engineering laboratory

Technical Investigation of the May 22, 2011, Tornado in Joplin, MO

December 10, 2012
NCST Advisory
Committee Meeting

Structural Response

Long Phan
Investigation Task Leader
Research Structural Engineer, NWIRP

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

Objective #3

Response of residential, commercial, and critical buildings, including designated safe areas

- **Task 3.1:** Collect field data, establish environmental conditions, develop failure hypotheses.
- **Task 3.2:** Obtain design drawings, refine failure hypotheses.
- **Task 3.3:** Review performance of designated safe areas, including shelters, safe rooms, and refuge areas.
- **Task 3.4:** Review appropriate model building codes and standards.
- **Task 3.5:** Assess building performance based on estimated wind field and observed damage.

Status of Data Collection

- Completed collection, review, and summarization of field performance data, including:
  - Photographs taken by NIST
  - Third party's photographs, notes, security camera videos (Structural Engineers Association of Kansas and Missouri, FEMA, St. John's Regional Medical Center (SJRMC), Joplin Schools)
- Obtained and reviewed design plans and specifications from:
  - Joplin Public Works Department
  - Building Owners (Mercy/SJRMC)
  - Architectural/Engineering Design Firms (PLJBD, Heery Intl, Inc., Structural Engineers Association of Kansas and Missouri)
- Obtained applicable building codes and design standards (BOCA, IBC, ASCE, ACI, SJI, SDI)

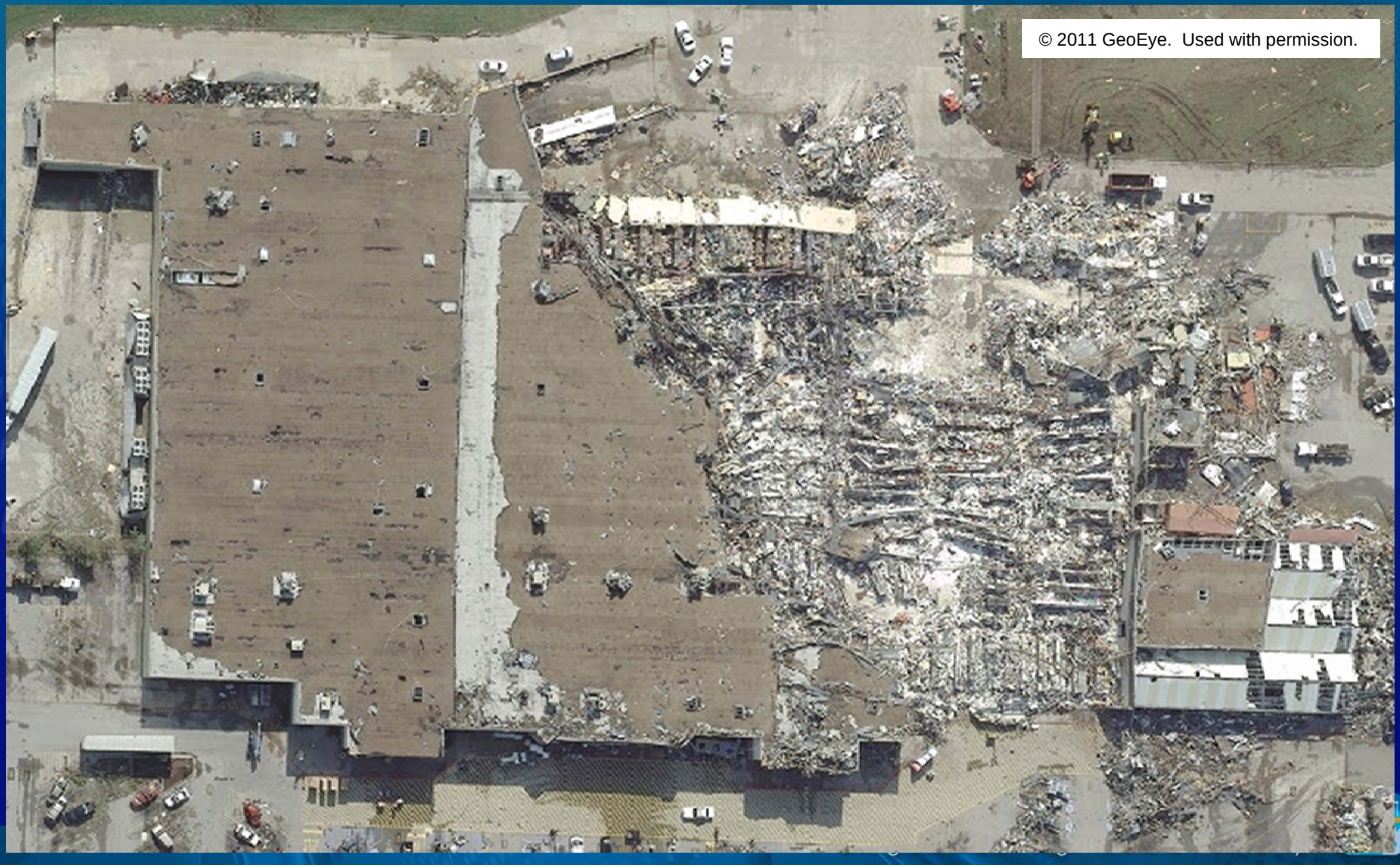
Summary of Damage and Design Information

