May 22, 2011
Joplin, MO Tornado Study

Draft Study Plan and Research Overview

Briefing for NCST Advisory Committee
November 7, 2011

Marc L. Levitan
Joplin Tornado Study Team Leader
Lead, National Windstorm Impact Reduction Program (NWIRP) Research and Development

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

Presentation Outline

- Background and Draft Study Plan – *Marc Levitan*
  - Rating Tornadoes – The Enhanced Fujita Scale
  - Joplin Tornado Overview
  - Preliminary Reconnaissance
  - National Construction Safety Team
  - Draft Technical Study Plan
- Tornado Hazard Characteristics – *Frank Lombardo*
- Emergency Communications and Public Response – *Erica Kuligowski*
- Building and Lifeline Performance – *Long Phan*

NOTE: The information contained in this presentation is preliminary and subject to change as additional data is collected and analysis is performed.

Rating Tornadoes – The Enhanced Fujita (EF) Scale

- EF Number is assigned to a tornado based on observed damage
- Estimated wind speed ranges associated with EF Numbers

EF Number	Wind Speed (mph)	% of US Tornadoes[1]
0	65-85	62.2
1	86-110	26.5
2	111-135	8.0
3	136-165	2.6
4	166-200	0.58
5	200+	0.04

[1]1991-2010, Data Source: NOAA

- Typical damage state with EF-scale rating:

EF1

EF3

EF5

Joplin Tornado Overview

- Touched down in Joplin beginning at 5:34 PM CDT, Sunday, May 22, 2011
- Enhanced Fujita Scale EF-5 tornado (highest category)
- Maximum estimated wind speeds: 200+ mph
- Path: up to 1 mile wide, 22.1 miles long (6 miles in Joplin)
- Track: generally West to East across Joplin (Newton and Jasper counties)
- ≈ 8,000 structures damaged or destroyed (≈30% of Joplin)
- 162 fatalities, >1,000 injuries (Joplin Population: 49,024)

Sources: National Weather Service (NWS), Federal Emergency Management Agency (FEMA), City of Joplin

Source: NOAA

Preliminary Reconnaissance

Four person NIST team

- Departed from NIST afternoon of May 24, (< 48 hours following tornado)
- Returned May 28, 2011

Objectives: Collect information and data on

- Tornado hazard
- Pattern, location, and cause of fatalities and injuries
- Tornado warning system, evacuation, emergency response, and occupant behavior
- Response of buildings, tornado shelters, and designated safe areas
- Damage to lifelines (natural gas, electrical distribution, etc.) and resulting fires

Preliminary Reconnaissance - Data Collection Scope and Sources

- Warning Procedures/Emergency Operations
  - Director of Joplin/Jasper County Emergency Management Agency
  - NWS Incident Meteorologists
  - St. John's Medical Center, Director of Quality and Risk Management
  - St. John's Medical Center staff, Safety and Security
- Federal and State Tornado Mitigation and Response Efforts
  - FEMA Region VII Mitigation Division Director
  - MO State Emergency Management Agency (SEMA) Branch Chief, Logistics, Resources, Mitigation, and Floodplain Management Branch
  - SEMA Earthquake Program Manager
- Building Codes and Documents
  - City of Joplin Building Official and Code Enforcement Supervisor
- Fires and Lifelines
  - City of Joplin Fire Chief and Fire Marshall
  - Media Relations for Missouri Gas Energy
  - Engineering Manager of Missouri American Water
- Building and Infrastructure Performance
  - Observed and documented over 20 buildings and structures
- Behavioral Response
  - Interviewed 25 persons who experienced the tornado

National Construction Safety Team

Based on analysis of the data collected and other criteria required by law and regulation, NIST Director Patrick Gallagher established a Team under the NCST Act on June 29, 2011, to proceed with a more comprehensive study of the impacts of the disaster.

- Team Members
  - Four NIST Engineering Laboratory employees
    - Dr. Marc Levitan: Study Team Leader, Wind Engineer, Leader of NIST NWIRP R&D
    - Dr. Erica Kuligowski: Fire Protection Engineer and Sociologist
    - Dr. Frank Lombardo: Wind Engineer and Meteorologist
    - Dr. Long Phan: P.E., Structural Engineer, Experienced in wind disaster studies
  - One National Oceanic and Atmospheric Administration (NOAA) employee
    - Dr. David Jorgensen: Research Meteorologist and Chief, National Severe Storms Lab (NSSL)/Warning R&D Div.

Draft Technical Study Plan

- Draft study plan available at
  - http://www.nist.gov/el/disasterstudies/weather/joplin_tornado_2011.cfm
- Goals
  - To study the wind environment and technical conditions that caused fatalities and injuries in the May 22, 2011, Joplin, MO, tornado, the performance of emergency communications systems and public response, and the performance of residential, commercial, and critical buildings; designated safe areas in buildings; and lifelines.
  - To serve as the basis for:
    - Potential improvements to design and construction of buildings, designated safe areas, and lifeline facilities in tornado-prone regions;
    - Potential improvements to guidance for tornado warning systems and emergency response procedures;
    - Potential revisions to building, fire, and emergency communications codes, standards, and practices; and
    - Potential improvements to public safety.

Draft Technical Study Plan - Objectives

1. Determine the tornado hazard characteristics and associated wind fields in the context of historical data
2. Determine the pattern, location, and cause of fatalities and injuries, and associated emergency communications and public response
3. Determine the response of residential, commercial, and critical buildings, including the performance of designated safe areas
4. Determine the performance of lifelines as it relates to the continuity of operations of residential, commercial, and critical buildings
5. Identify, as specifically as possible, areas in current building, fire, and emergency communications codes, standards, and practices that warrant revision

Draft Technical Study Plan - Technical Approach

1. Identification of Issues Requiring Technical Study
2. Data Collection
3. Analysis and Comparison of Designs, Codes and Practices for Buildings and Emergency Communications Systems
4. Technical Findings and Recommendations
5. Identification of Needs for Revisions to Codes, Standards, and Practices

Draft Technical Study Plan - Expected Outcomes

- Findings and recommendations that provide the technical basis for:
  - Assessing tornado hazard probabilities at the local, regional, and national levels
  - Potentially improving emergency communications systems and public response to those communications
  - Potentially improving tornado-resilient design and construction of buildings and structures, including residential buildings, designated safe areas within buildings, and lifeline facilities as related to maintaining building operations

Draft Technical Study Plan - Anticipated Impacts

- Improved resilience of buildings, infrastructure, and communities to tornadoes
  - specifically focused on life safety objectives and enhanced performance of buildings during tornadoes to better protect building occupants and property
- Enhanced emergency communications systems and lifeline performance in future disasters
- Inform future research for the development and dissemination of guidance and tools for
  - assessing and reducing vulnerabilities related to tornadoes
  - producing the technical basis for cost-effective changes in national codes, standards, and practices

May 22, 2011
Joplin, MO Tornado Study

Tornado Hazard Characteristics

Briefing for NCST Advisory Committee
November 7, 2011

Frank Lombardo
Study Task Leader
NRC Postdoctoral Research Associate, NWIRP
David Jorgensen
Study Task Leader
Research Meteorologist and Chief, NOAA/National Severe Storms Lab/Warning R&D Division

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

Primary Objective

- Determine the tornado hazard characteristics and associated wind fields in the context of historical data

