 32.7 Exposure
8. WL-CHTN-08r03_New Section 32.8 Tornado Topographic Factor
9. WL-CHTN-09r03_New Section 32.9 Ground Elevation Factor
10. WL-CHTN-10r03_New Section 32.10 Tornado Velocity Pressure
11. WL-CHTN-11r03_New Section 32.11 Tornado Gust Effects
12. WL-CHTN-12r04_New Section 32.12 Tornado Enclosure Classification
13. WL-CHTN-13r02_New Section 32.13 Tornado Internal Pressure Coeffs
14. WL-CHTN-14r03_New Section 32.14 Tornado External Pressure Coeffs
15. WL-CHTN-15r03_New Section 32.15 Tornado Loads-MWFRS
16. WL-CHTN-16r03_New Section 32.16 Tornado Loads-Other Structures
17. WL-CHTN-17r03_New Section 32.17 Tornado Loads-C&C
18. WL-CHTN-18r03_New Section 32.18 Wind Tunnel Procedure
19. WL-CHTN-19r04_New Section 32.19 Consensus Standards/References
20. WL-CHTN-20r04_New Appendix 32A Long Return Period Hazard Maps
21. WL-CHTN-21r01_Tornado Provisions for Chapter 1
22. WL-CHTN-21r03_Tornado Provisions for Chapter 2
23. WL-CHTN-21r03_Tornado Provisions for Chapter 26
24. WL-CHTN-24r03_Hurricane Shelter Provisions for Chapter 26
25. WL-CHTN-25r02_Tornado PBD
26. WL-CHTN-26r01_Tornado Maps and ASCE Hazard Tool

Tornado Load Methodology/Standard, cont'd

ASCE 7-22
CHAPTER 32 TORNADO LOADS

Scope

- Applies to Risk Category III or IV buildings and other structures located in the tornado-prone region
- Applies to main wind force resisting systems (MWFRS) and components and cladding (C&C)
- All MWFRS and C&C shall be designed and constructed to resist the greater of the Ch. 32 Tornado Loads or Ch 26 Wind Loads, using the Ch. 2. load combinations



Tornado-Prone Region

Tornado Load Methodology/Standard

'User-Friendly' Design

Tornado load framework adapted from ASCE 7 wind load procedures

- nearly all parameters have been modified, and a few new ones added

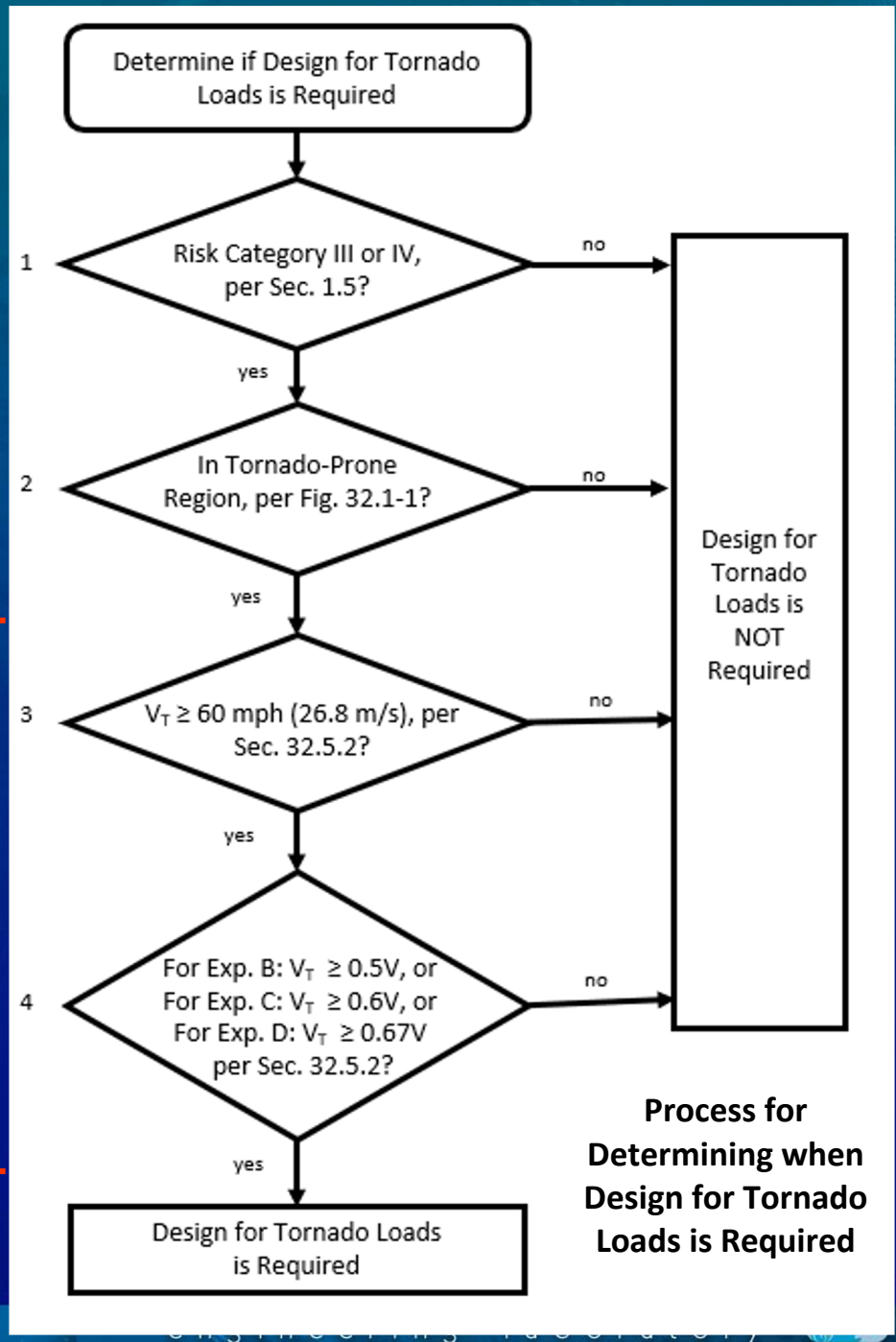
Tornado chapter layout follows that of wind load chapters