	Damage Condition			Design Information		
	Collapse of Main Wind Force Resisting System	Damage/Loss of Roof and/or Wall Cladding	Loss of Functionality	Const. Type	Code	Drawings Obtained by NIST
Engineered	Walmart Supercenter #59		Complete	BTS (CMU)	BOCA 1990/IBC 2000	Complete
	Joplin EM School auditorium		Complete	BTS (CMU)	IBC 2000	Complete
	St. Mary's School		Complete	BTS (CMU)	BOCA 1990	Partial
	Franklin Technology Center		Complete	BTS (CMU)	1978	Partial
	St. John's Generator & Chiller Bldgs		Complete	BTS (CMU)	BOCA 1990	Partial
	Home Depot #3023		Complete	BTS (Tilt-up)	BOCA 1996	Complete
	Joplin EM School Gymnasium		Complete	BTS (Tilt-up)	IBC 2000	Complete
		St. John's Hospital Bldgs	Complete	CF, SF	Not known	Partial
		St. Paul's Church	Complete	SF	BOCA 1996	Partial
		Joplin High School Bldgs	Complete	CF, SF	IBC 2000	Partial
		Ramesh Shaw Center	Complete	SF	BOCA 1990	Partial
		W. Meredith Center	Complete	SF	Not known	None
		Ozark Center	Complete	CF	Not known	Partial
Marginally Engineered	Single and multi-family homes	Single, multi-family homes	Complete/Partial/No	WF	Various years	None
		Mercy Village	Partial	WF	IBC 2000	Partial
		Swanson Office Building	Partial	WF	IBC 2006	Complete
		Fire, Police Station	Partial	WF	Not known	None

BTS: Box-Type System; CF: Concrete Frame; SF: Steel Frame; WF: Wood Frame; CMU: Concrete Masonry Unit

