Engineering Laboratory

NIST Preliminary Reconnaissance, Building Performance and Emergency Communications, Joplin, Missouri Tornado, May 22, 2011

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

Presentation Outline

- NIST National Windstorm Impact Reduction Program (NWIRP)
- NIST Disaster and Failure Studies Program (DFSP)
- Objectives of Preliminary Reconnaissance
- NIST Preliminary Reconnaissance Team
- The May 22, 2011 Joplin Tornado
- Data Collection Scope and Sources
- Overview of Observations
- Context for Preliminary Findings
- Preliminary Findings
- Next Steps

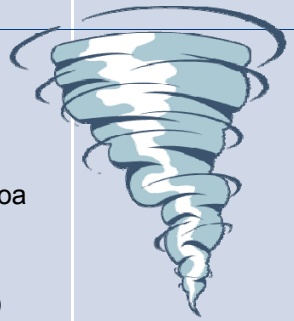
NOTE: The information contained in this presentation is preliminary and subject to change as additional data is collected

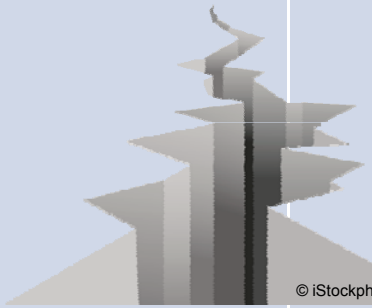
National Windstorm Impact Reduction Program (NWIRP)

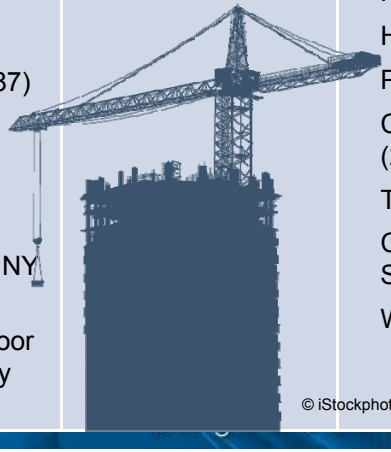
- Created by the National Windstorm Impact Reduction Act of 2004 (Public Law 108-360)
- Objective - "achievement of major measurable reductions in losses of life and property from windstorms"
- Interagency Working Group: NIST, NOAA, FEMA, and NSF
- NIST responsibilities (PL 108-360, Section 204(c)(1)): Support R&D to improve building codes and standards and practices for design and construction of buildings, structures, and lifelines
- Three program components, two of which address windstorm impact *data collection and analysis*
  - **Section 204(d)(2) Understanding of Windstorms** : Activities include research to improve knowledge of and data collection on the impact of severe wind on buildings, structures, and infrastructure
  - **Section 204(d)(3)(A) Windstorm Impact Assessment**: Activities include development of mechanisms for collecting and inventorying information on the performance of buildings, structures, and infrastructure in windstorms and improved collection of pertinent information from sources, including the design and construction industry, insurance companies, and building officials

