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

December 10, 2013
NCST Advisory
Committee Meeting

Performance of Buildings, Designated Safe Areas and Lifelines

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Investigation Objectives 2 and 3

2. Response of residential, commercial, and critical buildings, including performance of designated safe areas
3. Performance of lifelines as it relates to the continuity of operations of residential, commercial, and critical buildings

Presentation Outline

- Damage Summary
- Data Collection
- Findings Pertain to Investigation Objectives 2 and 3
  - Context
  - Building performance
  - Performance of shelters/safe rooms/designated refuge areas
  - Performance of lifelines

1. Damage Summary

Summary of Building-Related Damage, Fatalities, and Insured Losses

Buildings Damaged	Residential	**7,411 (43% sustained *heavy/totaled or demolished classification)***
	Non–Residential	**553 (1 of 2 major hospitals, 10 public and several parochial schools, 28 churches, 2 fire stations, and numerous commercial facilities)**
Fatalities	Total	**161**
	All Building–Related	**135 (of 161, or 83.8% of total fatalities)**
	Residential-Related	**74 (of 135, or 52.5% of building–related fatalities)**
Insured Losses (as of April 30, 2012)	Residential	**$0.552 billion**
	Commercial	**$1.228 billion**

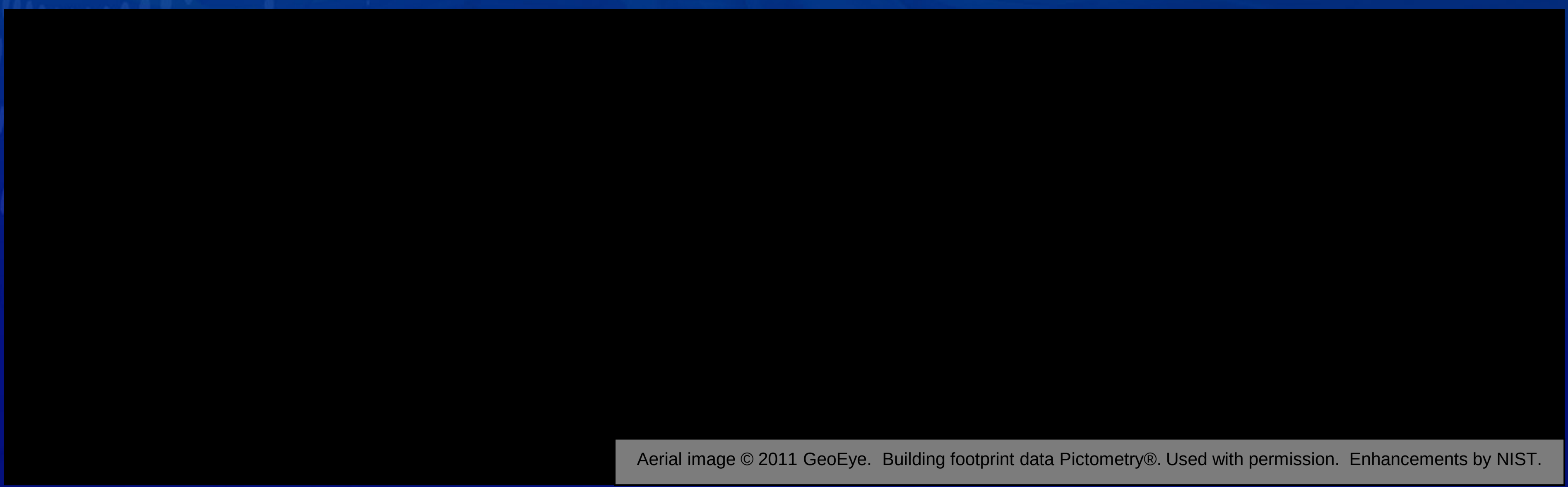
Summary of Damage to Lifelines

Electricity	Step-down Substations	**1 destroyed, 2 damaged**	~ 20,000 customers lost electrical power immediately after the May 22, 2011 tornado
	Distribution Poles/Transmission Towers	**~ 4,000 damaged**	
	Transformers	**1,500 damaged**	
	Transmission/Distribution Lines	**110 miles downed**	
Water	Service Lines	**~4,000 damaged/leaked**	Drastic decrease in water pressure and loss of water from the two elevated storage tanks within 2 hours
	Fire-Service Lines	**~25 broken**	
Gas	Meters	**~ 3,500 damaged**	~ 3,500 customers affected
	Main	**~ 55,000 ft damaged**	