Typical Analysis Process

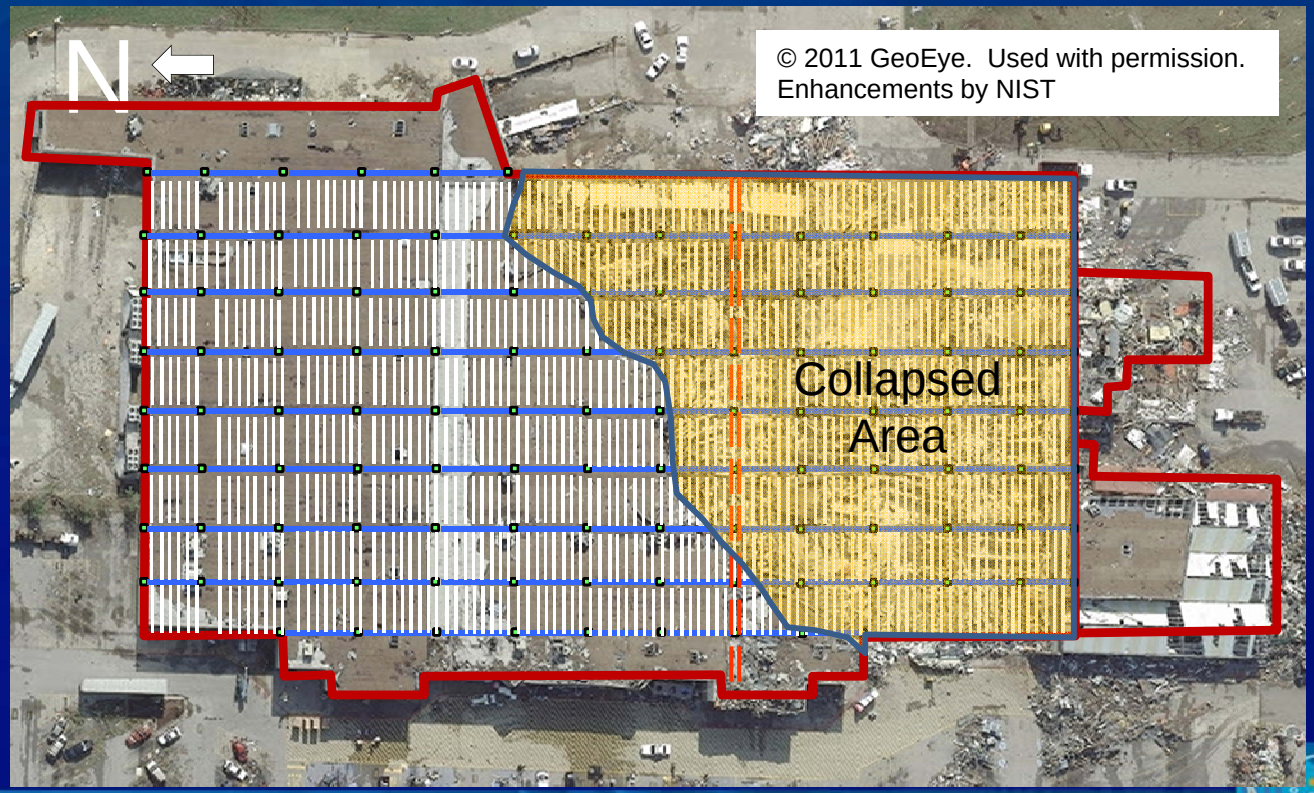
BTS Building, Located at 1501 South Range Line Road (Walmart Supercenter #59)



Typical Analysis Process (cont.)

Review Design, Understand Structural System

- **Series of individual plane frames: Gravity Loads** (*Open Web Joist Girders* simply supported by *Steel Tube Columns*)
- **Perimeter walls: Gravity and Lateral Loads** (*Reinforced CMU*)
- **Roof system: Diaphragm providing lateral bracing for walls** *(Open Web Bar Joists and Wide Rib Steel Deck)*



Typical Analysis Process, (cont.)

