Structural Performance

performance issues relative to extreme events

Figure 1: Toe-nailed connection for truss.

Tuscaloosa Tornado

Preliminary Observations on Wood-Frame Buildings Damage Assessment

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A forensic team, consisting of university engineers and scientists as well as industry professionals, surveyed the structural damage to wood-frame buildings caused by the April 27th tornado that ripped through the city of Tuscaloosa, home to the University of Alabama. The tornado cut approximately a ½-mile-wide swath through a densely populated urban area that consisted mainly of older 1930s to 1970s residential buildings and light commercial structures, with some newer multi-family structures scattered throughout. This was a powerful tornado that the National Weather Service (NWS) suggested was on the ground for nearly 90 minutes, causing damage from Tuscaloosa to North Birmingham. The NWS preliminary estimate of maximum wind speeds was around 190 mph, but a significant area of damage was caused by wind speeds estimated to be below 135 mph. Approximately 5,000 buildings were lost and some 500 businesses were directly affected. Over a period of six days, the team looked at hundreds of homes and other structures. Initial observations of the structural damage, and possible mitigation approaches to save lives and reduce losses in the future, can be summarized as follows.

Many of the failures of older buildings can be attributed to the lack of continuous vertical and/or lateral load paths, not just excessive wind speeds. In a series of perpendicular transects to the tornado's path, the team observed a gradual reduction in severity of damage from the center of the path towards the edges. There was complete destruction, with some houses shifted entirely off their foundations, at the center of the path. A short 100 to 200 yards away, major structural components such as roof trusses and walls failed, but the building remained in place. Beyond 200 yards, houses had severe siding damage, loss of roof covering, broken windows and failed patio/porch roofs. Many of the buildings at the outer boundaries of the damage zone had a discontinuity in vertical load paths created by inadequate connections at critical locations. This is not surprising, given the age and location of these buildings in a non-hurricane area where no building code mandates special attention to such details.

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Figure 2: Carport column uplift failure.

The study team found numerous instances where detailing in accordance with current building codes for hurricane-prone regions would have reduced the damage and potentially reduced injuries. Examples of damage included roof loss due to inadequate toe-nailed connections for trusses or rafters (*Figure 1*), porch or carport column uplift failures (*Figure 2*), and the attachment of sill plates with only concrete cut nails (*Figure 3*). The team also observed a lack of connections at the wall boundaries that may have contributed to the loss of exterior walls, especially when the building envelope was breached and the walls were pressurized from the inside (*Figure 4, page 26*). Many of these buildings were built before the existence of manufactured connectors that better provide a continuous load path. In addition, as expected in a tornado, windborne debris created many penetrations and openings through the building envelope.

For tornadoes of low to moderate intensity (EF0-EF2), it may be possible to save lives and reduce injuries by employing load path enhancement techniques known to work in hurricane-prone regions. At the moment, such measures would be optional for owners, but they need to be fully understood by builders and building code officials so that, for those who want them, the quality of the construction and inspections ensures improved building performance should the building be impacted by a tornado.

During the damage investigation, the team also observed that there might be a minimum size (square footage) building that provides enough interior wall lines to create a safer space somewhere in the middle of a light-frame wood structure. Small houses have fewer interior walls to help either resist uplift (if tied to the roof) or act as barriers to missile impacts and extreme wind pressures. Larger homes typically have more interior walls that could be used for increased lateral resistance, additional missile protection or improved interior shelter of occupants. There can be a safe location within wood frame construction if the walls remain standing and the roof stays in place in spite of building envelope failure, such as glass breaking and/or garage doors imploding.

The team observed that for the highest tornado wind speeds (EF5), even new buildings built to more recent building codes were completely destroyed, as one might anticipate given that the forces are in excess of four to five times the design values. *Figure 5 (page 26)* shows an apartment complex that was completed in 2010 and was about half occupied at the time of the tornado. The whole facility was damaged extensively because it was in the direct path of the tornado and wind speeds increased even further because of the terrain, which consisted of hills on all sides. Evidence suggests that the structures were likely designed and built according to the 2006 IBC, with hurricane clips between trusses and the top plates, code-required nailing of roof and wall sheathing, and anchor bolts in exterior wall sill plates every four to six feet. Part of the complex

Figure 3: Evidence of cut nail at sill plate.

Figure 4: Pressurized exterior wall.

Figure 5: Catastrophic damage at apartment complex.

was leveled down to a clean concrete slab, where even linoleum flooring was removed. This illustrates the difficulty of designing a wood frame building economically that can resist the effects of the most severe tornado wind speeds.

The team strongly believes that structural engineers should not simply accept the fact that people will perish in their homes from a tornado because the wind speeds are too high, and thus there is nothing that we can do. At the lower tornado wind speeds associated with EF0-EF2 events, there are known construction practices that could be used to enhance the robustness of typical light-frame buildings. One solution already practiced in "tornado alley" is the installation of safe rooms, but this life-saving measure is not yet widely used. The team believes that other building strengthening practices for these types of events should be developed, and then demonstrated by local builders and building officials so that owners who want to reduce their risk of injury or death from tornadoes are able to do so.▪

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