Designing for Tornados

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Traditionally, tornados have been overlooked in structural design in favor of more predictable straight-line winds. Indeed, all of the design wind speeds presented in ASCE 7 are based on either surface data analysis of thunderstorms and synoptic storms, or Monte Carlo simulations of hurricanes. There is no direct allowance for tornados. This is because the probability of any individual building or structure being impacted by a tornado is small given their infrequency of occurrence and very limited spatial extent.

In recent years, however, a number of very damaging tornados resulting in extensive life and property loss have caused a re-examination of approaches to structural design for tornados. Some more substantial structures are now specifying additional robustness to protect building contents and operations, while an increasing number of more modestly constructed buildings are incorporating places of safety to provide refuge to occupants.

The most recent uptick in awareness of tornados probably began around 2007 with the adoption of the Enhanced Fujita (EF) Scale for classification of tornado intensities. Like the earlier Fujita scale, this uses post-event damage surveys to estimate the wind speeds that occurred and retains a six-point classification scale from 0 to 5. The major change in the updated scale was revised wind speeds that better correlated with observed damage. The Enhanced Fujita Scale provides values as 3-second gust wind speeds, which are directly comparable with the design wind speeds in ASCE 7. They are not, though, directly comparable with the wind speeds in the Saffir-Simpson hurricane scale, which is based on *sustained* wind speeds with a duration of around one minute.

An EF5 tornado has an estimated wind speed of greater than 200 mph, and this is surprisingly close to the Saffir-Simpson Category 5 hurricane (when converted to a 3-second gust). Both the EF5 and Saffir-Simpson Category 5 are expected to result in catastrophic damage with a high percentage of homes destroyed. Based on ASCE 7 wind speed maps, this speed would only be expected to occur around once every 1,700 years right on the southern tip of Florida, the most hurricane-prone area in the continental United States. In the Midwest U.S., where tornados are most likely to occur, the ASCE 7 1,700-year design wind speed is around 120 mph, although most buildings (in Risk Category II and III) would be designed for the 700-year wind speed of 115 mph. This lower value equates to an EF2 tornado, which has an intensity that would be expected to result in severe damage, with roofs torn from well-constructed houses and foundations of frame homes shifted. As such, there is some degree of consistency in the reliability of design.

In April and May of 2011, there were a series of severe tornados that tore through Alabama, Missouri, and Oklahoma, the best known being the Joplin tornado. This tornado was extensively studied by academic and professional response teams from around the country. The Joplin tornado was notable for the large loss of life (158 people) and the economic cost of damage as reported by the insurance industries (greater than $2 billion). While it is not economically viable to design typical wood-framed residential properties to resist severe tornados, incorporation of reinforced tornado shelters (whether in basements or the interiors of homes) is feasible, and these are being increasingly adopted in newer construction.

The Alabama tornados occurred in an area with a large concentration of manufacturing facilities, particularly for the automobile industry. This was shortly after the Fukushima nuclear accident in Japan, which severely affected automobile production. These combined events led to risk studies by the industry to assess the potential costs of severe damage to component production facilities, especially when a number of those are located in a limited geographical area. Other facilities, such as data centers, are also increasingly specifying tornado resistance in their design specifications. In these cases, analyses of the economic benefits of additional robustness protecting building contents and operations are shown to outweigh the higher costs of construction.

In May 2013, a severe tornado hit two elementary schools in Moore, Oklahoma, resulting in 7 deaths in one school out of a total of 24 deaths and 212 injuries across the town. An ASCE/SEI-commissioned report in the wake of this tornado on *Performance of Schools and Critical Facilities* highlighted the roles of weak links in the load paths propagating more extensive failures. The reliance of the schools on plans based on "Best Available Places of Refuge" rather than dedicated tornado shelters was highlighted. Recommendations were given regarding the strengthening of existing buildings and incorporation of tornado shelters (for which ICC 500 provides design guidelines) in buildings that expect to shelter a large number of people in the event of a tornado. Further recommendations included revisions to ASCE 7 to incorporate additional guidance for practitioners, and examination of existing schools and critical facilities in tornado-prone regions for vulnerabilities.

Revisions to ASCE 7, at the current state of knowledge, would be expected to cover likely tornado wind speeds and methods of increasing provisions for tornado shelters and their robustness, rather than changing the pressure coefficients in the standard. However, recent research is beginning to suggest that pressure coefficients in a tornado wind field may differ measurably from those traditionally used for straight-line winds. Ongoing research is likely to result in modifications to the standard.▪

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