Progress on Implementation of Recommendations from Joplin Tornado NCST Investigation

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U.S. DEPARTMENT OF COMMERCE

Recent Tornado Preliminary Reconnaissance Missions

NIST Field Team Members:
Dan Rhee, Nico de Toledo, Steve McCabe, Marc Levitan

Supporting Member:

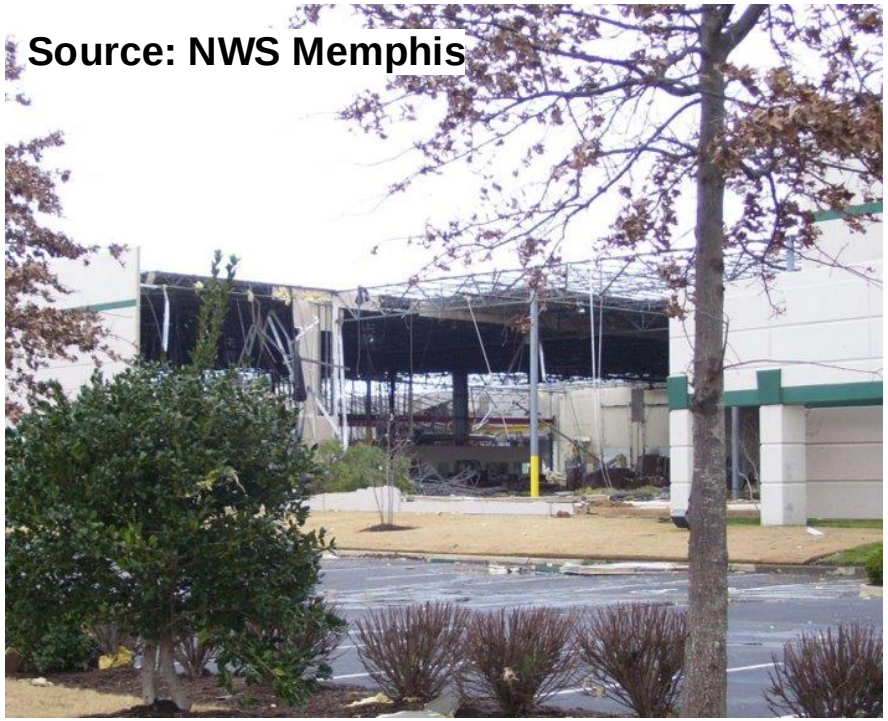
Nelson Tucker, SURF

Historical Tornado Strikes on Warehouses

Date	Name	State	Details
Aug 1993	Walmart	VA	3 fatalities, 198 injuries
Feb 2008	Proliance Distribution	MS	Destruction primary factor in 2009 bankruptcy (2008 net sales $350 million)
Feb 2008	DSC Logistics	TN	3 fatalities, 10 injuries - same tornado as Proliance
Apr 2011	Wrangler Plant	AL	1 fatality - likely far more if not for early severe weather closure
May 2011	Home Depot	MO	8 fatalities due to inward wall panel collapse
Apr 2016	Ozarka Plant	TX	$100 million in damage and lost production
Nov 2018	Amazon Warehouse	MD	2 fatalities due to wall panel collapse
Dec 2021	Amazon Warehouse	IL	6 fatalities
Apr 2023	Goodyear Tire Plant	MS	Insurance claim $325-350 million. Sale losses in 2023 2nd qtr up to $130 million
Jul 2023	Pfizer Plant	NC	Produces 25% of company sterile injectables. Worldwide supply disruption

Sources (by facility): Walmart: NWS; Proliance and DSC: FoxRothschild.com, Desoto Times-Tribune, BizJournals.com, Tanner & Reynolds 2010 (TTU); Wrangler: Alabama Dept. Of Commerce, Tornado Talk; Home Depot: NIST; Ozarka: news-journal.com; Amazon (2018): The Washington Post, CBS Baltimore; Amazon (2021): NWS; Goodyear: The Insurer, Daily Journal; Pfizer: Industrial Equipment News

Structural Failure Examples in the Past



**DSC Warehouse,
Memphis, TN, 2008**

**Home Depot,
Joplin, MO, 2011**

**Amazon Warehouse,
Edwardsville, IL, 2021**

Deployment Rationale

- There is an observed trend of significant tornado damage and fatalities in large warehouses and warehouse-like structures
- These buildings are not traditionally considered critical facilities, and therefore are not typically required to have storm shelters. New construction of this type would not generally be subject to the tornado load requirements in ASCE 7-22 and the 2024 IBC.
- Life safety and community resilience/economic/supply chain considerations might warrant a modification to the ASCE 7/IBC Risk Category definitions for certain warehouses
- This work is complimentary to ongoing Structures Group/Joplin Implementation research to document tornado strikes on critical facilities, in support of federal, state and local adoption of IBC requirements for tornado shelters and ASCE 7/IBC tornado load design requirements

Deployment Plan

- **Targeted reconnaissance focused on sheltering, failure modes, and wind speed estimation to see if there are lessons to be learned that could result in codes and standards changes for these kinds of facilities**

  Typical Structural System:
  - Large “box” type construction
  - Heavy load-bearing walls
    - Precast concrete walls
    - Masonry
  - Roof provides lateral resistance
    - Roof framing: steel joist girders supporting steel bar joists
    - Metal roof decking with foam insulation and membrane

Tornado Overview

Marietta, OK:

- Dollar Tree (Year Built: 2003, 2013)
- 4/27/24 EF4 Tornado
- 5/7/24 Deployment

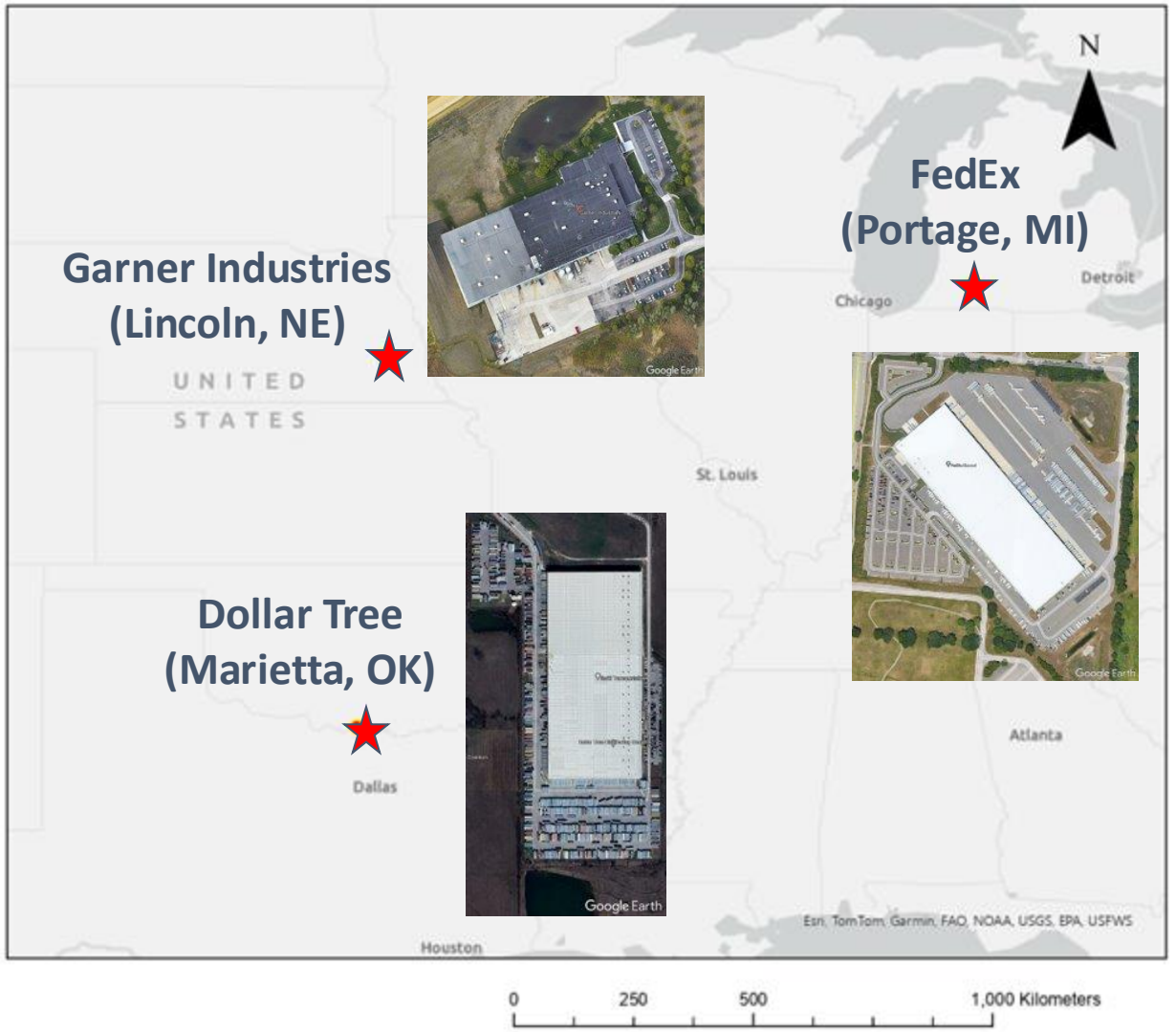
Lincoln, NE:

- Garner Industries (Year Built: 2000, 2017)
- 4/26/24 EF3 Tornado
- 5/8/24 Deployment

Portage, MI:

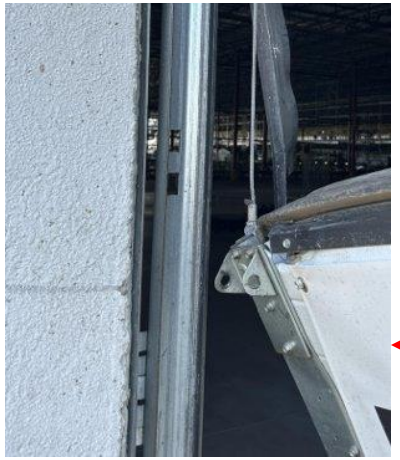
- FedEx (Year Built: 2020)
- 5/7/24 EF2 Tornado
- 5/13/24 Co-deployment with ASCE/SEI-UIUC

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



Observed Failure Modes

Common Failures: Garage Doors



The tracks for the failed garage doors remained in place and undamaged

- Dollar Tree (Marietta, OK)
- Garner Industries (Lincoln, NE)
- FedEx (Portage, MI)

Source: Civil Air Patrol (CAP)

<u>Preliminary hypothesis:</u>

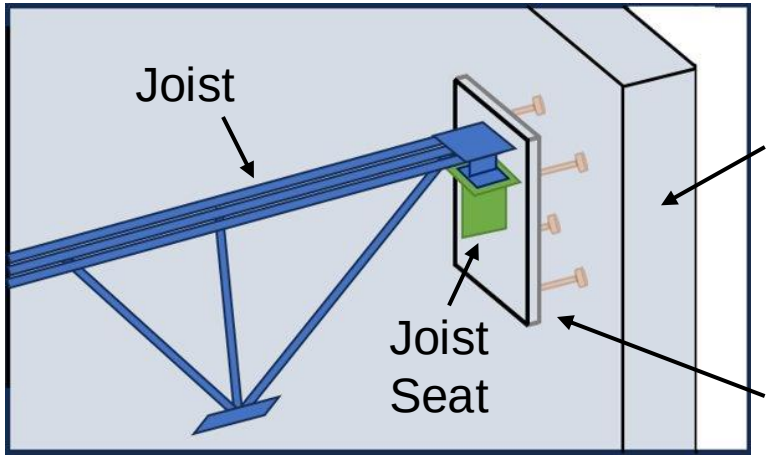
Garage door failures and open garage doors on windward walls led to positive internal pressurization inside the building, and subsequent increased uplift pressure on the roof

Common Failures: Roof-to-Wall

Weld Failure at Joist Seat

Dollar Tree (Marietta, OK)
Garner Industries (Lincoln, NE)
FedEx (Portage, MI)

Typical Roof-to-wall Connection



Common Failures: Roof-to-Wall

Weld Failure at Joist Seat

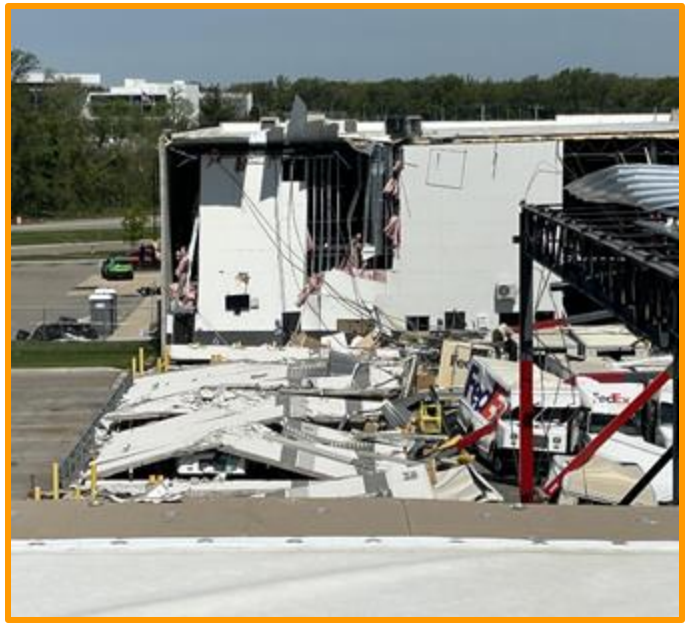
- Dollar Tree (Marietta, OK)
- Garner Industries (Lincoln, NE)
- FedEx (Portage, MI)

<u>Preliminary hypothesis on roof structure failure mechanism:</u>

Roof joist-to-windward wall connection failure due to uplift pressure led to removal of roof structure along with joists/girders

Common Failures: Wall Failure

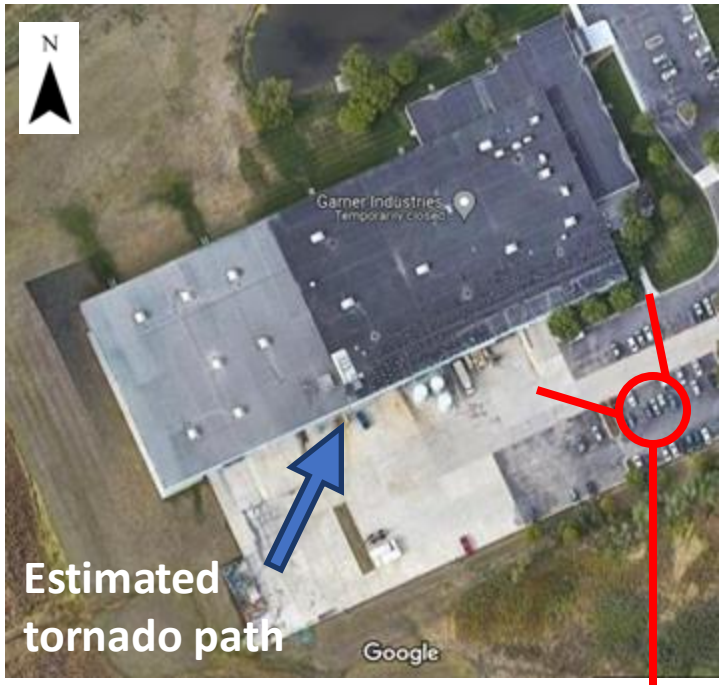
Dollar Tree (Marietta, OK)
Garner Industries (Lincoln, NE)
FedEx (Portage, MI)



Preliminary hypothesis on wall failure mechanism:

1. Removal of bracing at top of wall
2. Minimal lateral support for walls (free standing walls)
3. Windward walls fail inward, side/leeward walls fail outward

Garner Industries



Dashcam

*Used with permission from AccuWeather

Wind Speed Estimation

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Marietta, OK

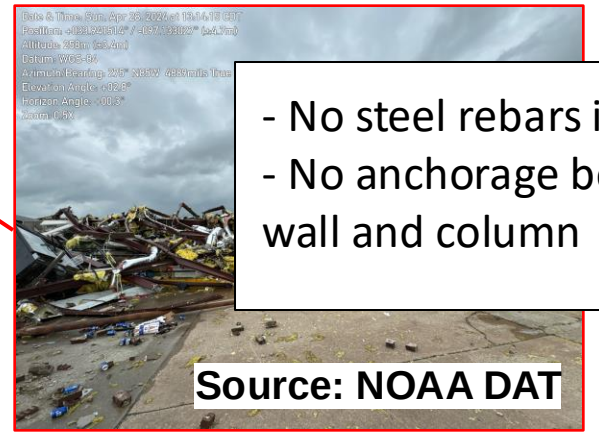
- EF4 (NWS)
- Peak wind speed at 170 mph from Homeland Grocery / Dollar General (DAT)

EF Scale Warehouse (WHB)

		EXP	LB	UB
6	Collapse of pre-cast concrete tilt-up panels	124	102	144
7	Total destruction of a large section of building or entire building	158	131	186

* Degree of Damage

Homeland Grocery / Dollar General



- No steel rebars in CMU
- No anchorage between wall and column

EF Scale Large Isolated Retail Building (LIRB)

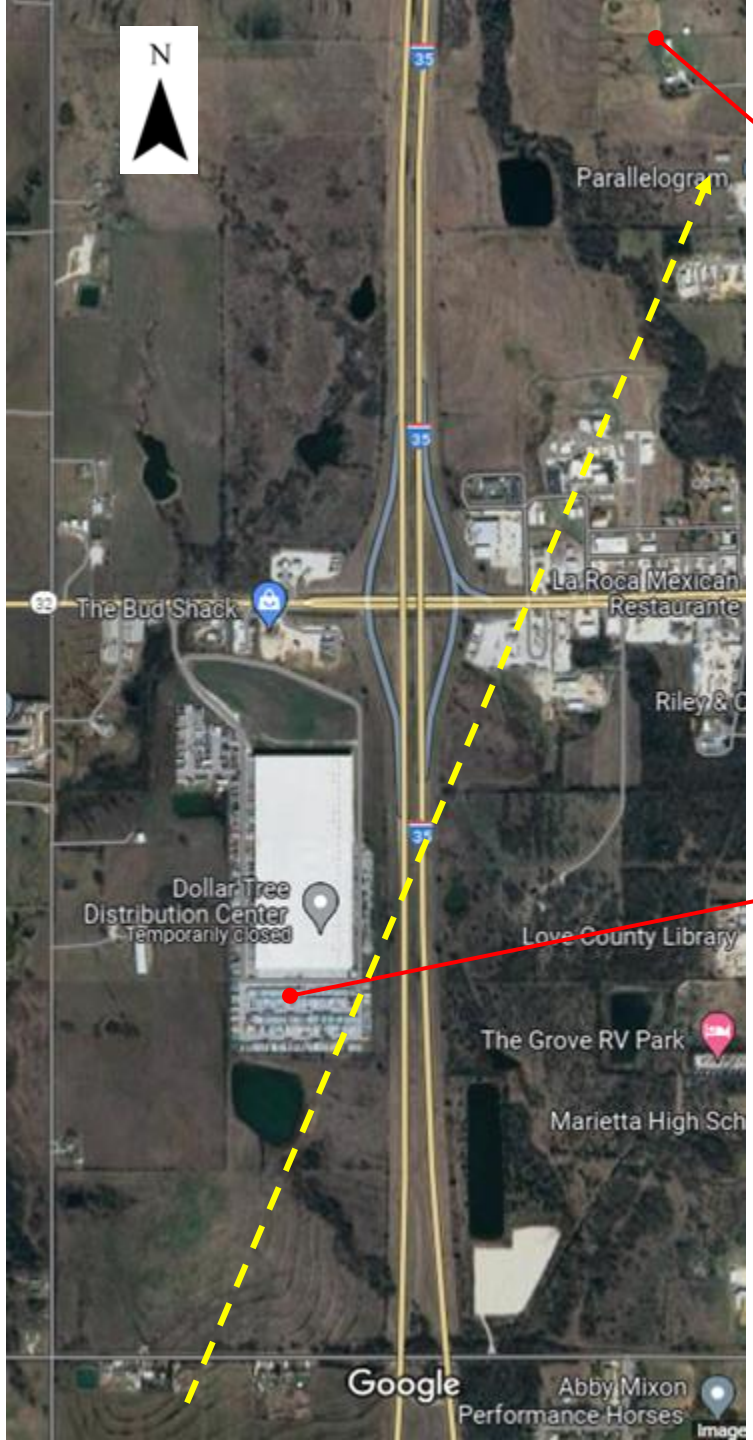
		EXP	LB	UB
7	Complete destruction of all or a large section of the building	173	147	201