2. Data Collection

Data Collection

- Conducted field surveys of 25 structures and lifeline facilities, including institutional, commercial, and residential buildings representative of typical construction types, building functions, and levels of damage.
- Obtained design and construction information for the surveyed buildings, including applicable building codes, and damage/outage information from utility companies by working with third parties.



Aerial image © 2011 GeoEye. Building footprint data Pictometry®. Used with permission. Enhancements by NIST.

SJRMC: St. John's Regional Medical Center

3. Findings

Findings – Context

- National model building codes, standards, and practices seek to achieve life safety for the hazards considered in design. Tornado hazards are not considered in the design of buildings currently, except for safety–related structures in nuclear power plants, storm shelters, and safe rooms.

- There are currently two tornado hazard maps for the contiguous U.S.:
  - ANSI/ANS 2.3 (2011) (also NRC/RG 1.76 and DOE 1020), for nuclear–related facilities (3 regions, 230 mph maximum wind speed); and
  - ICC 500 (2008) (also FEMA 320 and 361), for shelters and safe rooms (4 regions, 250 mph maximum wind speed).

- Current building codes and standards prohibit the use of aggregate roof surfacing materials or ballast for hurricane–prone regions, but allow their use elsewhere based on mean roof height and exposure category.

  For the City of Joplin, the building code at the time allowed aggregate roof ballast for buildings with a mean roof height of ≤ 110 ft.

Findings – Context (con'd)

- In the State of Missouri, adoption and enforcement of building codes are at the local government level. The City of Joplin's building department has a long history of code adoptions, and typically has adopted the latest national model building codes shortly after they have been issued.

- Like most other municipalities in tornado–prone areas and the contemporaneous model building codes, the City of Joplin did not mandate the construction of shelters or safe rooms in residential or non–residential facilities.

  Additionally, the City did not own or operate any public storm shelters.

  The lack of public shelters and requirements for safe rooms meant that many residents, particularly those who were living in multi–family residential buildings or older nursing homes, did not have access to such sheltering options during this tornado.

Findings – Building Performance

- F8: Buildings are not designed to withstand tornado hazards (extreme wind speeds and wind-borne debris). Most buildings in the damaged area of Joplin were subjected to wind speeds close to or above the non-tornadic wind design requirements of applicable building codes.
- F9: Regardless of construction type, buildings were not able to provide life–safety protection. Of the 161 fatalities, 135, or 83.8 percent, were related to building failure (slightly more than half in residential buildings, the rest in non-residential buildings).