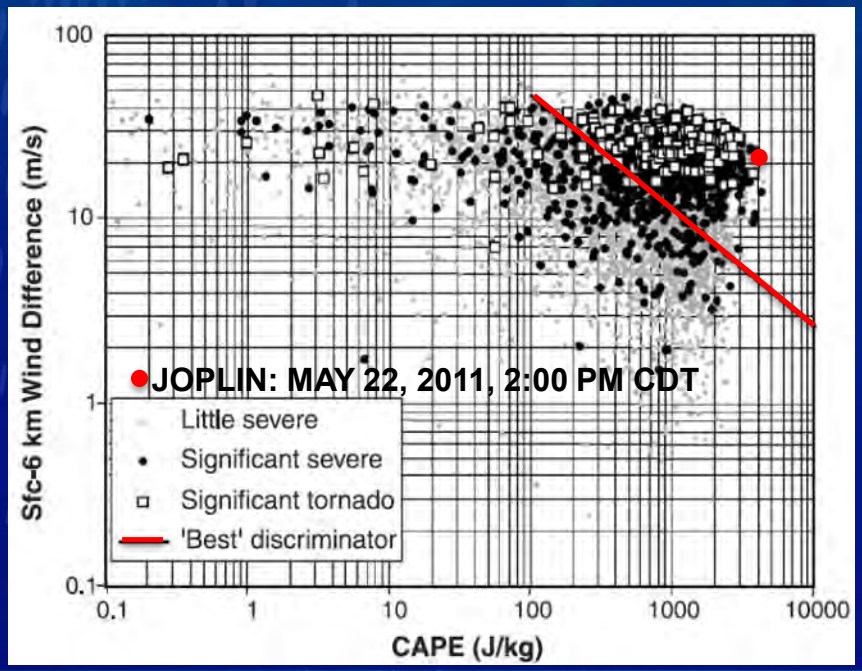
Presentation Outline

- Meteorological Conditions
- Near Surface Wind Environment
- Historical Context
- Tornado Climatology and Associated Risk
- Spatial Characteristics
- Enhanced Fujita Scale Assessment

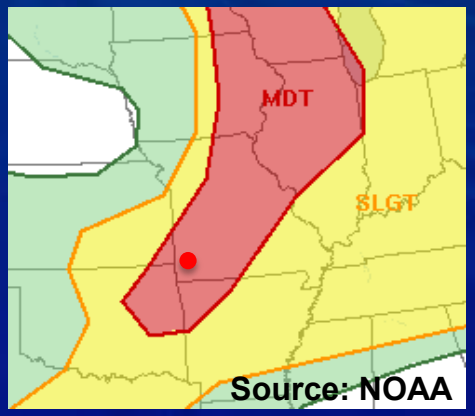
Meteorological Conditions

- Severe Weather Outbreak Likely
  - Instability and wind shear were sufficient for severe weather
  - 1:30 PM CDT - Tornado Watch issued for Joplin and vicinity
  - 3:00 PM CDT - Moderate (MDT) risk of severe storms
  - 3:00 PM CDT - 10% probability of strong tornadoes (EF2 or greater) within 25 miles of Joplin
  - 5:34 PM CDT - Approximate tornado touchdown in Joplin

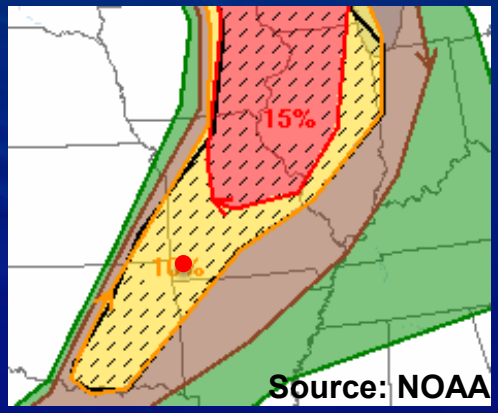
Source: NOAA



Categorical Severe Risk



Tornado Probabilities

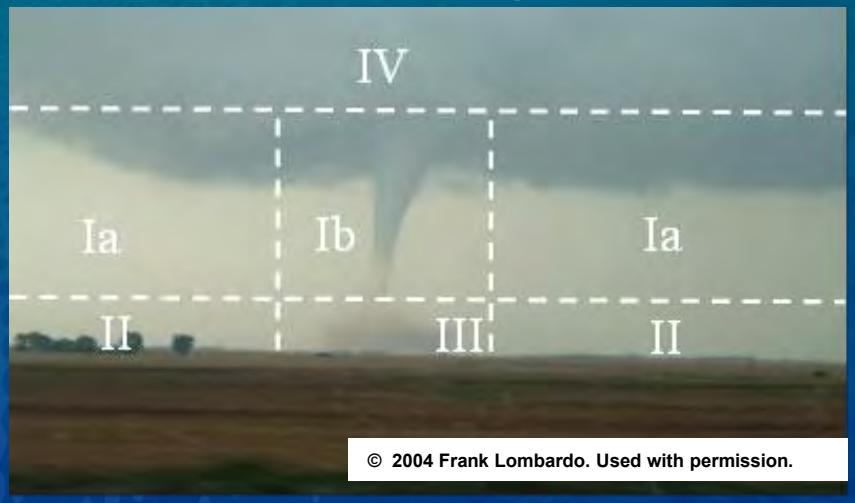


Source: NOAA
Enhancements: NIST

CAPE: Convective Available Potential Energy

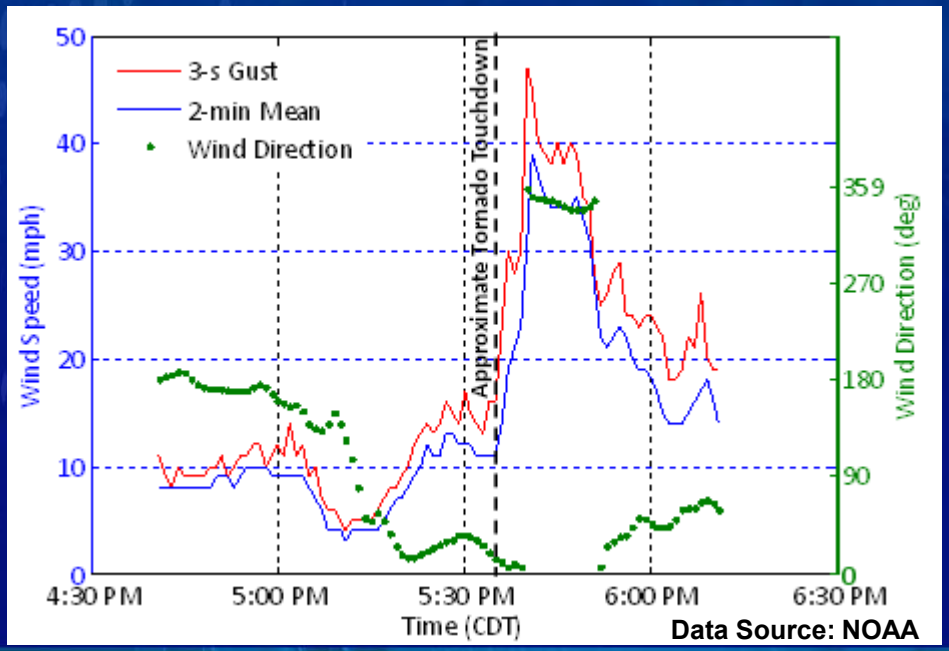
Near Surface Wind Environment

- Tornado Flow Regions



Ia. Outer Flow
Ib. Core Flow
II. Boundary Layer
III. Corner Flow
IV. Mesocyclone

- Direct Wind Speed Measurements



Joplin airport 10m anemometry data showing effects of tornado even though ~ 5-6 miles away! (Region II)