DOD*	Damage description	EXP	LB	UB
1	Small limbs broken (up to 1" diameter)	60	48	72
2	Large branches broken (1"-3" diameter)	74	61	88
3	Trees uprooted	91	76	118
4	Trunks snapped	110	93	134
5	Trees debarked with only stubs of largest branches remaining	143	123	167

* Degree of Damage

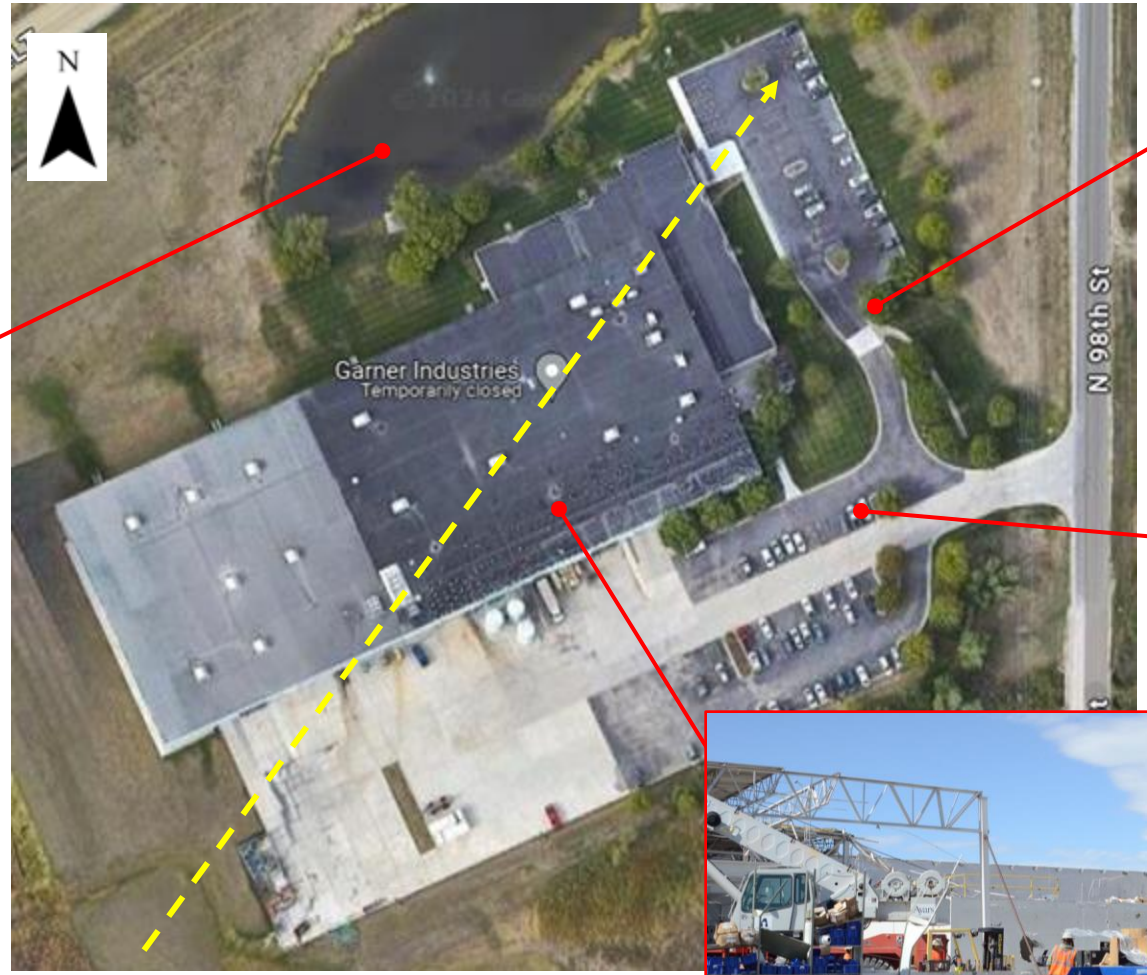
Marietta, OK

- EF4 (NWS)
- Peak wind speed at 170 mph from Homeland Grocery / Dollar General (DAT)
- Evidence of multiple vehicles (e.g., passenger cars, semi-trucks) airborne
- Indication of possibly violent tornado



Lincoln, NE

- EF3 (NWS) - Peak wind speed at 158 mph from Garner Industries



DBH: ~19 in
Height: ~ 33.3ft (10m)

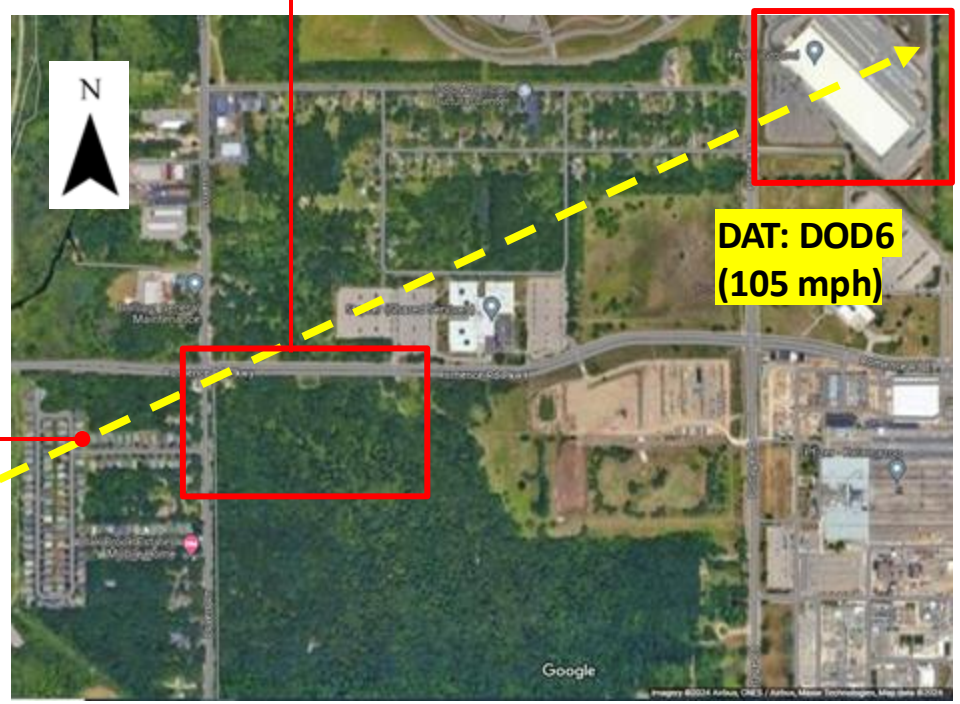
Car thrown into the lake according to GI worker

EF Scale Warehouse (WHB)

		EXP	LB	UB
7	Total destruction of a large section of building or entire building	158	131	186

Portage, MI

- EF2 (NWS)
- Estimated peak wind speed at FedEx building: 105 mph



Significant tree damage
- Treefall analysis
- UIUC prelim result: 115 mph

EF Scale Manufactured Home (MHWD)

		EXP	LB	UB
12	Complete destruction of unit; debris blows away	134	119	154

No evidence of anchor to the ground

Safety and Sheltering

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Source: Civil Air Patrol (CAP)
Tornado path
Refuge area
Dollar Tree


4
3
2
Dollar Tree

Refuge area

Garner Industries

Garner Industries

Garner Industries

Refuge area

Drone image by UIUC

FedEx

Refuge areas
(Bathrooms)