Nomenclature/symbols also follow those used for wind loads

- Gust effect factor ---> Tornado gust effect factor
- G ---> G_T

Tornado loads will not always control design of RC III/IV Buildings

- Tools provided in the standard to limit effort when tornado loads will not control



Process for Determining when Design for Tornado Loads is Required

Tornado Load Methodology/Standard, cont'd

Explicit provisions on Performance-based Design

Explicit consideration of functionality for Essential Facilities

- Including buildings/other structures required to maintain the functionality of Essential Facilities

Larger effective plan areas => greater design tornado speeds

Tornado Directionality Factor Increases

- Must use K_{dT} =1.0 for components and cladding, instead of the 0.75-0.9 applicable to other facilities

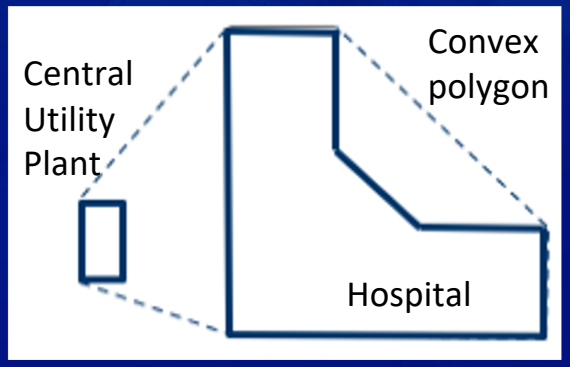
Glazing protection is required

- Impact resistant glazing, or
- Impact protective system

DEFINITION

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."
(*ASCE 7-22 Draft for Public Comment*)

For example, hospitals, fire and police stations, emergency operations centers, 911 call centers



Effective Plan Area

The effective plan area A_e equals to the area of the smallest convex polygon enclosing the building footprint.

For Essential Facilities, all of the essential buildings, and other structures that maintain the functionality of those buildings, are enclosed in the polygon.

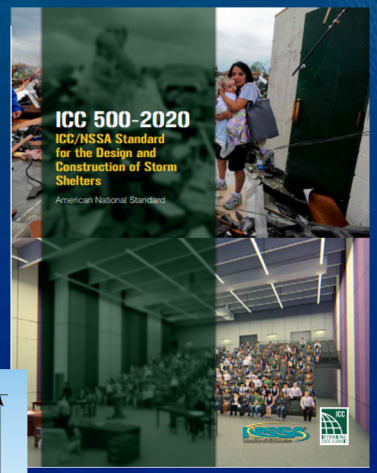
Progress – Tornado Shelter Standard

R7a: Development of tornado shelter standard for existing buildings

ICC 500-2020: ICC/NSSA *Standard on Design and Construction of Storm Shelters* *(NIST chaired this standards committee)*

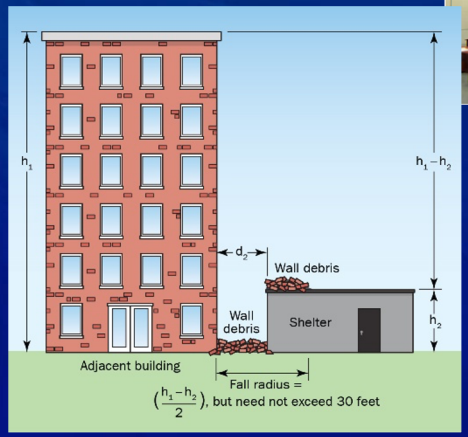
Standard published Dec. 2020

Commentary complete – publication pending



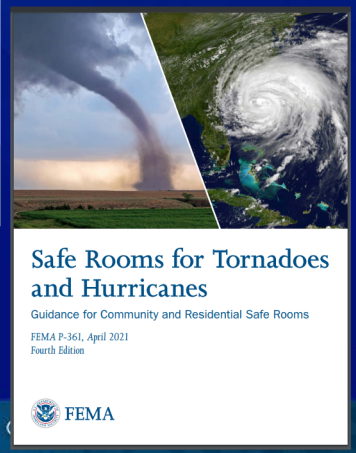
NIST-led ICC 500 proposals

- Expansion of scope to include existing buildings
- Treatment of design and construction issues specific to installation of shelters in existing buildings
- New provisions for impact loads due to laydown hazards and falling debris hazards
- New load combinations
- Many others