NIST Disaster and Failure Studies

Earthquakes	Hurricanes	Construction/ Building	Tornadoes	Fires
San Fernando, CA (1971)	Camille, MS/LA (1969)	Skyline Plaza Apartments, Bailey's Crossroads, VA (1973)	Jarrell, TX (1997)	DuPont Plaza Hotel, San Juan, PR (1986)
Mexico City, Mexico (1985)	Alicia, Galveston, TX (1983)	Willow Island Cooling Tower, WV (1978)	Spencer, SD (1998)	First Interstate Bank Building, Los Angeles, CA (1988)
Loma Prieta, CA (1989)	Hugo, SC (1989)	Kansas City Hyatt Regency, Kansas City, MO (1981)	Oklahoma City, OK (1999)	Loma Prieta Earthquake, CA (1989)
Northridge, CA (1994)	Andrew, FL (1992)	Riley Road Interchange, East Chicago, IN (1982)		Hillhaven Nursing Home (1989)
Kobe, Japan (1995)	Hurricanes Mitch and Georges, LAC (1998)	Harbor Cay Condominium, Cocoa Beach, FL (1981)		Pulaski Building, Washington, DC (1990)
Kocaeli, Turkey (1999)	Hurricanes Katrina and Rita (2005)	L'Ambiance Plaza, Hartford, CT (1987)		Happyland Social Club, Bronx, NY (1990)
Maule, Chile (2010)		Ashland Oil Tank Collapse, Floreffe, PA (1988)		Oakland Hills, CA (1991)
		U.S. Embassy, Moscow, USSR (1987)		Hokkaido, Japan (1993)
		Murrah Federal Building, Oklahoma City, OK (1995)		Watts St, New York City (1994)
		World Trade Center Disaster, New York, NY (2001)		Northridge Earthquake, CA (1994)
		Dallas Cowboys Indoor Practice Facility, May 2009		Kobe, Japan (1995)
				Vandalia St, New York City (1998)
				Cherry Road, Washington, DC (1999)
				Keokuk, IA (1999)
				Houston, TX (2000)
				Phoenix, AZ (2001)
				Cook County Administration Building Fire (2003)
				The Station Nightclub, RI (2003)
				Charleston, SC, Sofa Super Store Fire (2007)
				Witch Creek & Guejito Fire (2007)







NIST Disaster and Failure Studies

Results

- Probable technical cause
- Lessons learned: successes and failures
- Improvements to standards, codes, practices, technologies
- Future research priorities

NIST Authorities:

- ***NCST Act (2002):*** building failures, evacuation and emergency response procedures
- ***NIST Act (1985):*** structural investigations
- ***Fire Prevention and Control Act (1974):*** fire investigations
- ***NEHRP Reauthorization Act (1990):*** earthquakes
- ***National Windstorm Impact Reduction Act (2004):*** wind, storms and floods
- ***Federal Response Framework:*** structural and fire safety; disaster operations and situation assessment; urban and industrial hazard analysis; recovery

Program focus: Develop and maintain archival disaster and failure database of hazards, performance of buildings and infrastructure, evacuation and emergency response, and related factors (e.g., mitigation, response)

Types of NIST Disaster and Failure Studies

- A ***Preliminary Reconnaissance*** is a field study at the disaster or failure site to gather information and to determine if a technical investigation is warranted.

- A ***Technical Investigation*** is a fact-finding study that may include an assessment of the safety and performance of buildings and infrastructure, associated hazard(s), and/or emergency response and evacuation procedures and will likely result in recommendations for improvements to standards, codes, and practices and/or new knowledge. Studies may range anywhere from:
  - limited scope, i.e., *based on data collection and interpretation, modest analytical efforts, and judgment of technical experts*, to
  - extensive scope, i.e., *based on in-depth technical study—including extensive use of data, models, analytical and computational tools, laboratory and/or field experiments, and/or interviews*.

NIST's Role in Disaster and Failure Studies

- NIST may use any one or a combination of the study options below in conducting a preliminary reconnaissance or a technical investigation:
  - **NIST may lead post-event studies.** In many cases, these types of studies may involve a preliminary reconnaissance together with an extensive technical study that may include the characterization of the hazard, the safety and performance of buildings and structures, and the associated emergency response and evacuation procedures. Private sector and academic experts may be involved in these studies through contracts. Other public sector experts may also be involved in these studies.
  - **NIST may coordinate or participate in post-event studies.** These types of studies may involve significant participation and/or coordination by other federal agencies with mission responsibilities and expertise.
  - **NIST may sponsor or participate in private-sector led post-event studies.** In many cases, these types of studies may a involve preliminary reconnaissance together with a technical study that is limited in scope. NIST participation may be limited to guidance, oversight, and/or serving as a technical expert. These types of studies typically may involve significant private sector leadership and participation augmented with public sector experts.
  - **NIST may provide technical assistance** in the reconstruction process for international disaster and failure events at the request of US agencies, industry, private organizations, governments of other nations, or international organizations.