- Gusts ~50 mph
- Sustained ~40 mph
- Wind direction corroborates tornado position (south of airport)

Near Surface Wind Environment – Indirect

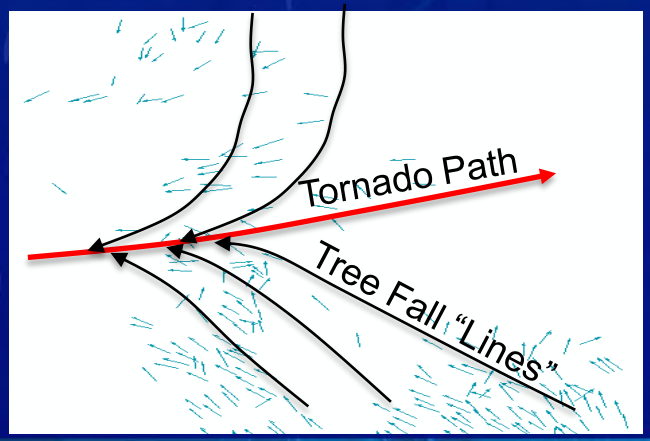
- Observed Damage (Using EF-scale)
- Three data sources
  1. NIST rated from aerial photos and ground photos/videos
  2. Jasper County Geographic Information Services (GIS)
  3. US Army Corps of Engineers (USACE)

Aerial Photo Source: NOAA
Enhancements: NIST

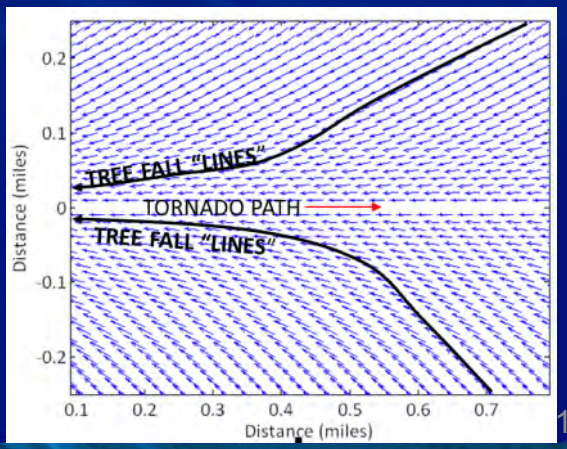
Near Surface Wind Environment – Indirect

- Back calculations of wind speed from discrete structural failures
  - Lower and upper bounds on wind speed
  - Sign/Lightpost Failure
    - Used in other studies → obtained samples from Joplin Public Works

- Tree fall analysis
  - Recent work (Beck and Dotzek, 2010) incorporates both:
    - Wind Field and Tree Damage Model → estimate wind speed



← Actual and Modeled → tree fall patterns near St. Johns Hospital



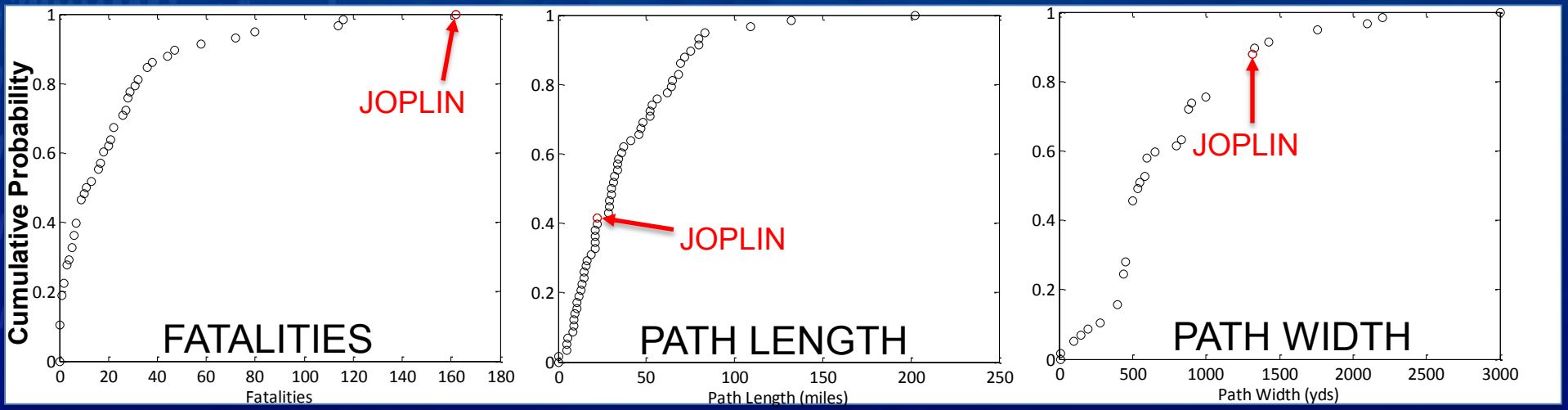
Near Surface Wind Environment – Indirect

- Photogrammetry
  - Surveillance videos obtained from Joplin School District for
    - Joplin High School
    - Joplin East Middle School
  - Estimate object speeds (i.e., windborne debris) from surveillance videos given distances and frame rates
  - Done in previous tornado investigations
  - Distances available from site survey and aerial photos

  - Object Speed = Distance/Time Elapsed Between Frames
  - Inferred as lower bound on wind speed

Historical Context of Joplin Tornado

- Local Tornadic Events Prior to May 22, 2011 (Source: NOAA)
  - May 5, 1971 (F2) → 1 fatality, 60 injuries, $2.5M
  - Three Nearby Significant Events (< 25 miles from Joplin)
    - April 3, 1956 (F4) → 118 injuries
    - May 4, 2003 (F3) → 17 fatalities, 116 injuries, $95M
    - May 10, 2008 (EF4) → 43 fatalities, 710 injuries, $122M
- US Tornadic Events - 58 F5 or EF5 tornadoes in official record (NOAA)



- Figure suggests causative factors at play in addition to size of tornado

Tornado Climatology and Associated Risk

Joplin Area Tornado Climatology (1950-2010)