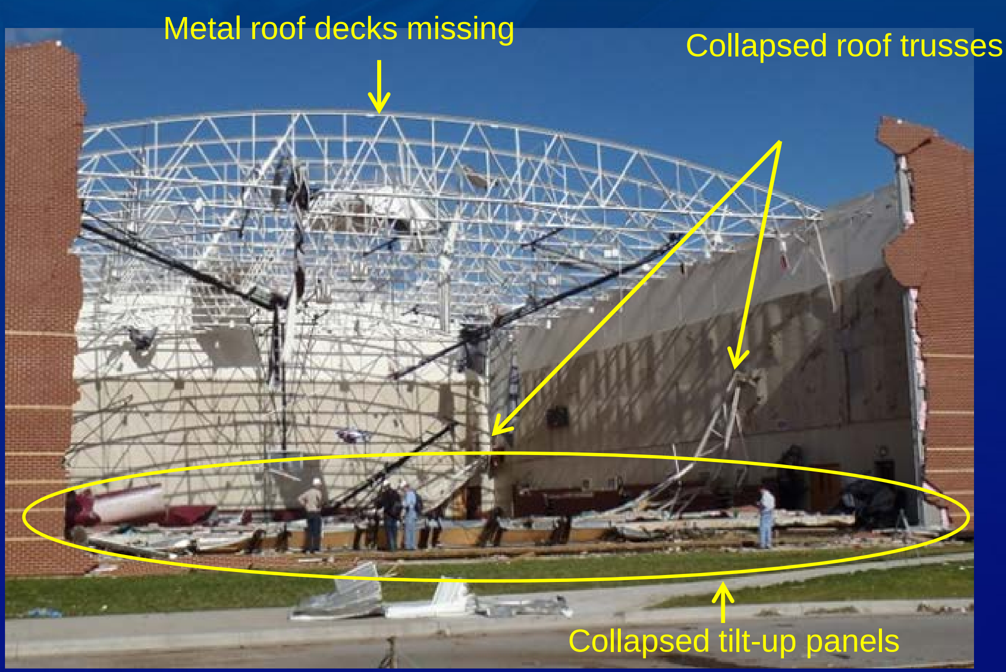
Findings – Building Performance

- F10: Engineered buildings that:
  - Had redundant lateral load capacity or that did not depend on roof bracing (steel and concrete moment frames) withstood the tornado without collapse.
  - Had reinforced concrete or composite concrete-steel roof also withstood the tornado without collapse.
  - Relied on bracing from a less robust roof system (such as box–type system (BTS) buildings with light steel roof decks) were prone to structural collapse.

Findings – Building Performance (cont)

- F11: Collapses of BTS buildings typically began with failure of the roof system due to wind uplift (failure of roof *deck–to–joist* or *joist–to–wall* connections), which led to the loss of lateral bracing for perimeter walls, causing them to collapse by rotation at the base due to lateral load.

Available design information showed that the roof connections of these buildings were adequate for code–level design wind pressures, making it unlikely that these buildings could have failed in wind speeds under 115–120 mph, which are the current code–level design wind speeds.



Findings – Building Performance (cont)

- F12: BTS buildings that sustained structural collapse had two common design features:
  - Light–gauge metal roof systems, and
  - Friction–only wall–to–footing connections (currently accepted practice for areas with low or no seismic risk).

- F13: Pre–engineered metal buildings (PEMB) sustained significant damage to envelopes, but no collapses of primary rigid steel frame.

Findings – Building Performance (cont)

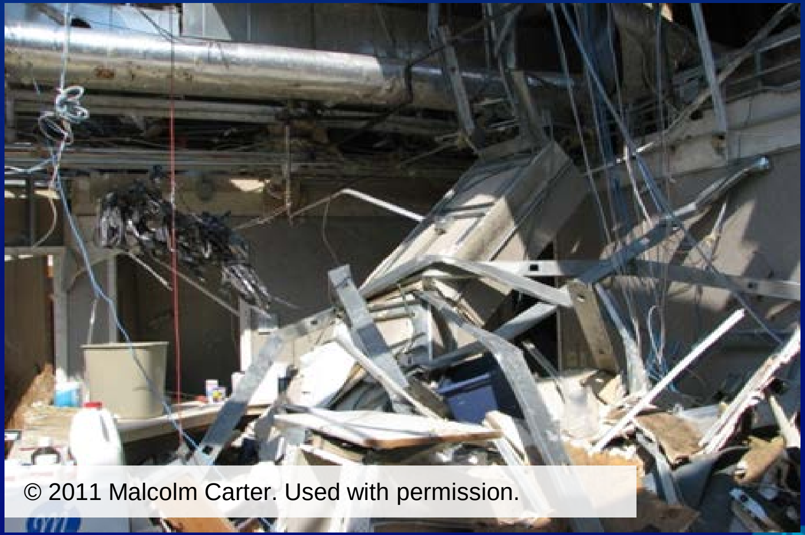
- F14: Failures of residential wood–frame buildings predominantly involved failure of the connections between structural components (roof from walls and walls from foundation). This indicates lack of robustness in the connections and in the continuity of the vertical load path from roof to foundation.