Typical Study Objectives May Include:

1. Establishing the likely technical factor or factors responsible for the damage, failure, and/or successful performance of buildings and/or infrastructure in the aftermath of a disaster or failure event.
2. Evaluating the technical aspects of evacuation and emergency response procedures that contributed to the extent of injuries and fatalities sustained during the event.
3. Determining the procedures and practices that were used in the design, construction, operation and maintenance of the buildings and/or infrastructure.
4. Recommending, as necessary, specific improvements to standards, codes, and practices as well as any research and other appropriate actions based on study findings.
5. Promoting, enabling, and tracking adoption of recommendations through improved standards, codes, and practices as well as any research and other appropriate actions based on study findings.

Objectives of the Joplin Tornado Preliminary Reconnaissance

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

NIST Preliminary Reconnaissance Team

Four NIST Engineering Laboratory employees:

- Dr. Marc Levitan: Reconnaissance Team Leader, Wind Engineer, Leader of NIST NWIRP R&D
- Dr. Erica Kuligowski: Emergency Evacuation Specialist/Fire Protection Engineer
- Dr. Frank Lombardo: Wind Engineer/Meteorologist
- Dr. Long Phan: P.E., Structural Engineer, experience in wind disaster studies

Deployment: Four days in Joplin, MO (5/25 to 5/28)

The May 22, 2011 Joplin Tornado

- Touched down in Joplin beginning at 5:41 PM CDT
- Initially rated a “high-end” Enhanced Fujita (EF)-4 tornado with estimated maximum wind speeds from 190-198 mph on May 23rd
- Upgraded to EF-5 on May 24th
  - Estimated maximum wind speeds 200+ mph
  - Maximum path width: ¾ mile, length: 13.8 miles (6 miles in Joplin)
  - Source: National Weather Service
- Track: generally West to East across Joplin (Newton and Jasper counties)

Courtesy: NOAA

Data Collection Scope and Sources

- Wind Environment/Basis For Tornado Rating
  - NWS meteorologists who made EF-5 determination
- Fatalities, Injuries and Damage
  - FEMA Branch Chief Regional Response Coordination Center
  - USACE[1] Disaster Program Manager and Emergency Support Function #3 (ESF-3) Team Leader
  - Building Official and Code Enforcement Supervisor, City of Joplin

[1] Unites States Army Corps of Engineers

Data Collection Scope and Sources *(Cont'd)*

- Warning Procedures/Emergency Operations
  - Director of Joplin-Jasper County Emergency Management
  - 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

Data Collection Scope and Sources *(Cont'd)*

- Building Damage
  - Photographic data from site damage survey of 20+ non-residential and numerous residential structures
  - Construction Types: Reinforced Concrete (RC) Frame, Steel Frame (Welded, Bolted), Precast Concrete and Concrete Masonry (e.g., commonly used in "big box" stores and schools), and Single and Multi-Family Wood Frame, Unreinforced Brick
  - Use: Hospital, Fire Station, Police Station, School, Medical & Commercial Office, Large Retail, Church, Nursing Home, Single Family Residence, Lifeline (Power Station, Water Treatment Plant)

Data Collection Scope and Sources *(Cont'd)*

- Building Codes and Documents
  - History of building and fire code adoptions, legislation, and ordinances in Joplin, dating back to 1877. Latest code adoption with City of Joplin amendments (May, 2008): 2006 International Building Code, 2006 International Residential Code, 2006 International Fire Code (Building Official and Code Enforcement Supervisor, City of Joplin)
  - Drawings requested for major buildings (City of Joplin Building Department)
  - Tornado also affected unincorporated/rural areas nearby; code practices for these areas unknown at this time
- Fires and Lifelines
  - City of Joplin Fire Chief
  - City of Joplin Fire Marshall
  - Media Relations for Missouri Gas Energy
  - Engineering Manager of Missouri American Water