FedEx

Preliminary Findings: Safety and Sheltering

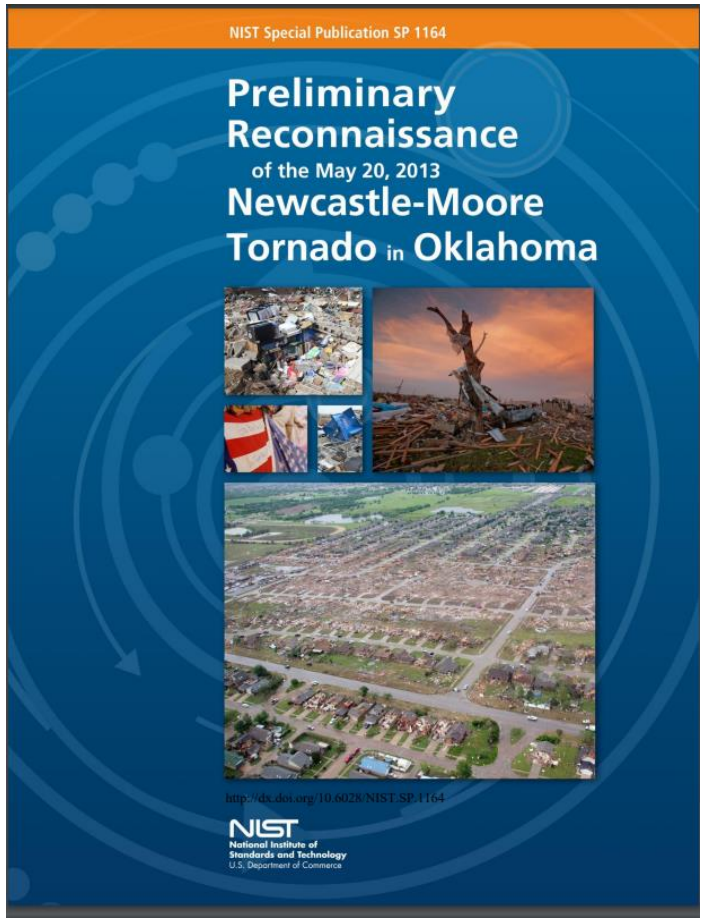
- None of the warehouses had storm shelters or safe rooms
- Lack of pre-storm planning for best available refuge area
  - Garner Industries: safety coordinator made plan two months before tornado hit
  - Dollar Tree & FedEx: plans developed on the fly
- Refuge area in Garner warehouse performed well
  - Interior room outside the laydown radius of exterior walls
- Refuge areas in Dollar Tree & FedEx were not directly impacted
- Challenges with egress from refuge area (Garner)
- Damaged utilities presented additional hazards after the tornado
  - Gas leak at the Garner warehouse

Preliminary Findings: Structural Performance

- Initial failure modes were similar for all three warehouses
  - Windward roof joist-to-structure failure due to combined:
    - External uplift forces, accentuated by updrafts near the core of the tornado
    - Positive Internal pressure pushing up on the roof
      - Potential contribution from Atmospheric Pressure Change (APC)
      - Wind-induced internal pressure from windward wall openings
        - Open doors (for thermal comfort/operations)
        - Garage door failures
  - Loss of lateral support at the top of windward walls - walls fall inward
- Progressive failures to more roof structure and in some cases, leeward walls
- Lack of load path redundancy
- Difference in severity of damage could be due to:
  - Tornado size: all tornadoes were narrower than the buildings
  - Relative size of tornado compared to the building
  - Difference in tornado wind speeds over the buildings and design wind speeds
  - Construction details/quality

Next Steps

- Collaborate with ASCE on FedEx warehouse report
  - Target timeline – publish by Spring 2025
- NIST Preliminary Reconnaissance Report- similar to the Moore tornado report, which focused on three facilities
  - Complete analysis and documentation of findings
  - Develop recommendations
  - Target timeline – publish report in Summer 2025
- Enhance understanding of warehouse performance in tornadoes from a national perspective
- Develop tornado-resistant design guidance for warehouse and warehouse-like construction



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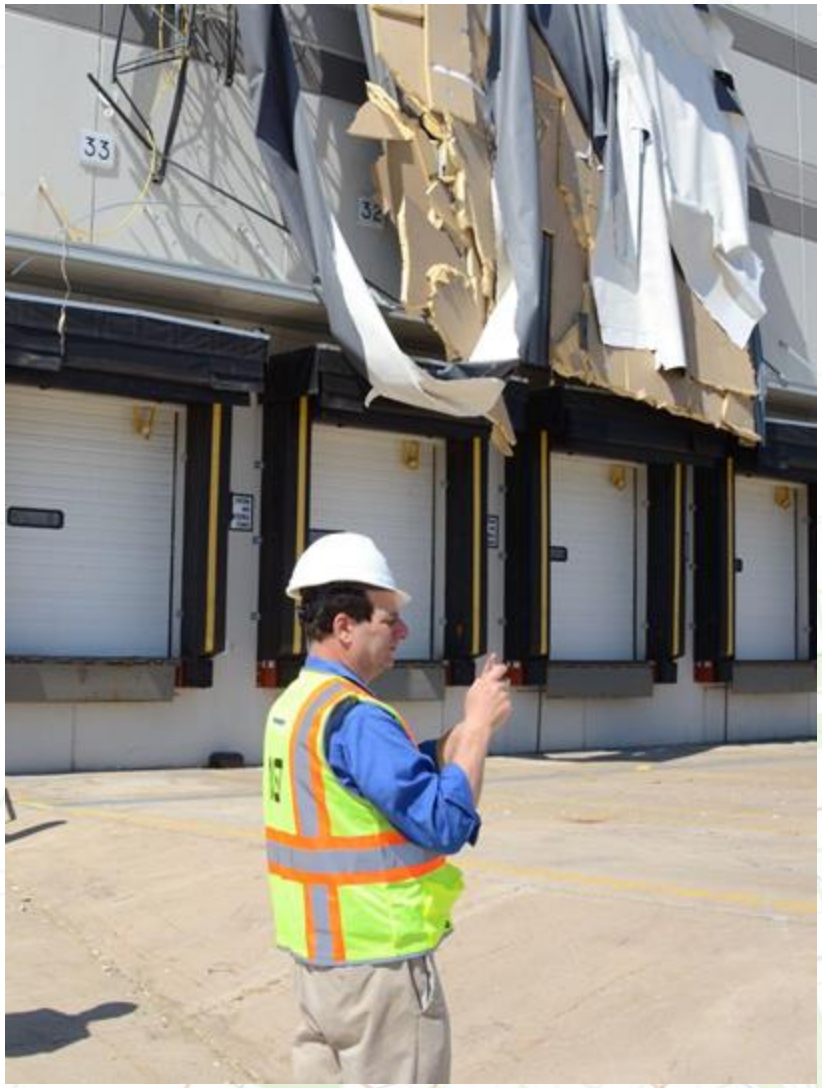
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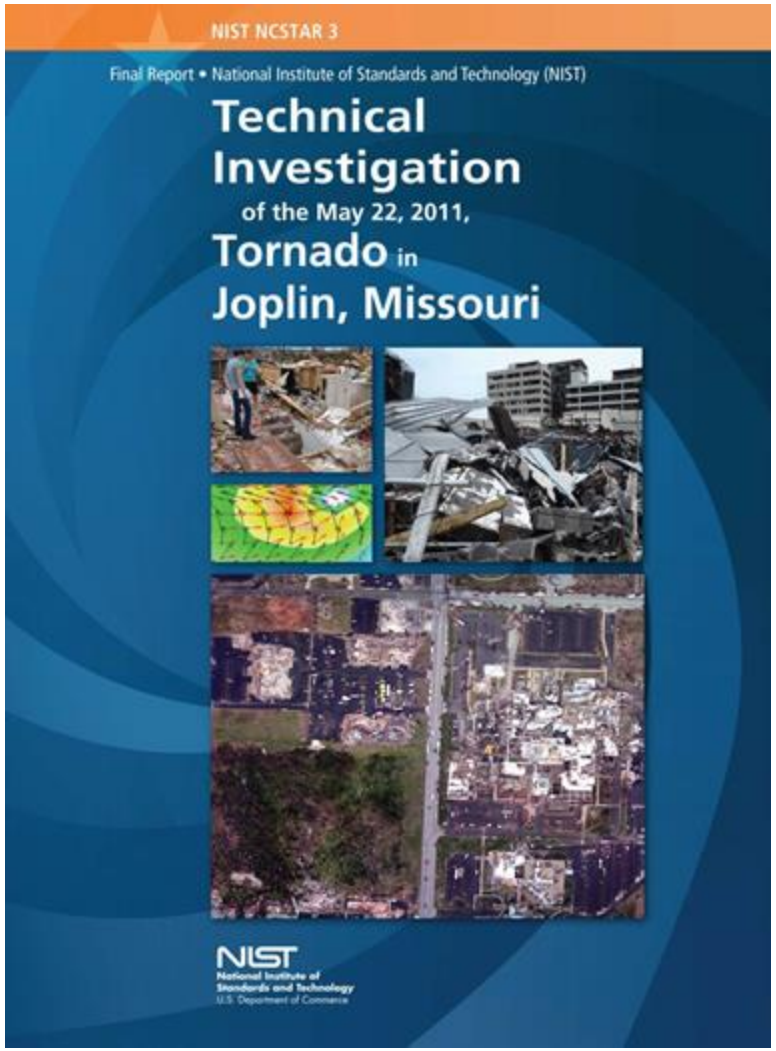
Joplin Tornado Recommendations

Marc Levitan
Research Engineer, Structures Group

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

NIST Joplin Tornado Investigation



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**

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

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**
	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**
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Tornado Wind Speed Measurements

R1: Development and deployment of technology to measure tornado wind fields
R2: Archival of tornado event data in publicly available and easily accessible databases

Multiple current/recent research projects

Low-Level Internal Flows in Tornadoes experiment (LIFT)

- Seeks to gather data to characterize tornado flows in the level of the atmosphere where they impact humans; the lowest 50-100 feet of the atmosphere
- Collaboration of NOAA/NSSL, Texas Tech University and the Cooperative Institute for Severe and High-Impact Weather Research and Operations (CIWRO)
- Supported by VORTEX-USA

Boundary-layer Evolution and Structure of Tornadoes (BEST)

- Goal: resolve tornado structure, evolution, the intensity of winds, and the temperatures and humidities near tornadoes that likely affect how intense they are
- PI - Karen Kosiba, Flexible Array of Radars and Mesonets (FARM) Facility, University of Illinois
- Supported by NSF, 2023-2026

Source: NOAA/NSSL

NIST/NSF Disaster Resilience Research Grants (DRRG)

- Measurement of tornado-like winds and wind loads
- Estimation of tornadic wind speeds from debris flight tracking
- Details on the following 2 slides