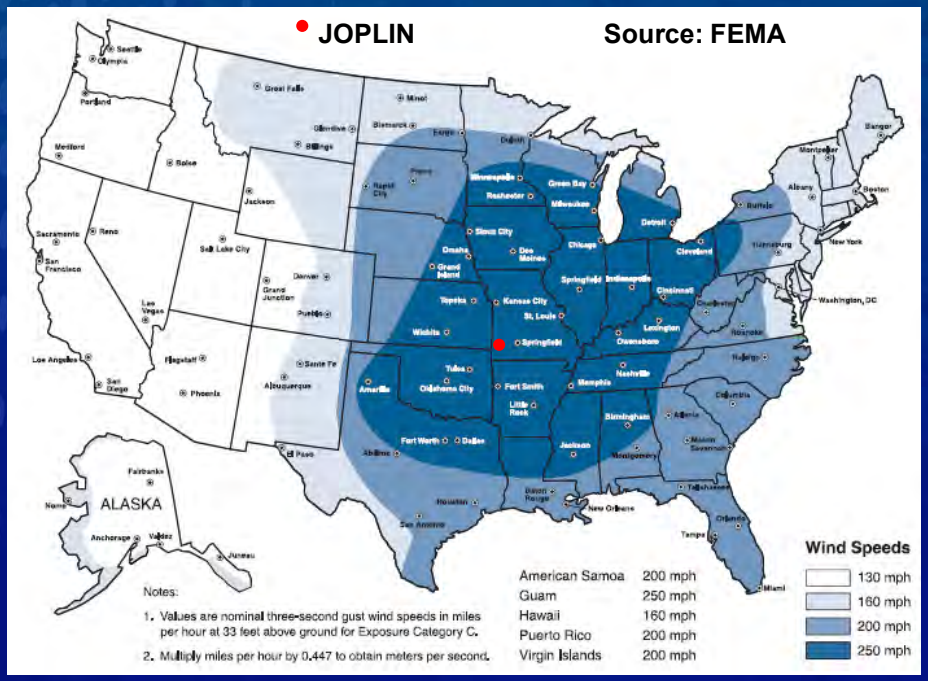
(25 mile radius)

(E)F Number	Tornado Count	Fatalities	Injuries
0	30	0	2
1	57	2	49
2	15	0	12
3	7	19	179
4	4	45	840
Unknown	2	0	0
Total	115	66	1082
5 (May 22, 2011)	1	162	1000+

Data Source: NOAA

Tornado Climatology and Associated Risk

- Tornado Hazards Specified in Standards and Guidelines
  - ANSI/ANS-2.3-2011 (for Nuclear Facilities)
  - ASCE/SEI 7-10 (Commentary) → 10^{-5} annual probability (ANSI map)
  - ICC 500, FEMA 361 (for Storm Shelters, Safe Rooms)
  - Typically based on a "point" approach → design of a single structure



Tornado Safe Room Design Wind Speed Map (FEMA 361)

Consistent with Tornado Hazard Map in the ICC 500 Storm Shelter Standard

ANSI: American National Standards Organization; **ANS**: American Nuclear Society; **ASCE**: American Society of Civil Engineers; **SEI**: Structural Engineering Institute; **ICC**: International Code Council

Spatial Characteristics of Joplin Tornado

- Tornado/Damage Path → Using ArcGIS, other sources
- Losses (Economic, Human, Physical)
  - Have locations of a majority of fatalities, structural damage, property info
  - Total estimated number of damaged and destroyed structures
    - 7,608 per Jasper County GIS
    - 8,369 per USACE
    - Majority are residential structures

Jasper County GIS Damage Estimate

	Light	Medium	Totaled	Demolished
Residential	3562	608	1010	2058
Commercial	245	90	185	272
Agricultural	7	20	12	98
Excepted	51	18	31	92

USACE Damage Estimate

	Limited	Moderate	Extensive	Catastrophic
Residential	1381	1166	1192	1612
Commercial	58	65	60	138
Industrial	13	1	1	0
Unknown	561	409	379	572

- Comprehensive characterization of all information described

Enhanced Fujita Scale Assessment

- History
  - Fujita (F) Scale developed in 1971 → operational in late 1970's
  - Limited damage indicators and construction quality issues (Phan and Simiu, 1998)
    - Enhanced Fujita (EF) Scale proposed
      - 28 "DIs" → damage indicators (homes, trees, etc…)
        - Each DI has a number of "DODs" → Degrees of Damage
        - Each DOD has a range of wind speeds determined by expert elicitation (wind engineers, meteorologists)
        - NWS adopted in 2007
- NIST Preliminary Finding
  - Tornado rating procedure (i.e., Enhanced Fujita intensity scale) lacks adequate indicators for distinguishing intense tornadoes (observations used in the determination not included as indicators in EF scale)

Next Steps

- Finalize analysis of meteorological conditions leading to and during the Joplin, MO, tornado
- Perform detailed analysis of direct and indirect wind speed estimates
- Assess the Joplin, MO, tornado in a climatological context. Probabilistic approaches to assess the tornado hazard at the local, regional, and national levels will be investigated.
- Evaluation of the overall spatial characteristics, including in a historical context.
- Assess rating tornadoes based on observed damage, using the EF scale. Implementation, directives and usage of the current EF scale and appropriateness and sufficiency of the existing damage indicators and degrees of damage will be studied.
- Identify issues and develop findings pertaining to tornado hazard characteristics
- Make recommendations, as warranted, for potential changes to building codes, standards, and practices to increase tornado resilience of buildings, lifelines, and communities

May 22, 2011
Joplin, MO Tornado Study

Emergency Communications and Public Response

Briefing for NCST Advisory Committee
November 7, 2011

Erica D. Kuligowski
Study Task Leader
Fire Protection Engineer, Fire Research Division

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

Study Objective

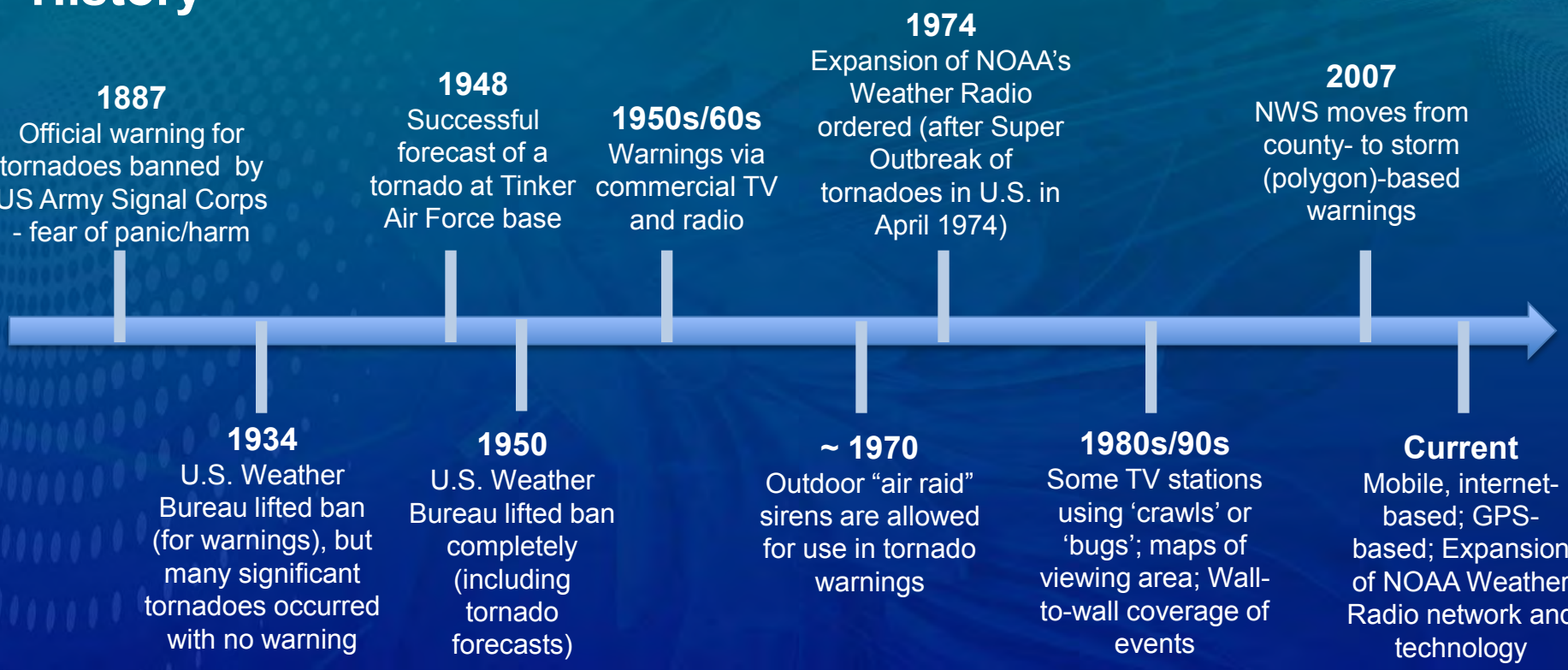
- Determine the pattern, location, and cause of fatalities and injuries, and associated emergency communications systems and public response