Overview of Observations

- Tornado Hazard
- Pattern, Location, and Cause of Injuries and Fatalities
- Tornado Warning System, Evacuation, Emergency Response, and Occupant Behavior
- Responses of Buildings, Tornado Shelters and Designated Safe Areas
- Fires and Damage to Lifelines

Overview of Observations

Tornado Hazard


Source: NIST

- Wind Speed (NWS)
  - Estimated EF-5 at 200+ mph in heaviest damage swath
  - EF-5 rating partially based on indicators not in EF scale
  - EF-1+ damage estimated over larger area (86+ mph)
- Debris
  - Estimated 3 million cubic yards of debris (USACE)
    Fill a football field (end zones included)~470 yards high (over 120 stories tall)
- Significant portion (20-30%) of Joplin affected resulting in:
  - Estimated 4,000-8,000 structures damaged or destroyed (USACE/FEMA)
  - Critical[1], institutional, commercial, residential and lifeline facilities damaged and destroyed
- NIST surveyed 20+ non-residential structures and multiple residential structures

Courtesy: NOAA/NWS

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

Overview of Observations

Pattern, Location, and Cause of Injuries & Fatalities

- 138 confirmed and identified deceased (MO Department of Public Safety, June 2, 2011)
- Age and city of residence identified for 138 deceased (MO Department of Public Safety)
- Data on location and causes of injuries and fatalities requested but not yet available
  - Six fatalities at St. John's Medical Center (Source: St. John's Medical Center staff and USA Today, May 24, 2011)
  - Seven fatalities at the Home Depot (Source: USA Today, May 24, 2011)

Overview of Observations

Tornado Warning System, Evacuation, Emergency Response, and Occupant Behavior

- Warning timeline
  - Joplin-Jasper County Emergency Management initiated two sirens prior to tornado (warning time 26 minutes) (Source: Director of Joplin-Jasper County Emergency Management)
    - First siren logged in at 5:11 PM (CDT)
    - Exact time of second siren initiation unknown – sometime between 5:11 PM and 5:37 PM (CDT) (when local spotter observed a tornado on the ground)
    - Uncommon procedure in City of Joplin to sound two sirens in sequence
  - National Weather Service issued Tornado Warning at 5:17 PM that included city of Joplin; first report of tornado 5:41 PM (CDT) (warning time 24 minutes) (Source: NWS)
    - National average NWS warning time is 13-14 minutes

Overview of Observations

Tornado Warning System, Evacuation, Emergency Response, and Occupant Behavior (*cont'd*)

- Warning siren information (Source: Director of Joplin-Jasper County Emergency Management)
  - Intended to alert people outdoors; not intended to alert people inside buildings
  - Continuous tone for 3 minutes, and then stop
  - Tested in city of Joplin every Monday morning (same time)
  - Average siren initiation in city of Joplin - 3 times per year for actual events
- Other Joplin Communications and Warning Capabilities – primary and local Emergency Alert System (EAS), TV and radio stations, reverse 911, and personal NOAA weather radios (Source: Joplin and Jasper County Local Emergency Operations Plan)

Overview of Observations

Tornado Warning System, Evacuation, Emergency Response, and Occupant Behavior (*cont'd*)

- Some, but not all, people in Joplin received warnings via several sources, including sirens, news stations and radios, and word of mouth. (Sources: Print and social media)
- Eyewitness accounts document individuals who confirmed the warning information they received (Sources: Print and social media)
  - For example, a Joplin resident called the Emergency Operations Center (EOC) seeking clarification about why the first siren was sounding (Source: Director of Joplin-Jasper County Emergency Management)