Measurement of Near-Surface Pressure, Wind and Wind-Induced Load Characteristics using Novel Sensors in Thunderstorm, Tornado and Tornado-Like Environments

NIST Award: 70NANB19H057
PI: Lombardo
Institution: University of Illinois Urbana-Champaign
Years: 2020-2024

RESEARCH OBJECTIVES

(1) Development, validation and production of low-cost sensors to measure wind and wind loading characteristics (near-surface)

(2) Rapid deployment and collection of unprecedented datasets

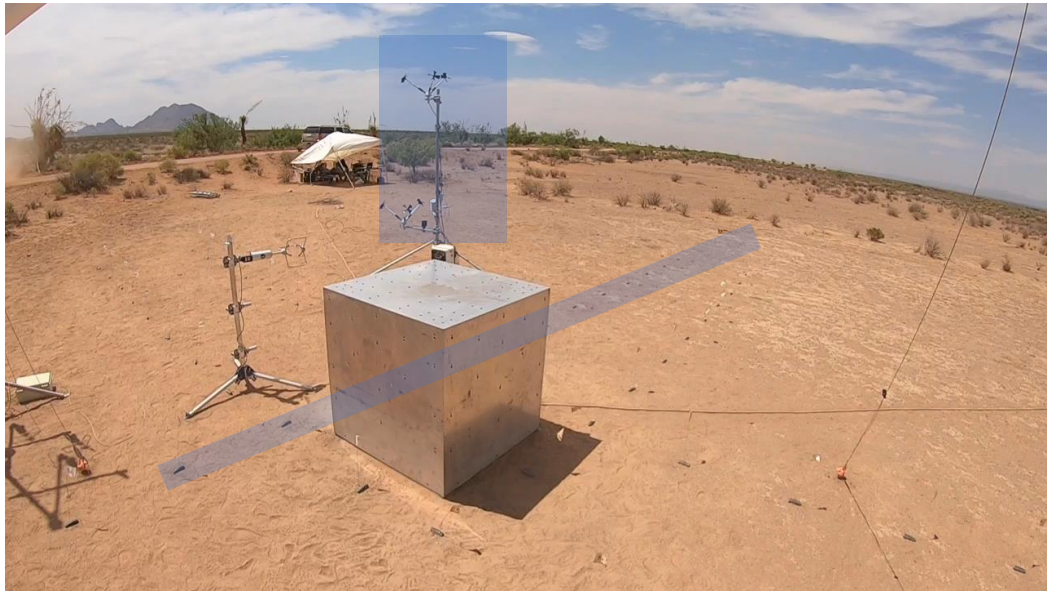
(3) Analysis and dissemination of these datasets

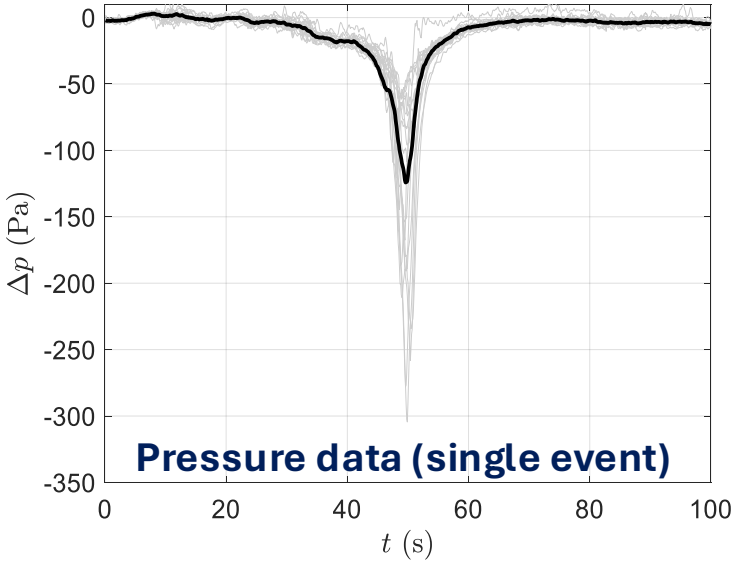
RESEARCH SUMMARY

Developed and/or validated wind loading cube, drag sphere anemometer and pressure sensors. Purchased instrumented towers to assist in validation.

Deployed on all storm types; full-scale vortex loading first documented; collection of dust devil (vortex) data possible way forward for use in tornado-based design.

Two papers published (cube, dust devil) as result of analysis. More analysis to follow.





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Reconstruction of Four-Dimensional Near-Surface Wind Characteristics from Debris and Damage Attributes using Computer Vision

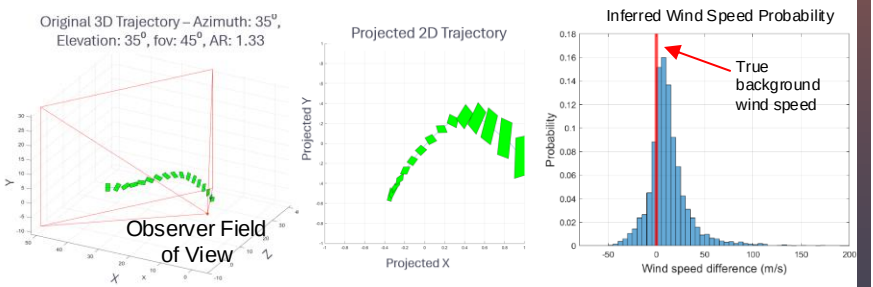
Grant Number: NSF CMMI-2053935 | Project Period: 10/2022 – 9/2024

Objectives

1. Build library of debris flight videos (real-world and experimental)
2. Deploy CV algorithms for detecting/tracking debris in videos
3. Develop framework for inferring near-surface wind characteristics from debris motion

Major Accomplishments

1. Multiple high-quality citizen science videos solicited and received
2. Extensive wind debris flight experimental program completed at FIU Wall of Wind
3. Digital twin of the wind speed inference framework established to evaluate uncertainties and improve methods



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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 distinguish between the most intense tornado events

New ASCE/SEI/AMS ***Standard for Wind Speed Estimation in Tornadoes and Other Windstorms*** under development

Chapter Status

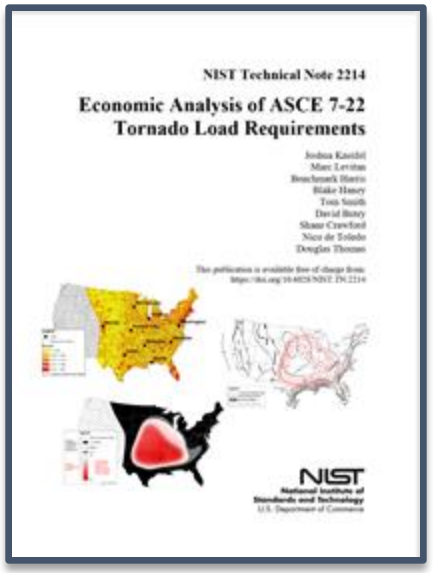
1. **General** – under development
2. **Radar** – approved March 2024
3. **In Situ** – first Main Committee ballot in Dec 2023
4. **EF Scale**
   - Finalizing revisions to existing DIs
   - Finalizing new DIs
   - Anticipated Main Committee ballot of entire chapter in spring 2025
5. **Forensic Engineering**
   - Substantive changes from last version
   - Subcmte Ballot in June 2024 to address revisions
6. **Treefall Pattern and Forest Damage Analysis**
   - Revised draft approved by Subcommittee
   - No Substantive Changes
   - 2nd Main Committee Ballot pending release
7. **Remote Sensing Imagery**
   - Draft approved by Subcommittee
   - Main Committee ballot in preparation

Adoption of Tornado Standard

R5: Develop PBD standards for tornado-resistant design and adopt in model codes and local regulations

Multi-year, multi-part strategy to maximize likelihood of success for incorporation of ASCE 7-22 tornado loads into the 2024 IBC and adoption into federal, state and local codes

1. **Documentation of tornado impacts to critical facilities**
2. Economic analysis of ASCE 7-22 tornado load provisions
3. **Extensive stakeholder communications**
4. Develop IBC proposal + testimony, in collaboration w/ ASCE & FEMA
5. Develop Tornado Load Design Guide, in collaboration w/ FEMA



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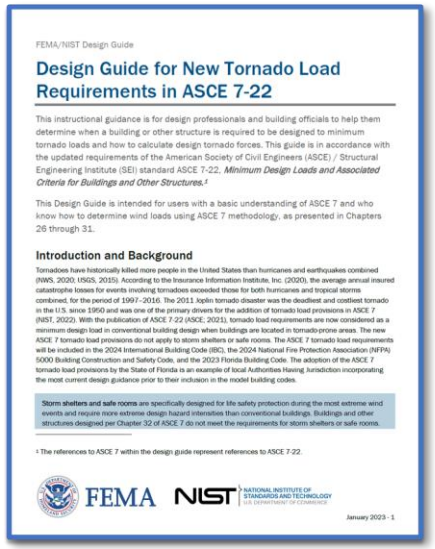

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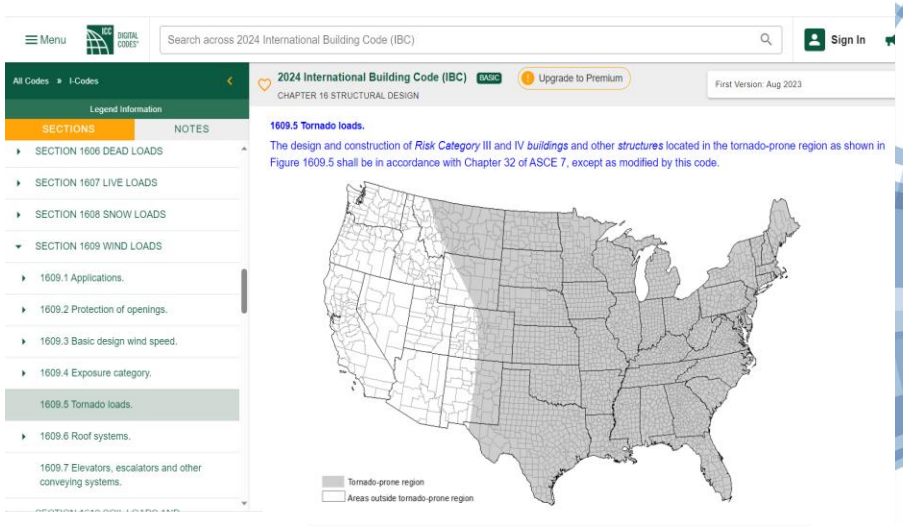