Source: FEMA

NIST contributed to updated FEMA Safe Room guidance, incorporating revisions in ICC 500-2020



Impacts/Outreach Summary to Date

Published
In progress
In planning

- **Existing Standards**
  - **NFPA 1600-2019**, Standard on Continuity, Emergency, and Crisis Management
  - **ICC 500-2020**, Standard for Design and Construction of Storm Shelters ← Published Dec. 2020
  - **ASCE/SEI 7-22**, Minimum Design Loads and Associated Criteria for Buildings and Structures ← Pending Public Comment
  - **ICC 500-2023**, Standard for Design and Construction of Storm Shelters
  - **ANSI/ANS 2.3** Standard Estimating Tornado, Hurricane, and Extreme Straight Line Wind Characteristics at Nuclear Facility Sites
- **New Standards**
  - **NFPA 1616-2017**, Standard on Mass Evacuation, Sheltering, and Re-entry Programs
  - **ASCE/AMS** Standard for Estimation of Wind Speeds in Tornadoes
- **Building Codes**
  - **2018** International Building Code (IBC)
  - **2018** International Existing Building Code (IEBC)
  - **2024** International Building Code (IBC)
- **Guidelines**
  - **FEMA P-320**, Taking Shelter from the Storm, 4th ed.
  - **FEMA P-320**, Taking Shelter from the Storm, 5th ed.
  - **FEMA P-361**, Safe Rooms for Tornadoes and Hurricanes, 3rd ed.
  - **FEMA P-361**, Safe Rooms for Tornadoes and Hurricanes, 4th ed. ← Published April 2021
  - **ICC 500-2014**, Commentary on the Standard for Design and Construction of Storm Shelters
  - **ICC 500-2020**, Commentary on the Standard for Design and Construction of Storm Shelters ← In press
  - **FEMA P-2062**, Guidelines for Wind Vulnerability Assessments of Existing Critical Facilities
  - **NIST Technical Note,** Alerting under Imminent Threat: Guidance on alerts issued by outdoor siren and short message alerting systems
  - **Nat. Hazards Rev.**, Alerts and warnings on short messaging channels: guidance from an expert panel process
  - **FEMA P-431**, Tornado Protection: Selecting Refuge Areas in Buildings, 3rd ed.
  - Guidelines for Tornado Resistant Design of Risk Category II Buildings
  - Guidelines for Public Tornado Sheltering Strategies

Workshops

- 1st NIST/ASCE Tornado Map Stakeholder Wkshp, 2015
- Federal Agency Tornado Map Workshop, 2015
- Workshop on Outdoor Siren Policies, 2016
- Workshop on Short Message Alerting, 2017
- Public Tornado Shelter Workshop: Opportunities and Challenges for Improving Tornado Safety, 2019
- 2nd NIST/ASCE Tornado Map Stakeholder Wkshp, 2019

Remaining Implementation Tasks

Legend
Primarily Completed
Significant progress
Modest progress
Next Steps

	R#	RECOMMENDATION SUMMARY	
Hazard Characteristics	1	Develop and deploy technology to measure tornado wind fields	
	2	Archival of tornado event data	← Linked with efforts for R4
	3	Development of tornado hazard maps	
	4	Improvement of EF Scale; adoption by NWS	← Complete the ASCE/AMS Standard
Buildings, Shelters, Designated Safe Areas, and Lifelines	5	Develop performance-based standards for tornado-resistant design	← Propose to IBC 2024
	6	Develop performance-based tornado design methodologies	← Develop guidance for RC II Buildings w/ FEMA
	7	a) Develop tornado shelter standard for existing buildings; b) Installation of tornado shelters in more buildings in tornado-prone regions	
	8	Develop guidelines for public tornado sheltering strategies	← Develop guidance w/ FEMA and NOAA
	9	Develop guidelines for selection of best available refuge areas	← Complete guidance w/ FEMA
	10	Prohibit aggregate/ballast roof coverings in tornado-prone regions	← Revise/Resubmit to IBC
	11	Develop req. for enclosures of egress systems in critical facilities	
	12	a) Develop tornado vulnerability assessment guidelines for critical facilities; b) Performance of vulnerability assessments by critical facilities	← Coordinating w/ FEMA
Emergency Communication	13	Develop codes, standards, and guidance for emergency communications; Develop joint plan by emergency managers/media/NWS for consistent alerts	
	14	Deploy “push” technologies for transmission of emergency information	
	15	Research to identify factors to enhance public perception of personal risk	
	16	Develop technology for real-time, spatially-resolved tornado threat information	← NOAA completion & implementation of FACETs

Progress on Implementation of Past Investigation Recommendations

June 11, 2021
NCST Advisory
Committee Meeting

QUESTIONS?

Please 'raise your hand' using the Blue Jeans Participant window and unmute your audio and video

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Leader, Structures Group

Marc Levitan
Research Wind Engineer, Structures Group