Media References

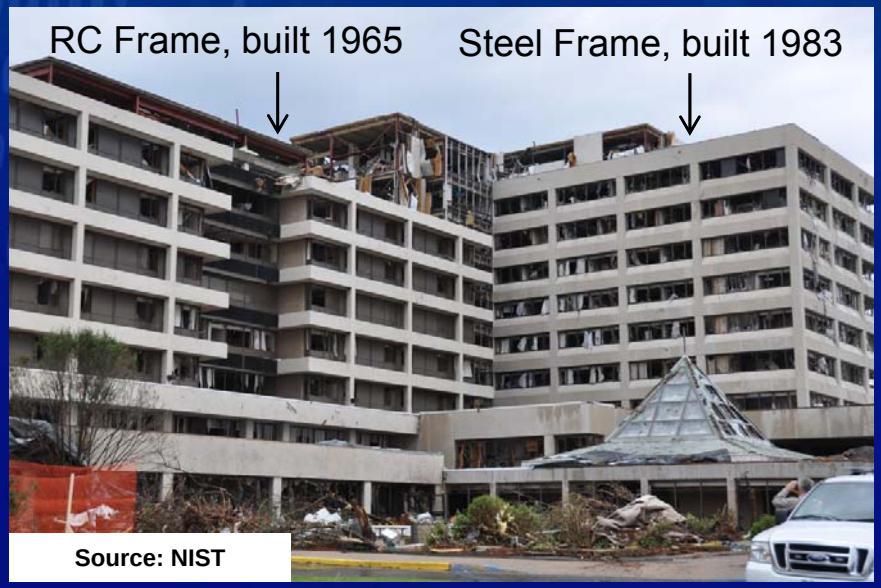
Tornado Warning System, Evacuation, Emergency Response, and Occupant Behavior

- Media Accounts
  - Los Angeles Times: May 22, 2011; May 26, 2011
  - CNN news: May 24, 2011
  - Kansas City Star: May 25, 2011
  - New York Times: May 25, 2011; May 29, 2011
  - Joplin Globe: May 30, 2011; June 2, 2011
  - Springfield News-Leader: June 2, 2011
- Social media/Eyewitness accounts
  - CNN transcripts: May 23, 2011
  - NPR news blog: May 23, 2011
  - Survivor's blogs
  - Facebook: Joplin Tornado Info page
  - YouTube eyewitness accounts

Overview of Observations

Responses of Buildings, Tornado Shelters and Designated Safe Areas

- RC and Steel Frame Buildings
  - Extensive damage to building envelope and interior
  - Loss of function
  - No observed damage to main wind force resisting systems



Source: NIST

Source: NIST

St. John's Medical Center

Overview of Observations

Responses of Buildings, Tornado Shelters and Designated Safe Areas (*cont'd*)

- RC and Steel Frame Buildings

St. John's Medical Center

Joplin High School

Overview of Observations

Responses of Buildings, Tornado Shelters and Designated Safe Areas (*cont'd*)