Presentation Outline

- Warnings
- Public Response to U.S. Tornadoes
- Historical Context of Joplin Tornado–Joplin/Jasper County, MO
- May 22, 2011 Joplin, MO Tornado

Warnings

History



Federal laws, codes, and standards

- No federal law requiring local broadcasters to provide tornado warnings
- FCC requires a broadcaster to operate in public interest (most TV/radio stations do provide severe weather info – varying degrees)

Sources: Coleman et al. (2011), National Weather Service (NWS)

Warnings (Cont.)

Codes/Standards applicable to public alerting systems (FEMA 2006)

- Codes/Standards on the system itself – focus on the construction, performance and testing of the individual physical components of the system

NFPA 72	National Fire Alarm and Signaling Code, Chapter 24 on Emergency Communications Systems
NFPA 1221	Standard for the Installation, Maintenance, and Use of Emergency Services Communication Systems, Chapter 14 on Public Alerting Systems
UL 1971	Standard for Signaling Devices for the Hearing Impaired

- Others focus primarily on sound and intelligibility levels (including how to measure each)

ANSI S1.13	Measurement of Sound Pressure Levels in Air
ANSI S1.26	Method for the Calculation of Absorption of Sound by the Atmosphere
ANSI S3.2	Method for Measuring the Intelligibility of Speech over Communications Systems
ANSI S3.5	Methods for the Calculation of the Speech Intelligibility Index (SII)
ISO 9921	Ergonomic Assessment of Speech Communication

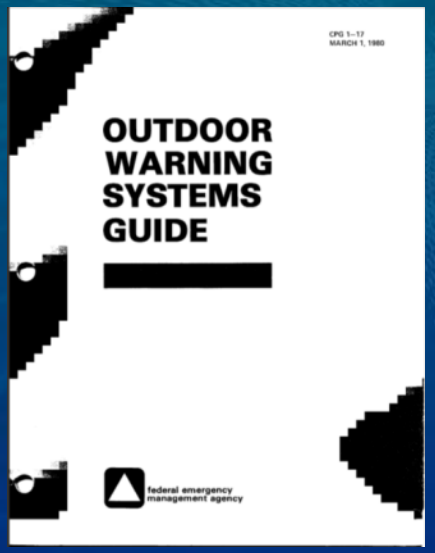
- Also standards devoted to the individual physical components of the systems

UL 1480	Standard for Speakers for Fire Alarm, Emergency, and Commercial and Professional Use
UL 1989	Standard for Standby Batteries

NFPA: National Fire Protection Association; ISO: International Organization for Standardization

Warnings (Cont.)

- Federal Guidance on outdoor warning systems (FEMA 1980, 2006)
  - **Guidance** on the use of these systems for two different hazards:
    - Attack signal
    - Alert signal



Source: FEMA

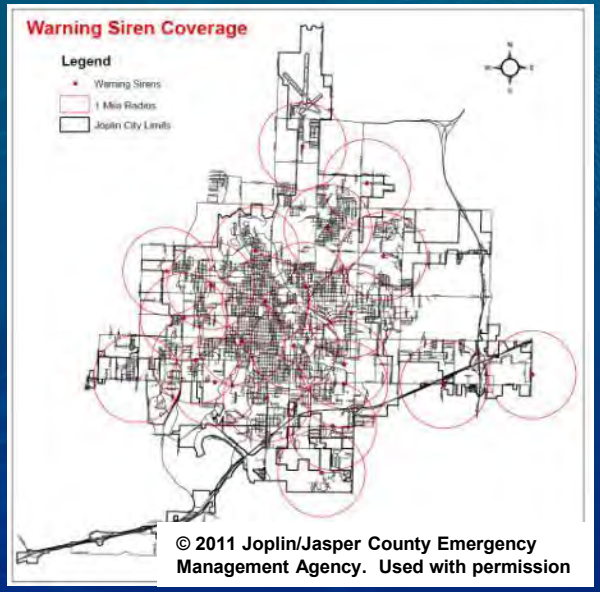
- Current practice in over 75 U.S. counties, cities and towns
  - Use of outdoor warning systems vary significantly among U.S. counties, cities, towns
  - Many communities (e.g., small towns and rural areas) do not have outdoor sirens

Public Response to U.S. Tornadoes

- Factors that contribute to injuries and fatalities (Simmons and Sutter, 2011)
  - 4 major vulnerabilities for casualties:
    - Tornadoes that occur overnight
    - Tornadoes that occur during the fall/winter months
    - Living/located in a manufactured home
    - Location in the United States (Southeastern part of the US, specifically)
  - The influence of warning lead time

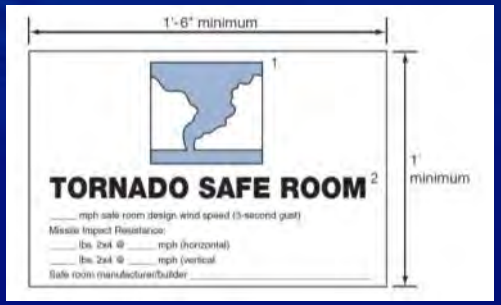
Historical Context of Joplin Tornado

- Emergency communications systems
  - Outdoor warning sirens (Source: Joplin/Jasper County Emergency Management Agency)
    - 25 sirens in Joplin "zone," all tied to the same system (if one activated, they all activated)
    - Tested weekly at 10:00 AM (CDT) on Mondays, sounded for 1 min only
  - Other channels (Source: Joplin/Jasper County Local Emergency Operations Plan)
    - Primary and local Emergency Alert System (EAS) TV and radio stations
    - Reverse 911
    - NOAA Weather Radios



Historical Context of Joplin Tornado

- Procedures for tornadoes
  (Source: Joplin/Jasper County Local Emergency Operations Plan)
  - Communication
    - Warning systems are sounded only after…
      - Communications Operator has been notified that a tornado has been sighted
      - Tornado warning is issued by the NWS for Jasper, Newton or Cherokee County
      - Sustained winds are 75 mph or higher
    - Sounded for 3 minutes continuously, once, no “all clear”
  - Protective Actions
    - The burden of heeding warnings - individual communities and citizens
    - No guaranteed safe place during a tornado
    - Some locations are better than others



