Lessons Learned from the JOPLIN TORNADO

By Curtis Geise, P.E., S.E.

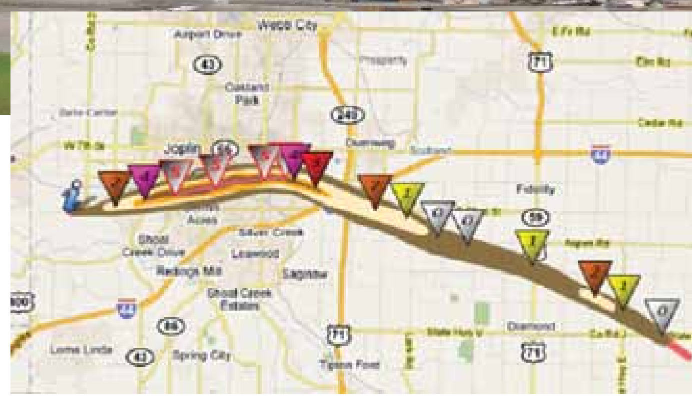
Non-residential building remains standing despite major damage.

The Joplin Tornado of May 2011 was one of the most destructive natural disasters ever to hit the state of Missouri. There were more than 160 deaths, 1,100 injuries and $3 billion in damages. The physical and psychological impact will not soon be forgotten. In consideration of the magnitude of devastation to the built environment, the Structural Engineers Association of Kansas & Missouri (SEAKM), a Member Organization of NCSEA, formed a committee to investigate the performance of structures affected by the tornado, whether directly or indirectly. This article offers some of the committee's observations and recommendations, which are based on site reconnaissance and other information. The committee's full report will be posted on SEAKM's website (**www.seakm.com**).

In general, structures designed in accordance with building codes, such as those published by the International Code Council (ICC), are not required to resist tornado wind effects. Tornado wind speeds vary greatly and may exceed 200 mph, as was the case with the Joplin Tornado. The International Building Code (IBC) 2006 establishes a baseline of 90 mph as the basic wind speed for this area of the country.

Observations of wood structures indicated the main area of vulnerability is maintaining a strong load path through connections. Overall, the wood structures reviewed were of an older generation of construction materials and methods and performed poorly. The few newer commercial buildings included in the committee's study performed better. Typically, wood structures have an inherit redundancy within the framing system, with multiple interior walls intersecting and connected to the outer structural frame; but today, with larger open spaces, this redundancy is reduced significantly and the prescriptive connections techniques in codes may no longer be appropriate.

Pre-engineered metal buildings are typically designed and constructed to provide column-free spaces. The pre-engineered building that the committee investigated suffered damage to the envelope, even though it was not directly in the path of the tornado. The damaged areas appear to be consistent with overpressures that are beyond the code-specified wind loads. Fortunately, main structural frames remained stable and did not collapse.



Mapping of the Joplin Tornado EF Rating. Courtesy of the United States Department of Commerce, National Weather Service, Central Region Headquarters, Kansas City, MO.

Structural steel and concrete framed buildings performed better in resisting the extreme wind effects of the tornado, although not without damage. St. John's Hospital and its Medical Office Buildings sustained damage, but the structural frames remained stable. The buildings' envelope materials were severely damaged, with most of the destruction caused by the ballasted roof systems used throughout the complex. Essential facilities should consider a comprehensive tornado preparedness plan when considering the layout of the facility and the respective infrastructure requirements. Emergency generators, electrical switch gear, mechanical systems and the structures that support them require consideration of the implications of windborne debris. Reports indicate that cars impacted the backup generator building for the hospital during the tornado, which rendered the facility inoperable.

Hard wall structures are a building type that is constructed to be very efficient in the use of materials, while providing the most building square footage for the minimum amount of cost. These buildings are commonly described as "big box stores." A few such buildings experienced a near-direct hit by the tornado. The high wind speeds caused significant damage, including roof deck connection failure, leading to the failure of several structural framing members and, in some cases, almost total collapse of the hard wall system.

The roof deck diaphragms of buildings have a propensity to fail first when tornado winds impose high uplift on the structure. This was most evident in hard wall buildings that the committee reviewed where roof framing was light and material usage was efficient. Roof deck diaphragms are an essential building component that typically does not incorporate a redundant load path; once it fails, other structural members will likely fail, as seen in both of the hard wall structures investigated.