- RC and Steel Frame Buildings

St. Paul's United Methodist Church

Source: NIST

Source: NIST

Source: NIST

4-Story RC Frame Professional Building

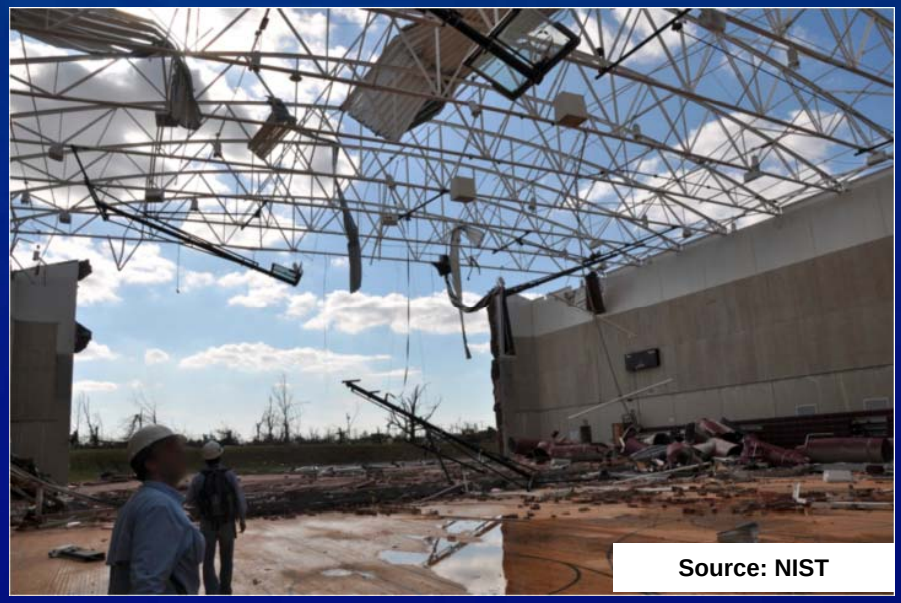
Source: NIST

Overview of Observations

Responses of Buildings, Tornado Shelters and Designated Safe Areas (*cont'd*)

- Precast Concrete Wall Buildings
  - Partial or complete loss of roofing system
  - Failure of roof to wall connections
  - Collapse of wall panels

Home Depot

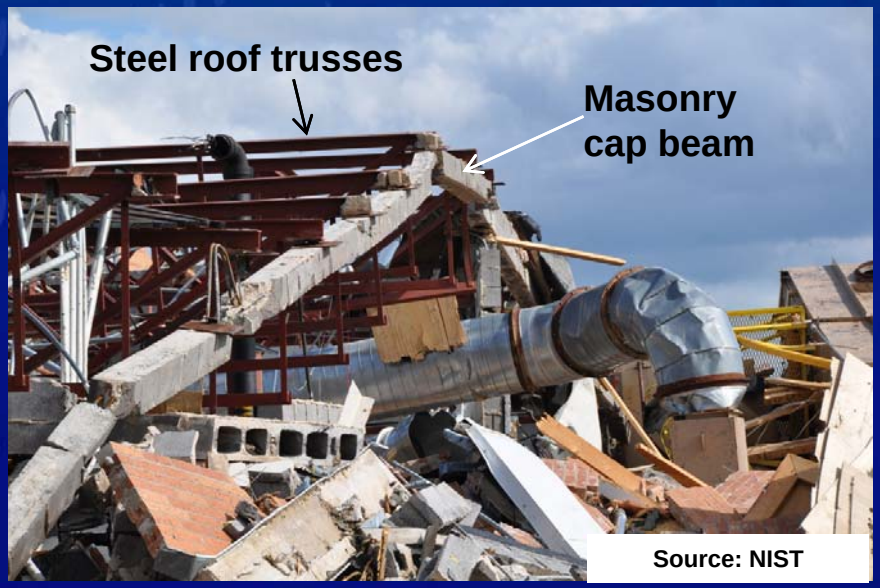


Joplin East Middle School

Overview of Observations

Responses of Buildings, Tornado Shelters and Designated Safe Areas (*cont'd*)