SOURCE: FEMA

May 22, 2011 Joplin, MO Tornado

- Emergency Communications Timeline Prior to Tornado Touchdown
  - 26 minutes - First siren sounded
    - Source: Joplin/Jasper County Emergency Management Agency
  - 17 minutes – NWS Tornado Warning
    - Included parts of the City of Joplin (Source: NWS)
  - Second siren sounded (time not logged)
    - Not usual procedure to sound second siren (Source: Joplin/Jasper County Emergency Management Agency)

- *"So...what other factors, if any, influenced the behavior and fate of individuals, and what did they do in response?"*

May 22, 2011 Joplin, MO Tornado

NIST Interview Recruitment Strategies and Methods

- Tornado survivors, families/friends of victims, building managers/owners
- Recruitment of survivors and families/friends of victims for interviews
  - Over 100 eyewitness media accounts
  - NIST Tech Beat article (10/14/11)
  - NIST flyer
  - Contacts in Joplin – radio stations, newspapers, public information officer, local emergency managers, faith-based organizations, chamber of commerce
  - In-person and phone interviews

May 22, 2011 Joplin, MO Tornado

NIST Interview Recruitment Strategies and Methods

- Interview methods (2 phases)
  - Convenience sample to generate specific knowledge about a particular event;
  - Data collection will cease when the Team deems the topics of interest as saturated
  - Phase 1: Respondents will be asked to describe their experiences from the time when they first became aware that something was wrong until the moment when they responded to the disaster
  - Phase 2: Unstructured, follow-up or clarification questions about important topics

Preliminary Findings – Interviews

- Survivors' Behavior (n≈70)
  - Not everyone heard sirens
  - People did not react until perceiving danger
  - Residents delayed taking protection; some did not take shelter
- Findings from NWS Service Assessment Study (NWS, 2011)
  - Initial siren given little credibility; confirmation was key
  - Residents were desensitized to the warnings
  - Information/warnings provided via multiple means or channels

May 22, 2011 Joplin, MO Tornado

Fatalities and Injuries Analysis

- 162 fatalities
- Locations of death vary: residences, businesses, outdoors, and vehicles
- Other information on fatalities: date of birth, date of death, home address
- Factors of interest (to obtain):
  - Cause of death
  - Exact location found
  - Experiences of the deceased during the event

Preliminary Locations of Deceased	# of Victims
Academy Sports Store	1
AT&T store	1
Elks Lodge	5
Full Gospel Church	7
Greenbriar Nursing Home	21
Harmony Heights Baptist Church	3
Home Depot	8
Meadows Healthcare Facility	2
Outside (6 in vehicles)	14
Pizza Hut	5
Residences - apartments	11
Residences - single family home	54
Stained Glass Theater	2
St. John Regional Medical Center	15
Unknown	9
Walmart	3
Officer killed in the line of duty	1

Sources: NWS; MO State Police; Dr. Andrew Curtis; Media accounts; NIST Survivor interviews

Next Steps

- Complete interviews on the response of individuals (survivors and victims) to the Joplin, MO tornado
- Determine how situation awareness, decision-making, and the environment, including the tornado effects and physical location of the individual, influenced the performance of protective action (e.g., sheltering in place), injuries, and survival
- Compare data on public response from previous tornadoes to the Joplin, MO tornado
- Compare local community procedures and codes/standards on public alerting to practices in Joplin, MO
- Make recommendations, as warranted, for potential changes to emergency communications and building and fire codes, standards, and practices to improve life safety in tornado disasters

May 22, 2011
Joplin, MO Tornado Study

Performance of Buildings, Designated Safe Areas, and Lifelines

Briefing for NCST Advisory Committee
November 7, 2011

Long Phan
Study Task Leader
Research Structural Engineer, NWIRP

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

Primary Objectives

- Determine the response of residential, commercial, and critical buildings, including the performance of designated safe areas
- Determine the performance of lifelines as it relates to the continuity of operations of residential, commercial, and critical buildings

Presentation Outline

- Wind Design Context for Tornadoes
- Joplin City Building Code History
- Overview of Damage and Structures Surveyed
- Performance of Facilities
  - Buildings
  - Designated Safe Areas
  - Lifelines
- Preliminary Findings
- Next Steps

Wind Design Context for Tornadoes

- Current national codes, standards, and practices:
  - Seek to achieve life safety for hazards considered in design
  - Do not require conventional buildings and other structures to withstand tornadoes
  - Design criteria specifically for tornado shelters and safe rooms are addressed, however, use of tornado shelters or safe rooms is not mandatory
- Trade-offs between risks and costs are made during the model building codes and standards development process and during adoption and enforcement at the state or local level

Joplin City Building Code History

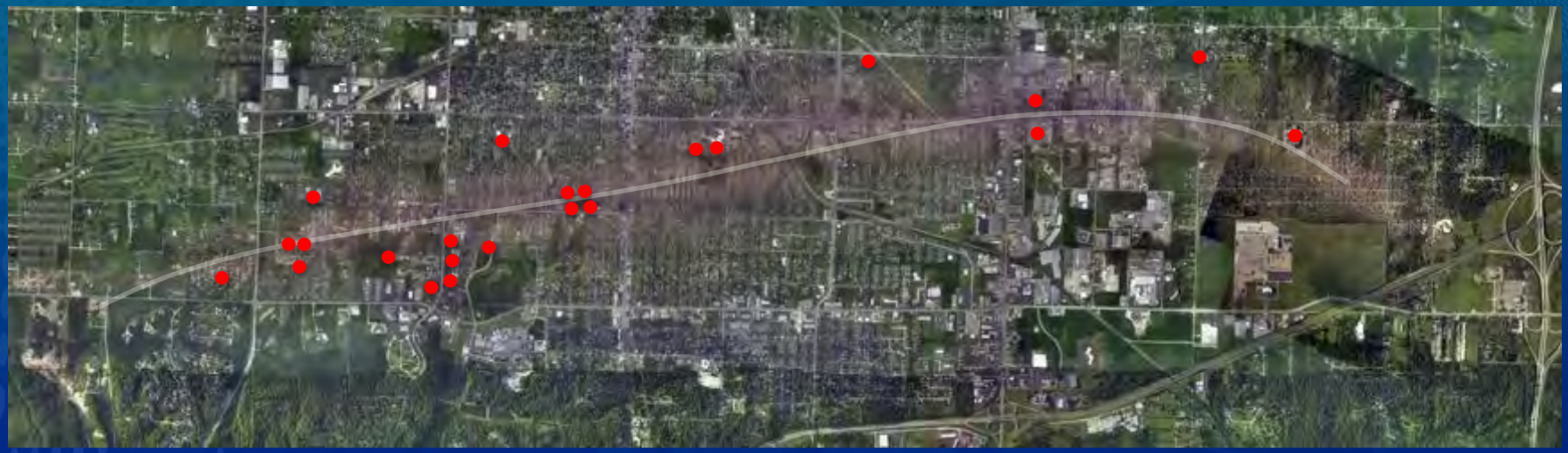
- City of Joplin has long history of code adoptions, dating back to 1877.