It is understood that tornados are an extreme loading event, with a low probability of occurrence, but it is also evident that society is impacted by these events. As professionals, structural engineers need to lead in determining if and when enhancements to the building codes are warranted. We understand that most buildings do not need to be designed to the maximum wind speeds of a tornado to provide life safety, but we need to be prudent and consider these potential events to some extent.

St. John's Hospital damage; note the ballasted roof, lightweight concrete and glazed curtain wall destruction.

Summary of Recommendations

The intent of the following recommendations is to increase life safety for occupants and overall building integrity and robustness when impacted by tornado type winds. However, it should be understood that a structure built in accordance with them will not be "tornado proof."

1) Implement statewide building code legislation in all 50 states.

The public has the opportunity to enhance the built environment by passing legislation requiring compliance with an appropriate building code. Such legislation is currently being considered in the state of Missouri, and at least fifteen other states have already enacted such a provision. This legislation should enable local jurisdictions to enforce the statewide building code and include funding for this enforcement. Studies have shown that a building code provides a safer built environment for all.

2) Determine if the use of mechanical deck connections for steel metal deck thicknesses of 22-gauge or less should be mandatory.

The roof diaphragm is essential to the overall integrity of a building's structural system. Inspections by several groups have revealed failures of the decking metal around supposedly sound arc-spot (puddle) welds. Today, steel deck manufacturers and their governing bodies do not recommend welding of side laps for 22 gage decks. It seems apparent that this may need to be considered for typical fastening of the deck to the supporting structure.

3) Design roof deck fasteners considering simultaneous uplift tension and diaphragm shear and reflecting the different factors of safety in accordance with the [*Steel Deck Institute Diaphragm Design Manual*], Third Edition.

Steel deck manufacturers' data typically does not consider tension and shear simultaneously, and at times will provide notes regarding the different factors of safety for wind and seismic. Inspection of damaged structures indicates that uplift in the field of the roof may have been much higher than traditional loading patterns currently indicate. This is likely due to the large atmospheric pressure drop in the vortex of a tornado. There is little or no available research into the wind patterns on a structure during a tornado, but designing the fastening of the diaphragm system for an amplified wind pressure load capacity in both shear and uplift seems appropriate.

4) Require a specific design for open web steel joist connections to primary framing members and joist girders.

In many instances, connections between joists and joist girders and between joist girders and building columns are standard details provided by the joist supplier. These details need to reflect the design practice of forcing any failure into the member itself, rather than allowing it to occur within the connection. Connection failures are often sudden and catastrophic, whereas member failures tend to be more ductile and may not result in a catastrophic failure. The Engineer of Record or joist manufacturer should design the connection based on the strength of the most critical component of the joist or joist girder assembly, such as top chord shear or end diagonal compressive capacity.

5) Develop code requirements for greater robustness or redundancy in hard wall buildings. These may be in the form of specifying: a defined base moment; a maximum length of continuous wall prior to a full-height lateral-load-resisting member, wall or frame; or a system of continuous cross-ties.

One of the buildings impacted by the Joplin Tornado experienced a near-total collapse of the tilt-up wall panel system except at the loading dock area, where the base of the panel was well below grade such that it behaved as a cantilever. Details could be designed and provided that would offer a fixed or partially restrained base condition. Alternatively, if a lateral bracing element, such as a perpendicular wall or steel brace, is placed to restrain the wall system at some prescribed length, the potential for failure of a significant portion of the wall system is greatly reduced.

Building codes should also include requirements for more robust continuous ties across the roof diaphragm so as to preserve walls when the diaphragm fails. Wind force levels could correspond to EF-0 or EF-1 and allowable stresses could be ultimate, with a factor of safety equal to 1.0. This would allow significant damage, but minimize the propensity for collapse of the hard wall system.

6) Require a storm shelter, or at a minimum an area of refuge, in retail stores, manufacturing buildings and similar types of structures with a certain number of occupants, for employees and customers that may be inside during a tornado event.

According to published accounts, lives were saved in one hard wall building because store employees and patrons were able to shelter themselves in an employee break room. Although not specifically designed as a storm shelter, the inherit robustness and redundancy in the framing of the room provided sufficient protection for the occupants who took refuge there. Design could be based on the principles of ICC-500, *ICC/NSSA Standard for the Design and Construction of*

Devastation near the center of the path of the EF-5 Joplin Tornado.