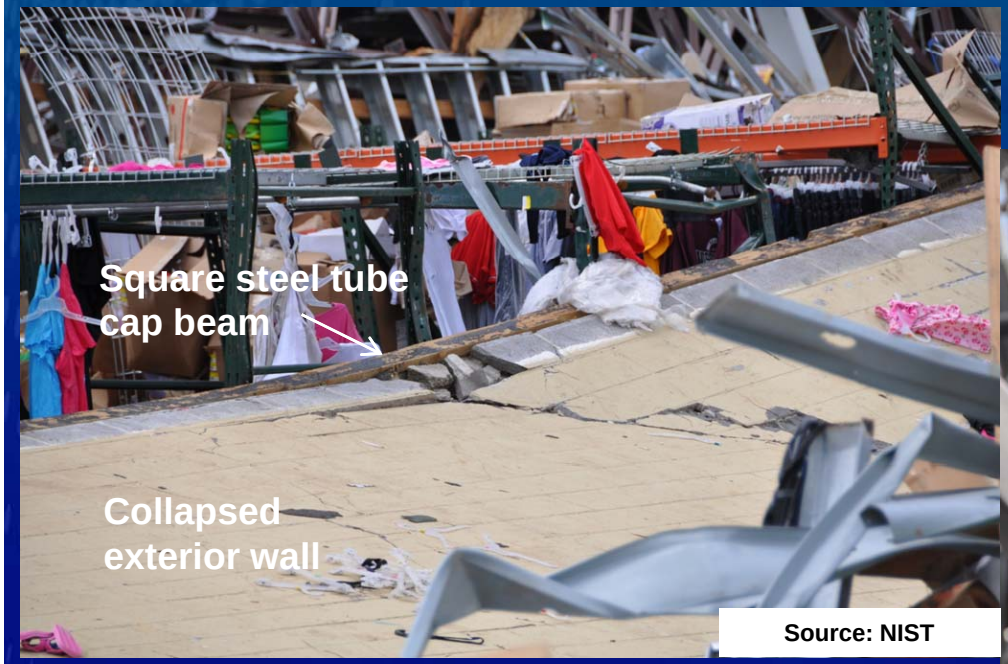
- Concrete Masonry Wall Buildings
  - Partial or complete loss of roofing system
  - Failure of roof to wall connection
  - Collapse of walls



Overview of Observations

Responses of Buildings, Tornado Shelters and Designated Safe Areas (*cont'd*)

- Concrete Masonry Wall Buildings



Wal-Mart

Joplin East Middle School

Overview of Observations

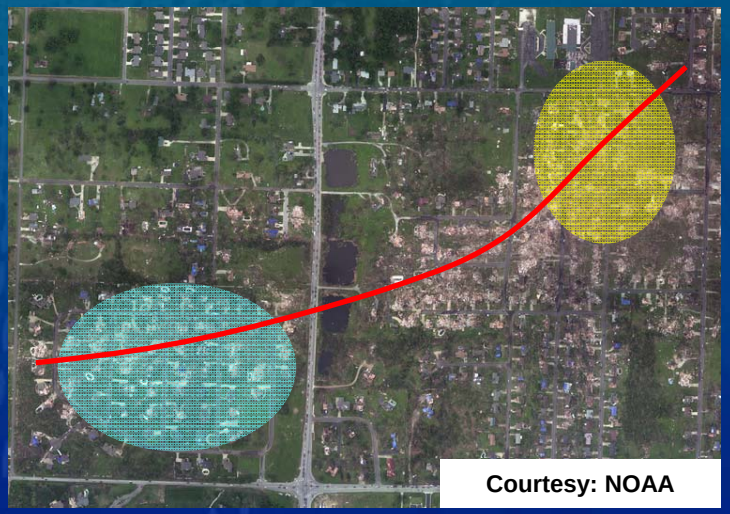
Responses of Buildings, Tornado Shelters and Designated Safe Areas (*cont'd*)

- Tornado Shelters, Safe Rooms, Designated Safe Areas, and Best Available Refuge Areas
  - Definitions:
    - Buildings, structures, or spaces designed to ICC 500-2008, Standard for the Design and Construction of Storm Shelters, are called "storm shelters." The standard defines a storm shelter as "a building, structure or portion(s) thereof, constructed in accordance with this standard, designated for use during a severe wind storm event such as a hurricane or tornado."
    - FEMA uses the term "safe rooms," which applies to all shelters, buildings, or spaces designed to the FEMA criteria (FEMA 320 and 361), whether for individuals, residences, small businesses, schools, or communities.
    - "Designated safe areas" refers to spaces within buildings that have been identified to provide shelter for the building occupants.
      - "Best Available Refuge Areas" are the safest areas in buildings identified using FEMA P-431 methodology.
  - No known community storm shelters or safe rooms in affected area (Sources: Director of Joplin-Jasper County Emergency Management and FEMA)
  - Uncommon for buildings in the City of Joplin to have basements (Source: City of Joplin Building Official and Code Enforcement Supervisor)
  - Information on the performance of storm shelters, safe rooms, and designated safe areas was not available to collect during the preliminary reconnaissance