Code Adopted (Date) [1]	Relevant Amendments[1]	Required Increased Wind Loads for Critical Facilities[2]
1961 BOCA/NBC (7/1961)		TBD
1965 BOCA/NBC (10/1966)		TBD
1970 BOCA/NBC (3/1970)		TBD
1978 BOCA/NBC (5/1980)		Yes
1984 BOCA/NBC (7/1984)		Yes
1990 BOCA/NBC (11/1990)	Ord. 93-6 (snow and wind loads)	Yes
1996 BOCA/NBC (7/1997)		Yes
2000 IBC, IRC (3/2003)		Yes
2006 IBC, IRC, IFC (5/2008)	Ord. 08-068 (snow and wind loads, roofing and exterior finish materials)	Yes

[1] Data Source: Building and Code Enforcement, City of Joplin
[2] Based on Model Code adopted

BOCA/NBC: National Building Code, IBC: International Building Code, IRC: International Residential Code, IFC: International Fire Code

Overview of Damage and Structures Surveyed



Aerial Photo Source: NOAA
Enhancements: NIST

- NIST surveyed 20+ non-residential (critical[1], commercial, industrial) and numerous residential structures
  - Representative construction types, with typical damage
  - Spatially distributed throughout damage area

[1] For example, hospitals, fire stations, schools

Overview of Damage and Structures Surveyed (Cont'd)

Category	Name	Construction Type	Use	Year	Damage Condition	Fatalities/ Injuries
Critical	St. John's Hospital	RC, Steel, CMU	Hospital	1965-1985	Envelope/Collapse	15/TBD
	Fire Station	Wood Frame	Fire	TBD	Roof	0/0
	Police Station	Wood Frame	Police	TBD	Minor Exterior	0/0
	Joplin High School	RC, Steel, CMU	School	TBD	Collapse	0/0
	Joplin East Middle School	Tilt-up Wall, CMU	School	2009	Collapse	0/0
	St. Mary's School	CMU	School	TBD	Collapse	TBD/TBD
High Occupancy	Home Depot	Tilt-up Wall	Retail	2000	Collapse	8/TBD
	Wal-Mart	CMU	Retail	TBD	Partial Collapse	3/TBD
	St. Paul's Church	Steel Frame	Church	TBD	Roof/Envelope	TBD/TBD
Commercial	Ramesh Shaw Eye Center	Steel Frame	Office	TBD	Roof/Envelope	TBD/TBD
	W. Meredith Eye Center	Steel Frame	Office	TBD	Roof/Envelope	TBD/TBD
	4-Story RC Office Building	RC Frame	Office	TBD	Envelope	TBD/TBD
Residential	Mercy Village	Wood Frame	Apartment	TBD	Envelope	TBD/TBD
	Greenbriar	Wood Frame	Nursing Home	TBD	Collapse	21/TBD
	Single family	Wood Frame	Residence	TBD	Envelope to collapse	TBD/TBD
Designated Safe Areas	Wal-Mart's	TBD		TBD	TBD	TBD/TBD
	St. John's	Interior			TBD	TBD/TBD
	In-Residence	RC room, Steel Box		TBD	Intact	TBD/TBD
Lifelines	Power	Open Frame	Substation	TBD	Collapse	0/0
	Water Treatment Plant	Brick	Storage	1898	Collapse	0/0

RC: Reinforced Concrete; CMU: Concrete Masonry Unit

Performance of Facilities

Buildings

Critical/High Occupancy: Hospital

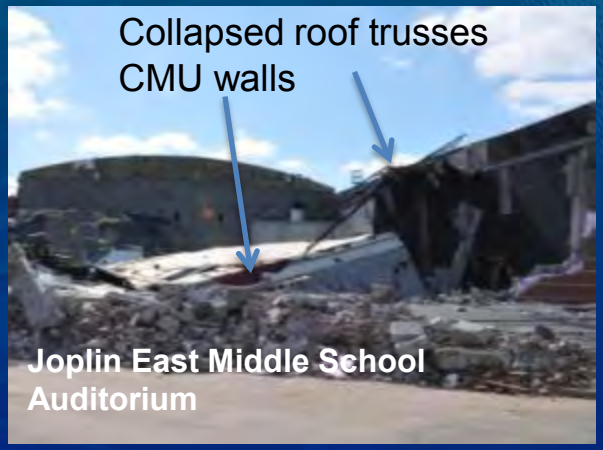
- Main Buildings (RC, Steel Frame): Extensive damage to envelope (glazing; roof blow-off) and interior; No observed damage to Main Wind Force Resisting System (MWFRS);
  Loss of function
- Ancillary Buildings (CMU): Collapsed or substantially damaged
- Performance Issues:
  - Building envelope/Loss of function
  - Collapse/damage of ancillary buildings
  - Life safety, continuity of vital service not achieved

Performance of Facilities (Cont'd)

Buildings (Cont'd)

Critical/High Occupancy: Schools, "Big Box" Stores

- Tilt-up Wall, CMU Wall with Long-Span Joist Roof: Partial or complete loss of roofing system; Failure of roof-to-wall connections; Collapse of walls
- Performance Issues:
  - Load Path Continuity
  - Robustness



Joplin East Middle School Auditorium

Wal-Mart

Home Depot

Joplin East Middle School Gymnasium

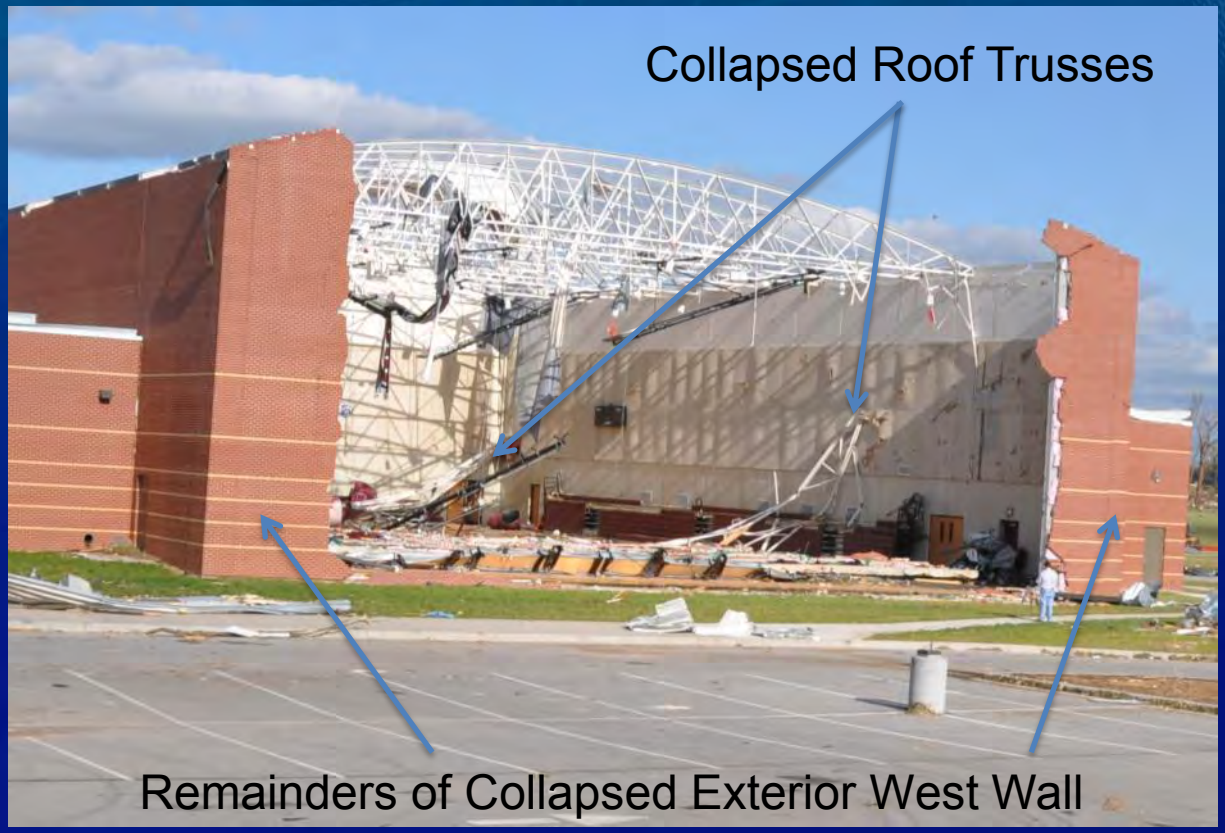
Performance of Facilities (*Cont'd*)