Confirm Actual Construction Details

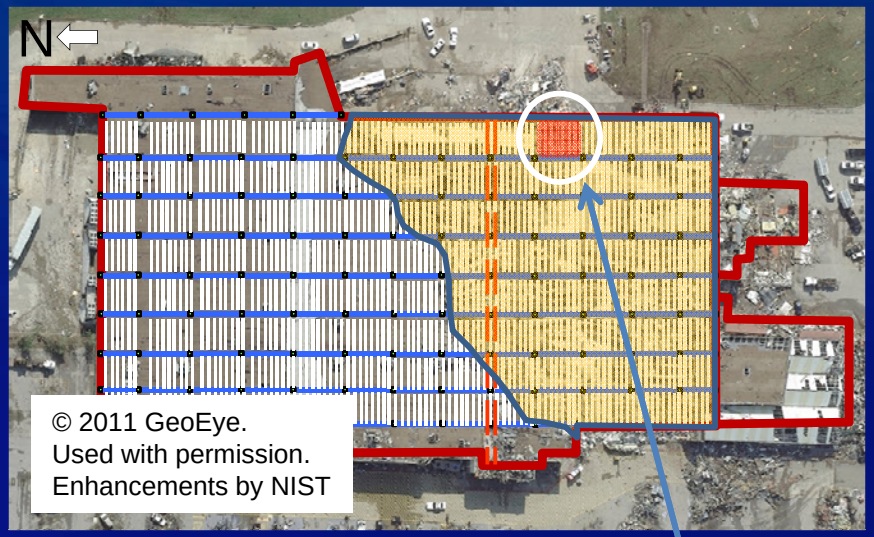
Dimensions

Reinf. schedule

Review Plans

Expansion joint , bond & link beams

Connections



Refuge area with exterior fire exit door

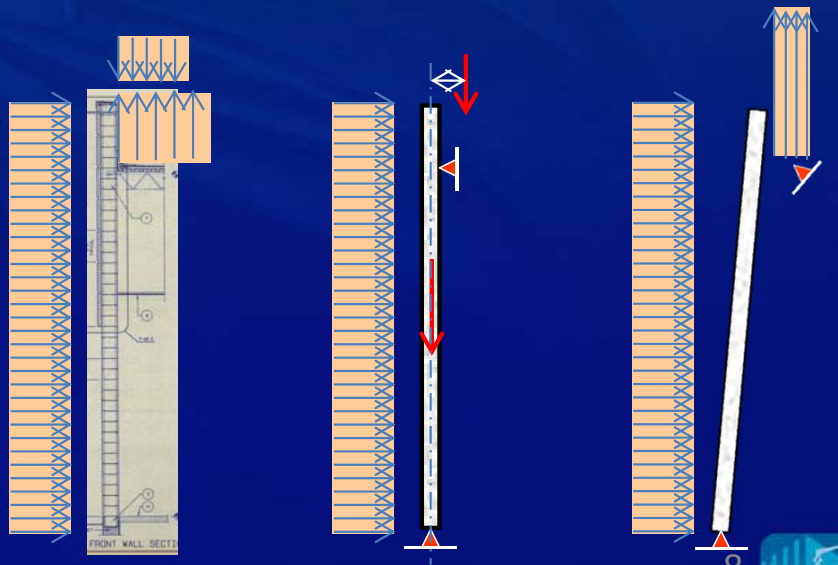
Typical Analysis Process (cont.)

Develop Failure Hypothesis

- **Observed response**
  - Loss of roof decks
  - Loss of roof joists
  - Most joist girders remained in place, albeit damaged (bent upward)
  - All interior columns remained in place
  - Sections of perimeter walls collapsed inward
- **Modeled wind speed and direction**
- **Failure load analysis**

Roof Decks and Joists missing

Joist Girders bent upward



General Observations and Trends

- Current national codes and standards do not require conventional buildings to be designed to withstand tornadoes
- The building codes adopted by Joplin did not require conventional buildings to be designed to withstand tornadoes
- The buildings surveyed were not explicitly designed for tornado hazards
- Tornado hazards (wind speed, wind-borne debris) exceeded design requirements of the applicable codes in some areas of Joplin

General Observations and Trends

- In areas experiencing wind speeds above design requirements, for the buildings surveyed, different construction types typically performed differently
  - **Box-Type System (BTS) with light metal roof diaphragm**
    - Partial or complete collapse
  - **Steel frame and concrete frame with light metal roof deck**
    - Partial or complete loss of roof deck
    - Damaged envelope
  - **Steel frame and concrete frame with concrete roof deck**
    - Damaged envelope