Overview of Observations

Single Family Residential Construction

- Surveyed two representative subdivisions near the beginning of the tornado track on the west side of Joplin within damage path



- Different ages of subdivision construction
- Avg. Age: Yellow – Late 1980's, Blue – Early 2000's
- Both types sustained heavy roof damage

OLDER

NEWER

- Houses removed from foundation leaving only anchor bolts in some instances
- In some instances, homes in close proximity suffered a wide range of damage

Overview of Observations

Lifelines and Fires

- Lifelines
  - Power substation damaged, supporting steel frame collapsed
  - Unreinforced brick storage building at water treatment plant collapsed. Plant remained operational on back-up power (Source: Missouri American Water Engineering Manager)

- Fires
  - Initial estimates of less than ten fires following the tornado; fires confined to original structure (Sources: City of Joplin Fire Chief and Fire Marshall)
    - Causes of fires: mainly due to gas leaks and downed power lines
    - Joplin Fire Department received loaner equipment and mutual aid from surrounding departments (equipment/trucks were damaged)

Context for Preliminary Findings

- Current national standards, codes, and practices do not require buildings and other structures to withstand tornadoes
- Current national codes, standards, and practices seek to achieve life safety for hazards considered in design
- Current national model codes require critical and high-occupancy buildings to resist greater wind loads than other buildings
- 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

Preliminary Findings

- Tornado Hazard
  - 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)
- Pattern, Location, and Cause of Fatalities & Injuries (Preliminary findings pending receipt of additional information requested)
- Tornado Warning Systems, Evacuation, Emergency Response, and Occupant Behavior
  - More warning time for this event compared with NWS national average (almost doubled)
  - The Joplin siren-based warning system was intended to alert people outdoors; it was not intended to alert people located indoors
  - In the City of Joplin, there were no designated public safe rooms or tornado shelters
  - In the City of Joplin, most buildings did not have basements; general NOAA Weather Radio guidance is to "…move to an interior room on the lowest floor of a sturdy building, avoid windows..."

Preliminary Findings (*cont'd*)

- Response of Buildings, Tornado Shelters, and Designated Safe Areas
  - The City of Joplin has adopted a model building code over the past five decades with modifications (see table)
  - A large number of residential and non-residential buildings in Joplin sustained complete loss of function and require either major repair or replacement
  - The high level of fatalities in the Joplin tornado indicate that life safety was not achieved; there is no such expectation in current model codes or standards
  - The critical and high-occupancy buildings in Joplin did not perform better than buildings of similar construction type in lower-risk categories with regard to loss of function or damage
  - Reinforced concrete frame and steel frame buildings that were surveyed also 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 pre-cast concrete wall construction, metal buildings, concrete and brick masonry, and wood-frame construction, suffered partial or complete collapse
- Lifelines and Fires
  - Utility-related fires did not appear to play a prominent role in fatalities, injuries, or property damage

City of Joplin Building Code Adoption Summary

Code Adopted	Date	Required Increased Wind Loads[1] for Critical Facilities[2]
1961 BOCA/NBC	July 1961	TBD
1965 BOCA/NBC	October 1966	TBD
1970 BOCA/NBC	March 1970	TBD
1978 BOCA/NBC	May 1980	Yes
1984 BOCA/NBC	July 1984	Yes
1990 BOCA/NBC	November 1990	Yes
1996 BOCA/NBC	July 1997	Yes
2000 IBC, IRC	March 2003	Yes
2006 IBC, IRC	May 2008	Yes

[1] Based on Model Code adopted.
[2] For example, hospitals, fire stations, schools

Source: Building Official and Code Enforcement Supervisor, City of Joplin

Next Steps-Technical Investigation

- 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 and fire codes, standards, and practices that warrant revision