FIGURE 1609.5 TORNADO-PRONE REGION

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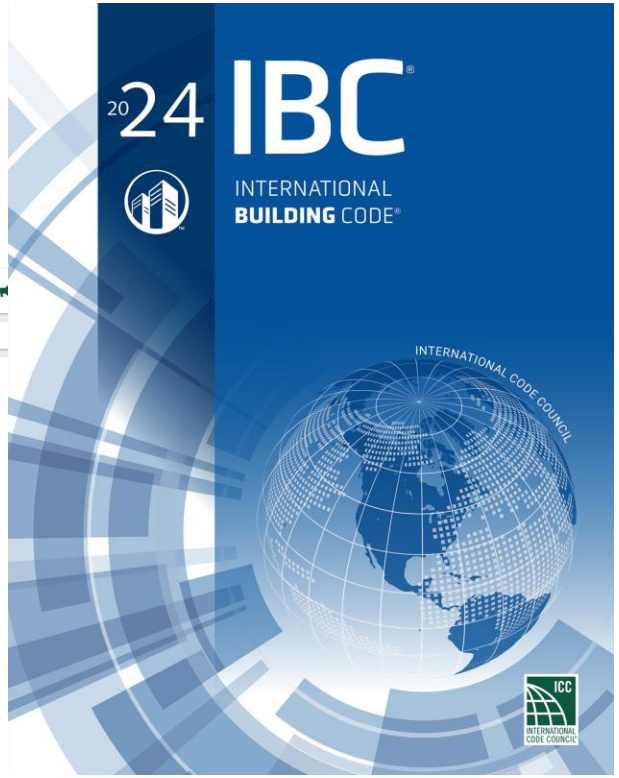

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Adoption of Tornado Standard
Documentation of Tornado Strikes on Critical Facilities (1/4)

Goal:

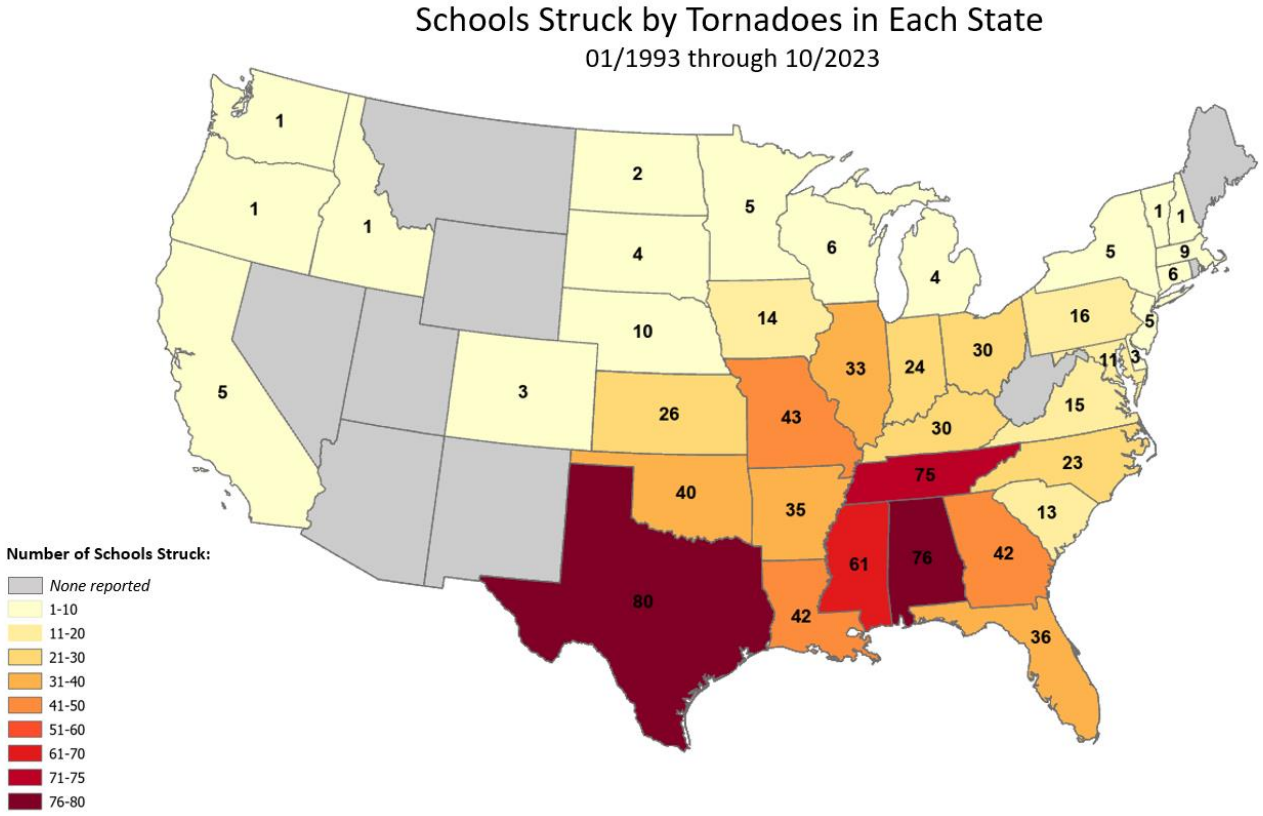
- Help stakeholders make risk-informed decisions on adoption of emerging engineering design standards and codes for tornadoes, and requirements for storm shelters in schools and other facilities

Methods:

- Mining NOAA Storm Events Database, NWS Damage Assessment Toolkit (DAT), news media, technical reports, and other sources

Updates:

- Expanded methodology to include more efficient language processing techniques using SQL
- GIS analysis (intersecting damage paths with critical facility datasets)- expanded to whole nation
- Total counts through 10/2023 are now over **850 tornado strikes on schools and 200 tornado strikes on fire/rescue/EMS stations**



New to database in 2024

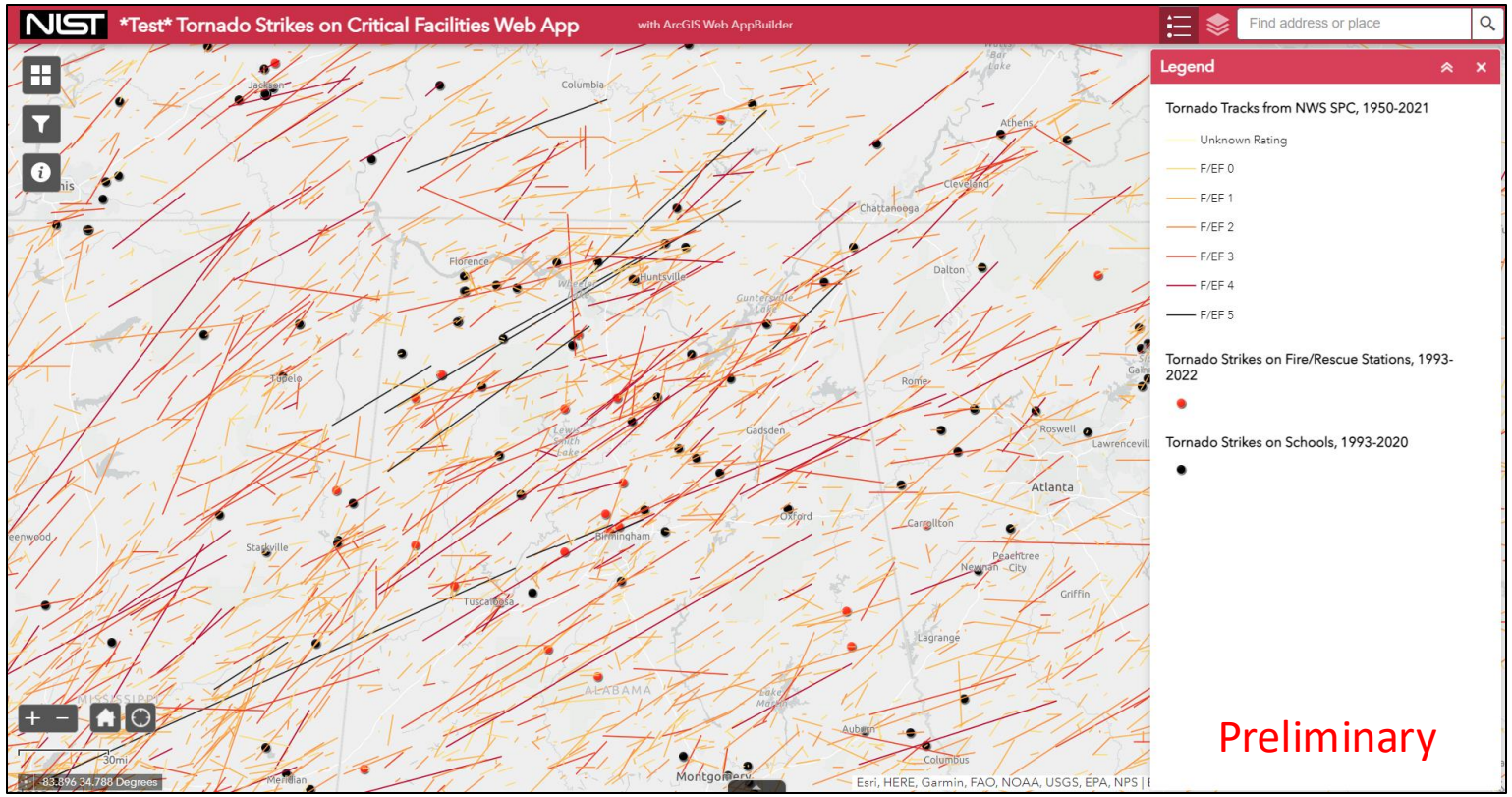
- **Hospitals**
- **Nursing homes**
- **Airports**
- **Warehouses**