General Observations and Trends

- Critical facility (hospital) provided collapse prevention, but not life safety or continuity of operation due to
  - **Damage to roof envelope**
    - water intrusion
    - Loss of aggregate roof ballast contributed to window damage
  - **Damage to wall envelope**
    - Wind, debris and water intrusion
    - Significant damage to building interior and systems
  - **Loss of power**
    - Loss of line power and backup power
    - Damage to electrical system
  - **Loss of vertical transport**
    - Damage to penthouse housing elevator equipment and to elevator shaft
    - Loss of power

© 2011 Malcolm Carter. Used with permission.

© 2011 Jon Shull. Used with permission.

General Observations and Trends

- High Occupancy BTS Buildings (common for schools, big-box stores)
  - Lack of ***robustness in lateral stability*** ("efficient" design consistent with code requirements but critically dependent on roof diaphragm for load path continuity)
  - Presently not required to have ***hardened refuge area***
- Wood-frame Residential Buildings
  - Failure predominantly involved ***disconnection of structural system*** (roof-to-wall; wall-to-foundation)
    - Majority of damage involved failure of the roof system
  - Current practice, which is based on component (not system) design approach, does not provide **specific guidance for maintaining continuous load path for transmission of uplift forces** from rafter and truss ties to the foundation

Objective #4

Performance of Lifelines as Relates to Continuity of Operations of Buildings

- **Task 4.1:** Gather information on lifeline systems and facilities
- **Task 4.2:** Evaluate performance and timelines, from disruption to restoration of service.
- **Task 4.3:** Evaluate performance of backup power systems
- **Task 4.4:** Collect data on building fires
- **Task 4.5:** Develop findings
- **Task 4.6:** Draft chapter of final report

Lifeline Damage

- Power (Source: Empire District Electric)
  - 1 substation destroyed (supporting steel frame collapsed), damaged. 20,000 without power
  - Approx. 3,900 poles damaged; 100 miles of line downed; circuits off
  - 10 transmission lines out of service; 135 transmission structures affected; 30 fiber lines cut
- Loss of emergency backup power (Source: SJRMC)
- High Pressure Gas Valve (Source: SJRMC)
  - 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 buildings
  - Unable to use fire hydrants in some areas due to low pressure
- Water Treatment Plant (Source: Mo. Amer. Water Eng.)
  - Unreinforced brick storage building (1898) collapsed
  - Plant remained operational on back-up power

General Observations and Trends

- Loss of power supply to critical facilities, like SJRMC, can:
  - Reverse their roles from providing care to needing care
  - Contribute to fatalities
- Prior to ASCE 7-98, buildings that house emergency power generators at critical facilities were not specifically designated Category IV. Thus, emergency generator buildings of older critical facilities might have been designed for wind load with lower importance factor and therefore increased vulnerability for maintaining backup power
- The SJRMC's emergency generator building was designed for 70 mph (fastest mile) based on 1990 BOCA (source: Hospital Designers, Inc.)
- Compared with all other construction types at the SJRMC (SF, CF), the emergency generator building's was the least robust
  - CMU walls braced with light steel deck and open bar joists roof

Latest Progress/Next Steps

- Tasks 3.1-3.5 near complete (Task 3.2: Still seeking design information for some of the buildings at SJRMC)
- Tasks 4.1-4.6 near complete (Task 4.4: Still seeking additional data on fires following the tornado)
- Rough draft of objective chapter near complete
- Analysis and report writing in progress on integration of Objectives 1-4 Chapter with Drs. Lombardo and Kuligowski
- Findings pertaining to building and lifeline performance are being developed
- Develop recommendations, as warranted, for potential changes to building codes, standards, and practices to increase tornado resilience of buildings, lifelines, and communities

engineering laboratory

Technical Investigation of the May 22, 2011, Tornado in Joplin, MO

December 10, 2012
NCST Advisory
Committee Meeting

Current NCST Investigation Progress Report

Questions/Discussion

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