- F15: Better structural performance in one of the NIST–surveyed multi–family residential buildings can be attributed to use of robust hurricane connectors, typically only required for residential wood–frame buildings in hurricane–prone regions.

Findings – Building Performance (cont)

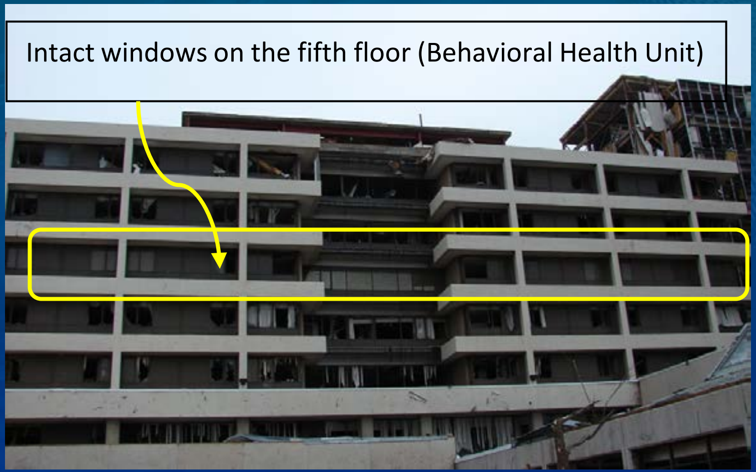
- F16: All NIST–surveyed engineered buildings that did not collapse, as well as engineered buildings that collapsed, sustained significant damage to the envelopes and interiors due to the combination of wind pressure, impacts by wind–borne debris, and water intrusion.

- F17: The failure of building envelopes at SJRMC, which led to loss of protection and subsequent extensive damage to building interiors, was the primary cause for the complete loss of functionality of this critical facility despite the robust structural system that withstood the tornado without structural collapse.



Findings – Building Performance (cont)

- F18: The majority of the impact–resistant windows on the fifth floor (Behavioral Health Unit) of the West Tower of SJRMC remained intact, whereas most regular dual–pane insulated windows at SJRMC were broken when exposed to the same tornado hazards.



- F19: While there was no direct evidence that roof aggregate contributed to any injuries or fatalities in Joplin, there was evidence that roof aggregates contributed to envelope damage in SJRMC buildings and surrounding structures, thus adding to the tornado debris hazard and the potential for injuries or fatalities.

Findings – Performance of Shelters/Safe Rooms/Designated Refuge Areas

- F20: Joplin residents had limited access to underground or tornado–resistant shelters. There were no community shelters or safe rooms in the City of Joplin or Jasper County at the time. About 82 percent of the homes in Joplin did not have basements. Only a few non–residential buildings had underground locations (e.g., basements).

- F21: Most high–occupancy commercial and critical facilities surveyed by NIST had designated refuge areas for tornadoes. However, many of these areas suffered severe damage and yielded no positive outcomes with respect to loss of life. The locations of these areas were not always based solely on structural considerations.

  There are currently no standards, requirements, or guidelines for designating refuge areas in commercial or critical buildings

Findings – Performance of Shelters/Safe Rooms/Designated Refuge Areas (cont)

- F22: Currently there are optional model code provisions for the design of specially purposed shelters, but such shelters are not required.
- F23: Based on a few instances observed in this tornado, in–home shelters did perform well and provided life–safety protection to the home occupants. NIST found no statistics on how many of the 7,411 damaged residential structures had in–home tornado shelters.

Findings – Performance of Lifelines

- F24: All utilities (water, gas, power) were lost in the areas damaged by the Joplin tornado. The utility providers restored service to critical buildings (SJRMC, water treatment plant) within 24 hours.
- F25: The failure of building envelopes at NIST–surveyed critical facilities, and resultant severe damage to their interior and internal utility distribution systems, was the primary cause of the facilities' complete loss of functionality despite restoration of utility services within 24 hours.
- F26: In critical facilities constructed in Joplin prior to 1998, the design wind speed for high–occupancy buildings was higher than that specified for buildings housing the facilities' backup power generators.