Hospital ID	Hospital Name (add an asterisk if uncertain)	Picture
670809	BATON ROUGE GENERAL MEDICAL CENTER	
3857108	AVERA BEHAVIORAL HEALTH CENTER	
3257108	AVERA HEART HOSPITAL OF SOUTH DAKOTA	
18518901	DOYLESTOWN HOSPITAL	
90030265	SOUTHEASTERN REGIONAL MEDICAL CENTER	
15863841	SOUTHEASTHEALTH CENTER OF STODDARD	
8467901	SOUTHWEST MEDICAL CENTER	
5667544	CLARA BARTON HOSPITAL	

Adoption of Tornado Standard
Documentation of Tornado Strikes on Critical Facilities (2/4)

Developing interactive web map:

- Will allow stakeholders and local decision-makers to view past tornado strikes on critical facilities in their regions, along with historic tornado tracks
- Possibility for inclusion of Citizen Science component – ability to submit more data on facilities in the database or additional critical facility tornado strikes



Documentation of Tornado Strikes on Warehouses (1/2)

- Adding warehouses and warehouse-type structures to the database to support NIST research on warehouse performance in tornadoes
- Two relevant definitions for “warehouse”

  Functional:
  Warehouse/distribution/manufacturing role

  Structural:
  “Box-type” structures as defined in the NIST Joplin Report (NCSTAR 3)

- Mined over 2,900 NWS DAT damage points for tornado strikes on these facilities
- Collected data on 33 attributes for each facility, including construction type/materials, extent of damage, time to reopening, etc.

Source: NWS Paducah

Documentation of Tornado Strikes on Warehouses (2/2)

- Analyzing warehouse performance with respect to wind speed, structure type, and other factors
  - Preliminary analysis in progress, focused on:
    - Quantifying uncertainty in wind speed estimation for warehouse-type structures in the DAT
    - Performance of “box-type” structures vs. metal building systems vs. other structure types
    - Rates of wall collapse vs. roof damage and structure type
    - Frequency of garage door damage
- Plan to study patterns with injuries and fatalities, sheltering locations, supply chain impacts, and employment disruption/job loss


Source: NWS Memphis


Source: NWS Birmingham

Thanks to colleagues Jamil Malik, Warren Stewart, Katherine J. Johnson, P. Shane Crawford, Dominique Paige, Colten Brunhoeber, Nelson Tucker, Silvia Brown, Kevin Ly, Josiah Main, and Katherine Tang!

How can Warehouse Safety in Tornadoes be Improved?

Are the current IBC Risk Categories appropriate for all warehouses in the tornado-prone region?

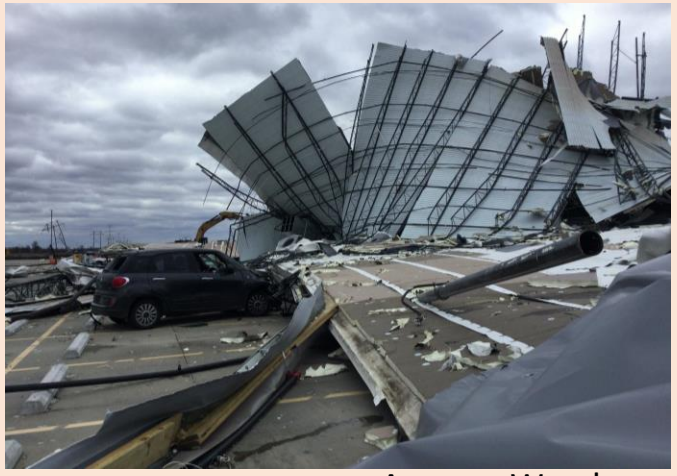
RC III: Buildings and other structures that represent a substantial risk to human life in the event of failure

RC IV: Buildings and other structures designated as essential facilities and buildings where **loss of function represents a substantial hazard to** occupants or **users**

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

Research Questions

- Do these large warehouses and warehouse-like structures represent a greater risk to human life? If so – use RC III?
- Does loss of function of these warehouses represent a substantial hazard to *users*? If so – use RC IV?
  - Consider impacts to community resilience, economy, and supply chain?
  - 'Users' can be hundreds or thousands of miles away



Source: NOAA/NWS.

Amazon Warehouse
Edwardsville, IL, Dec. 2021
6 Fatalities

Illinois House Labor and Commerce Committee Hearing

- Oral and written testimony, 2022

Illinois Warehouse Safety Task Force

- Oral testimony, 2024

NIST provided information on options to improve life safety and reduce damage

- Require storm shelters, and/or
- Require warehouses to be Risk Category III or IV, or
- Specify minimum required ASCE 7 tornado design speed

Adoption of Tornado Standard
Stakeholder Communication Highlights (since June 2023 briefing, 1/2)

Industry/Professional Conferences and Meetings

- IIBEC Leadership visit to NIST
- 2023 National Disaster Resilience Conference*
- IIBEC International Convention and Tradeshow 2024*
- ASCE 2023 National Convention
- ASCE Inspire Conference 2023
- National Storm Shelter Association Annual Conference 2023
- Structural Engineers Association of Nebraska Annual Structural Conf.
- Nebraska Section ASCE Meeting
- Inaugural Meeting, National Capital Section, Structural Engineering Institute

Research Conferences/Meetings

- Tornado Hazard Wind Assessment and Reduction Symposium (THWARTS)*
- NHERI Research Summit 2024
- VORTEX-SE Outreach & Engagement Advisory Council

Federal Agency Briefings

- U.S. Nuclear Regulatory Commission (NRC)
- Dept. of Housing and Urban Development (HUD)
- Science for Disaster Reduction (SDR) Interagency Working Group

University Seminars

- Johns Hopkins Department of Civil and Systems Engineering
- Purdue Department of Civil Engineering

National Disaster Resilience Conference

NIST Frontiers Lecture, May 2024
Surviving the Whirlwind:
Design of Buildings for Tornadoes

*Keynote Address

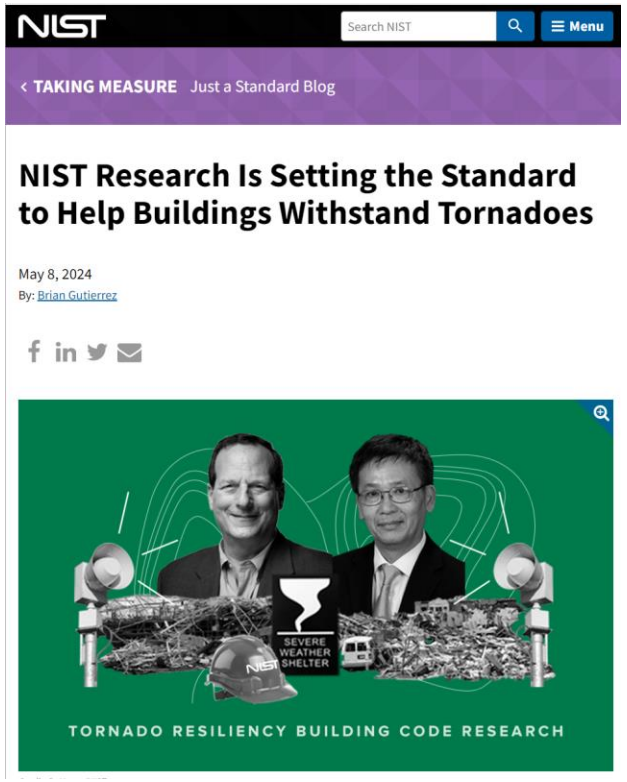
Adoption of Tornado Standard
Stakeholder Communication Highlights (since June 2023 briefing, 2/2)

8 Media interviews, including:

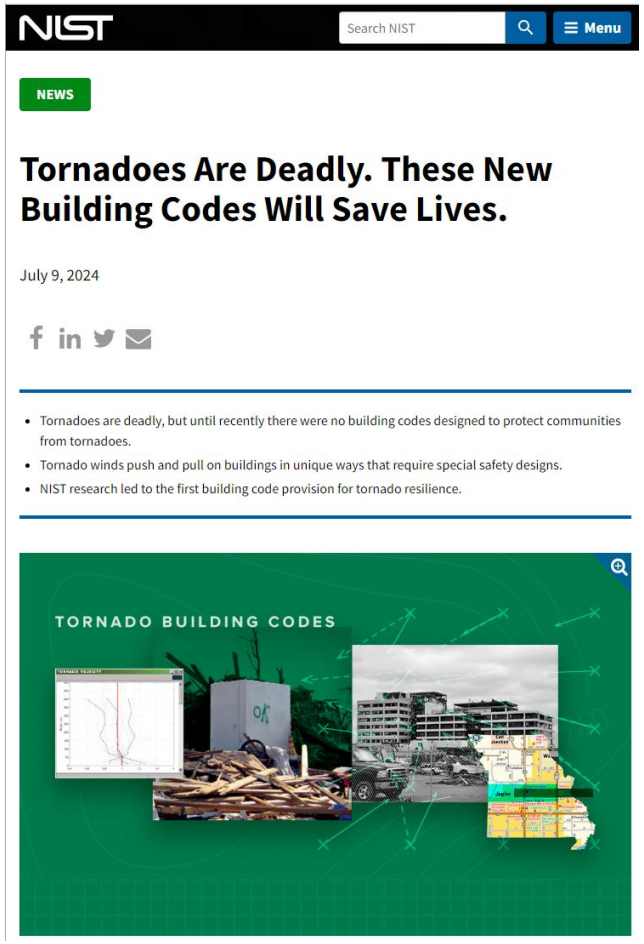
- WOSU Public Radio – Columbus OH
- TG Magazine - Texas A&M Real Estate Research Center
- Scripps News (TV and web article)
- NTWC Live (web broadcast)
- KTTZ-FM 89.1 Lubbock NPR (web article)
- WFLD-TV/Fox 32 Chicago
- Engineering News Record
- Federal Laboratory Consortium for Technology Transfer (FLC) – Labs in Action Series