Storm Shelters, and FEMA 361, *Design and Construction Guidance for Community Safe Rooms*.

7) Require storm shelters designed in accordance with ICC-500 and FEMA 361 for all elementary, middle and high schools, as well as other critical facilities, such as police and fire stations, emergency preparedness centers of control and other post-disaster structures including hospitals.

Society relies on the public school system to protect their children while they are being educated, and expects critical facilities and infrastructure to withstand extreme loadings. The tornado that struck Joplin provides sufficient evidence that schools need to consider alternative measures for offering security during these times of violent weather. It is very fortunate that, at the time of the tornado, the schools were empty. It is unfortunate that some of the critical facilities were unusable after the event.

8) Require essential buildings to have impact-resistant glazing systems and door units, similar to those required in hurricane-prone regions.

The winds of the Joplin Tornado caused significant damage to envelope materials of several important buildings, including the St. John's Hospital complex. The hospital facilities may have been able to treat some of the injured had these items not catastrophically failed. Critical structures should conform to the same practices required in regions where windborne debris is a concern during a hurricane.

9) Prohibit the use of ballasted roofs in all construction.

During high wind events, both hurricanes and tornadoes, loose roof ballast is ineffective at preventing roof blow-off. In fact, roof ballast often becomes airborne debris that typically destroys glazing systems and exterior finishes and may directly injure people. Many hurricane-prone regions of the country have enforced codes restricting or eliminating their use.

10) Research the concept of implementing similar design considerations for wind load distribution to diaphragms, drag struts and chord attachments in high-risk tornado areas that are currently codified for seismic lateral force distribution.

Enhanced design requirements for diaphragms, drag struts and chord development will lead to more robust connections of the diaphragm to the bearing walls and to other lateral-force-resisting system elements. The research should consider all aspects.

11) Enhance inspection requirements for big box structures.

Adopt provisions similar to those in the Florida Building Code, which requires a "threshold inspection" for all structures over a certain size.

12) Review and update prescriptive practices for wood construction to ensure a robust load path through connections, from roof to foundation.

Connections in wood with nailing procedures as outlined in prescriptive guidelines should be reviewed, for both the International Residential Code (IRC) and the IBC. Several studies indicate that simple, low-cost modifications can achieve significant robustness in the load path; for example, metal plate connections for roof trusses, top plates and sill plates.

13) Place renewed emphasis on special inspections, with improvements for wood framed buildings, including residential.

As design and construction professionals, we should review our past practices and determine ways to enhance them to serve the public better. In the wake of a disaster, there tends to be a renewed effort in inspections and other requirements for design and construction. Several cities around the country have developed their own special inspection manuals that typically are more stringent than a recognized building code.

14) Encourage installation of tornado shelters in existing buildings.

There are several available pre-manufactured storm shelters that satisfy FEMA 320, *Taking Shelter from the Storm: Building a Safe Room for Your Home or Small Business*. The guidelines offer simple and economical methods to designing and constructing residential structures. This document, along with others regarding tornado preparedness, is available at **www.fema.gov**.

15) Study the impacts to design and construction practices if codes required the design of buildings for EF-1 or EF-2 tornados in tornado-prone areas.

It seems appropriate to consider the design of structures for a higher level of wind pressures, based on the current observed wind speeds through the Enhanced Fujita Scale Rating System. However, we must realize that these wind speeds are estimated from observed damage and not measured directly.

16) Study tornados further in an effort to develop appropriate code design equations.

The current equations consider straight-line winds, which are significantly different from winds near the vortex of a tornado, where uplift forces are considerably higher and turbulence occurs.

Tornados are one of nature's most elusive adversaries to the built environment. Although modern technology has enabled the prediction of potential tornadoes and their possible paths, it is still a struggle to record wind speeds and develop structural design methodologies based on actual conditions. This is an opportunity for design professionals, the construction industry, government agencies and the general public to learn from these devastating events and react to these recommendations.

Readers are encouraged to conduct further research by reading other Joplin reports that have been or will be issued by the National Institute for Standards and Technology (NIST), Federal Emergency Management Administration (FEMA), and National Oceanic and Atmospheric Administration (NOAA), along with reports regarding the Tuscaloosa, Alabama tornado and Enhanced Fujita (EF) Scale developed by Texas Tech University (TTU) in cooperation with the National Weather Service (NWS) in 2004, **www.spc.noaa.gov/efscale/ef-ttu.pdf**.▪

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