Buildings (Cont'd)

Critical/High Occupancy: Joplin East Middle School

Analysis of Video from Joplin School District Shows Damage Sequence at Joplin East Middle School's Gymnasium

- Loss of steel roof deck
- Collapse of roof trusses (loss of roof-to-wall connection)



Performance of Facilities (Cont'd)

Buildings (Cont'd)

Commercial

- RC Frame: Extensive damage to envelope; No observed damage to MWFRS; Loss of function
- Light Steel Frame: Loss of roofing system and building envelope; Damage to structural frame varied from none to moderate, but no collapse
- Performance Issues:
  – Building envelope/Loss of function

4-Story RC Frame Professional Building

William Meredith Eye Center

Ramesh Shaw Eye Surgeon Building

Performance of Facilities (Cont'd)

Buildings (Cont'd)

Residential

- Wood Frame Single and Multi-Family:
  - Both older (late 1980's) and newer (early 2000's) construction sustained similar damage
  - Damage typically ranged from damage to roof and exterior walls to complete collapse.
- Performance Issues:
  - Building envelope
  - Collapse

Performance of Facilities (Cont'd)

Designated Safe Areas

- **Definitions**
  - ***Designated Safe Areas***: Spaces within buildings that have been identified by owners or operators to provide shelter for occupants.
  - ***Best Available Refuge Areas***: Safest areas in buildings based on FEMA P-431.
  - ***Storm Shelters*****:** Building, structure or portion(s) thereof, constructed in accordance with ICC 500-2008, *Standard for the Design and Construction of Storm Shelters*, and designated for use during a severe wind storm event such as a hurricane or tornado.
  - ***Safe Rooms***: Building, structure or portion(s) thereof designed to meet FEMA 320 (residential or small business) or FEMA 361 (community) safe room guidelines
- No known community storm shelters or community safe rooms in Joplin
  (Sources: Joplin/Jasper County Emergency Management Agency and FEMA)
- Uncommon for buildings in Joplin to have basements
  (Source: City of Joplin Building and Code Enforcement)
- In-residence shelters (concrete room in basement and steel box on grade) and designated safe area at Wal-Mart

Performance of Facilities (Cont'd)

Lifelines

- Power: (Source: Empire District Electric)
  - 1 power substation destroyed (supporting steel frame collapsed), 2 damaged. 20,000 without power.
  - Approx. 3,900 poles damaged; 100 miles of line downed; 31 circuits off
  - 10 transmission lines out of service; 135 transmission structures affected; 30 fiber lines cut
- Water Treatment Plant: (Source: Missouri American Water Engineering)
  - Unreinforced brick storage building (1898) collapsed
  - Plant remained operational on back-up power
- High Pressure Gas Valve (Source: St. John's Hospital)
  - Major leak adjacent to area used to triage tornado victims
  - Not shut off for some time
- Water: (Source: Joplin Fire Department)
  - Numerous small leaks due to broken pipes in damaged buildings
  - Unable to use fire hydrants in some areas due to low pressure

Preliminary Findings

- Performance of Buildings and Designated Safe Areas
  - The high level of fatalities indicates that life safety was not achieved; there is no such expectation in current model codes or standards
  - A large number of residential and non-residential buildings sustained complete loss of function
  - Critical and high-occupancy buildings did not perform better than those of similar construction type in lower risk categories with regard to loss of function or damage
  - Reinforced concrete and steel frame buildings suffered total loss of function and major damage to the envelope and the interior, but the structural frame remained largely intact
  - Most other buildings, including tilt-up wall construction, metal buildings, concrete and brick masonry, and wood-frame, suffered partial or complete collapse
- Performance of Lifelines
  - Utility-related fires did not play a prominent role in fatalities, injuries, or property damage
  - Loss of power affected functionality of hospital
  - Residential water leaks presented potential negative effect on fire fighting effectiveness
  - High pressure gas leak at hospital presented potential hazardous condition

Next Steps

- Continue analyzing field performance data. Establish environmental conditions affecting facilities. Develop failure hypothesis for buildings of interest.
- Obtain design and actual performance information, including drawings and available videos. Compare designs with field observations to assess consistency between design and actual construction.
  Refine failure hypothesis.
- Review design/performance of designated safe areas within buildings, including shelters, safe rooms, and areas of buildings used for refuge from the tornado.
- Review/evaluate appropriate model building code and standards requirements for building envelopes and main wind force resistance systems. Assess performance based on observed damage relative to code requirements.
- Identify issues and develop findings pertaining to performance of buildings, designated safe areas, and lifelines.
- Make recommendations, as warranted, for potential changes to building codes, standards, and practices to increase tornado resilience of buildings, lifelines, and communities.

References

- Brooks, H.E., Lee, J.W., Craven, J.P. (2003). “The Spatial Distribution of Severe Thunderstorm and Tornado Environments From Global Reanalysis Data”, *Atmospheric Research*, 67-68, 73-94
- Beck, V. and Dotzek, N. (2010). “Reconstruction of Near-Surface Tornado Wind Fields from Forest Damage”, *J. Appl. Met. and Clim.*, 49, 1517-1537
- Coleman, T.A., K.R. Knupp, J. Spann, J.B. Elliott, and B.E. Peters. (2011). “The History (and Future) of Tornado Warning Dissemination in the United States.” Bulletin of the American Meteorological Society, pp 567-582.
- FEMA (1980). “Outdoor Warning Systems Guide.” Federal Emergency Management Agency, Washington, DC.
- FEMA (2006). “Outdoor Warning Systems, Technical Bulletin (Version 2.0).” Federal Emergency Management Agency, Washington, DC.
- FEMA (2008). Design and Construction Guidance for Community Safe Rooms, 2nd Edition, Report FEMA 361.
- FEMA (2009). Tornado Protection: Selecting Refuge Areas in Buildings, 2nd Edition, Report FEMA P-431.
- FEMA (2011) Taking Shelter from the Storm: Building a Safe Room for Your Home or Small Business, 3rd Edition, Report FEMA 320.
- NWS (2011). “NWS Central Region Service Assessment Joplin, Missouri Tornado – May 22, 2011”. National Weather Service , 33 pp.
- Phan, L. and Simiu, E. (1998). “ Tornado Aftermath: Questioning the Tools.” ASCE Civil Engineering Magazine
- Simmons, K.M. and D. Sutter (2011). “Economic and Societal Impacts of Tornadoes.” American Meteorological Society: Washington, DC.

May 22, 2011
Joplin, MO Tornado Study

Study Plan and Research Overview

Briefing for NCST Advisory Committee
November 7, 2011

Questions/Discussion