2 NIST stories

- Taking Measure Blog and Article



https://www.nist.gov/blogs/taking-measure/nist-research-setting-standard-help-buildings-withstand-tornadoes



https://www.nist.gov/news-events/news/2024/07/tornadoes-are-deadly-these-new-building-codes-will-save-lives

Improving the Tornado Load Methodology (1/2)

R6: Development of performance-based tornado design methodologies

Comparison of tornado pressure coefficients from tornado simulator (TS) with ASCE 7-22

- Evaluation of tornado uplift factor (K_{vT}) for roof
- Consideration of both MWFRS and C&C
  * Additional uplift force due to vertical wind component (V_{ver})

$$p_T = qG_T K_{dT} K_{vT} C_p - q_i (GC_{piT})$$

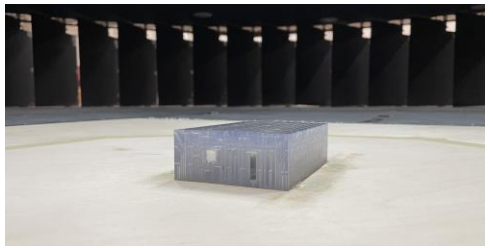
$$K_{vT} = \frac{GC_{p,TS}}{GC_{p,ASCE}}$$

← Pressure coeff from TS, with V_{ver}

← Pressure coeff from ASCE 7, w/o V_{ver}

- Extensive literature review to ensure "apples-to-apples comparison" of experimental data with ASCE 7-22 tornado provisions

Wind Engineering Research Field Laboratory



Building Model in TS (1:100 length scale)

Source for photographs and video:
National Wind Institute at Texas Tech University
Used with Permission.

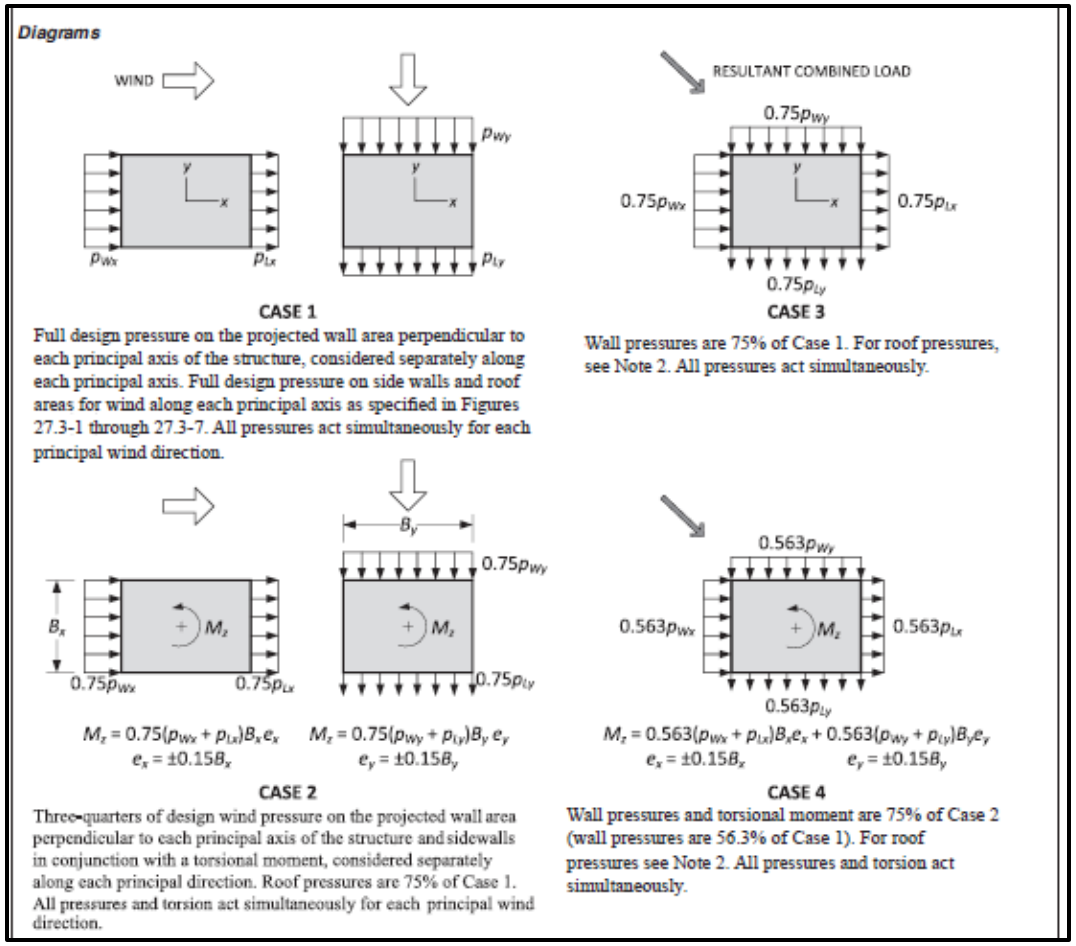
Improving the Tornado Load Methodology (2/2)

R6: Development of performance-based tornado design methodologies

Evaluating the Tornado Load Cases in ASCE 7-22

ASCE 7 Wind Load Cases for design of the Main Wind Force Resisting System (MWFRS) are likely not representative for tornado loads, particularly for small tornadoes hitting large buildings

- Awarded NIST Measurement Science and Engineering (MSE) Research Grant to ARA, Inc to analyze Tornado Load Cases
- Will review the analysis and develop modifications for tornado load cases, as needed, and propose for ASCE 7-28



Impacts/Engagement Summary

Published
In Progress
In Planning / Development
Updates Since June 2023 Briefing

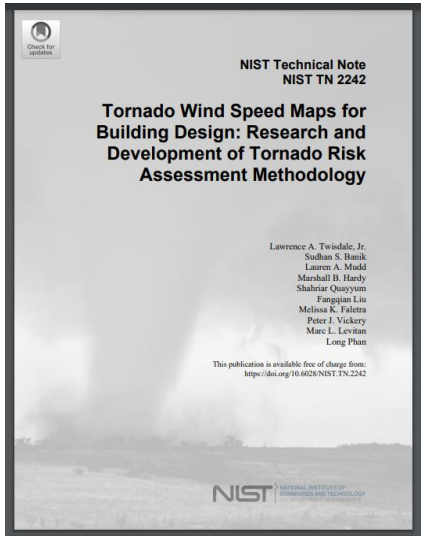
- **Existing Standard**
  - **NFPA 1600-2019**, Standard on Continuity, Emergency, and Crisis Management
  - **ICC 500-2020**, Standard for Design and Construction of Storm Shelters
  - **ASCE/SEI 7-22**, Minimum Design Loads and Associated Criteria for Buildings and Structures
  - **ICC 500-2023**, Standard for Design and Construction of Storm Shelters ← **Published Nov 2023**
- **New Standards**
  - **NFPA 1616-2017**, Standard for Mass Evacuation and Sheltering
  - **ASCE/AMS** Standard for Estimation of Wind Speeds in Tornadoes
- **Building Codes**
  - **2018 International Building Code (IBC)**
  - **2018 International Existing Building Code (IEBC)**
  - **2023 Florida Building Code** ← **Published Fall 2023**
  - **2024 International Building Code (IBC)** ← **Published Fall 2023**
  - **2024 NFPA 5000 Building Construction and Safety Code** ← **Published Fall 2023**
  - **2024 Houston TX Building Code** ← **Published Fall 2023**
- **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.

  } New editions of safe room guidance to align with ICC 500-2023 in development
  - **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
  - **FEMA P-2062**, Guidelines for Wind Vulnerability Assessments of Existing Critical Facilities
  - **NIST Technical Note,** Alerting under Imminent Threat: Guidance on alerts by outdoor siren & 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.
  - **FEMA/NIST,** Design Guide for New Tornado Load Requirements in ASCE 7-22
  - **FEMA/NIST,** Fact Sheet: Improving Windstorm and Tornado Resilience: Recommendations for 1&2-Family Residential Structures
  - Guidelines for Tornado Resistant Design of Risk Category II Buildings
  - Guidelines for Public Tornado Sheltering Strategies

Workshops

- 1st NIST/ASCE Tornado Map Stakeholder Workshop, 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 Workshop, 2019
- Quad-State Tornado Outbreak Workshop, 2022
- **Tornado R&D Needs Workshop (with ASCE), 2024**

Published in Fall 2023



Remaining Implementation Tasks

Legend
Primarily Completed
Significant Activities/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 new ASCE/AMS Standard
Buildings, Shelters, Designated Safe Areas, and Lifelines	5	Develop PBD standard for tornado loads/incl. in model code/local adoption
	6	Develop performance-based tornado design methodologies ← Develop guidance for RC II Buildings
	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	Prohibition of 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 mgrs/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

Tools and outreach to support local adoption

R&D for improvements to ASCE 7-28 tornado load provisions (R6 and R5)

Recent Tornado Preliminary Reconnaissance Missions
and
Joplin Tornado Recommendations

QUESTIONS?