Structural Sustainability

sustainability and preservation as they pertain to structural engineering

Hurricane-Driven Building Code Enhancements

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Designing structures to resist extreme wind events is critical to providing sustainable structures that perform as needed throughout their design life. While the primary structural system is usually sufficiently designed by the structural engineer, the building envelope is composed of a variety of elements with minimal input from the structural engineer. Due to the wide range of systems and elements that compose the building envelope, the building code provides one of the strongest tools available to communities to implement a sustainable building stock that functions after extreme wind events.

A review of the building code enhancements over the past 20 years shows a focus on exterior envelope components and provides insight for engineers practicing in regions with less rigorous code requirements. Many of these provisions are gaining traction in tornado-prone regions as jurisdictions look for ways to mitigate tornado damage. Whether applied to residential or commercial projects, utilizing existing building code provisions from hurricane-prone regions provides an economic methodology for designing structures that are more resistant to extreme wind events.

For a structural engineer to provide leadership on a project, one should be able to discuss the advantages of designing beyond the "minimum" building code requirements. Owners or developers of critical facilities may be especially interested in understanding the economy of available options.

Designing for Extreme Winds

To appreciate the basis for utilizing design provisions greater than those specified in the local building codes, an understanding of the relationship between design winds for hurricanes and design winds for tornados is useful. In South Florida, the basic wind velocity required when utilizing ASCE 7-10 is 175 mph for Category II structures and 186 mph for Category III and IV structures. These wind speeds correlate to an EF4 tornado as shown in *Table 1*. Design wind speeds for most tornado-prone regions is 115 mph. In ASCE 7-10 and the Enhanced Fujita Scale, wind speeds are based on a 3-second gust and commonly termed "ultimate" wind velocities.

While the ICC/NSSA *Standard for the Design and Construction of Storm Shelters* (ICC 500) addresses the design of structures to resist specific tornado conditions, it is intended for storm shelters. Many of the provisions of ICC 500 are similar to those used in hurricane-prone regions, but with more conservative requirements for the resistance to windborne debris and slightly higher factors of safety on tested components. Because this standard is relatively new and not commonly used, the extent of systems and products available to comply with these provisions is limited.

The wind mitigation provisions adopted in hurricane-prone regions, especially the High Velocity Hurricane Zone of the *Florida Building Code* utilized in South Florida, are similar to the provisions specified in ICC 500, but with numerous economic building envelope systems already developed to comply.

Historical Code Review

A review of the evolution of the codes utilized in South Florida is provided so one may understand the history and basis for these provisions. This provides an engineer a background to evaluate the measures that may be based on scientific principles rather than political ones so that one may implement the provisions appropriate for a given project.

South Florida has led the country in hurricane-related building code enhancements since the devastating impacts of Hurricane Andrew in 1992, and by Katrina and Wilma in 2005. Before Hurricane Andrew, South Florida did not require the use of storm shutters to protect glazing. The only building code provision addressing hurricane protection stated that *if* storm shutters were used, deflection should be limited to avoid breaking the glass behind them.

In August of 1992, Hurricane Andrew exposed the shortcomings of the existing *South Florida Building Code*. The storm struck a less densely populated area of South Florida but was more than three times as costly as any other previous hurricane, causing over forty-five billion dollars in damage (adjusted to 2010 dollars). Of interest, the destruction differed significantly among neighborhoods. In some neighborhoods, all the houses were severely damaged, while in other adjacent developments the damage was minimal. What made the difference in these neighborhoods

Enhanced Fujita Scale	
EF Number	3-Second Gust (mph)
EF 0	65-85
EF 1	86-110
EF 2	111-135
EF 3	136-165
EF 4	166-200
EF 5	Over 200

Table 1. Enhanced Fujita Scale wind speeds.

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Figure 1. Hurricane Andrew damage in four neighborhoods. Courtesy of Aerial Cartographics of America, Inc.

was the design and construction methods used to build the homes (*Figure 1*).

Recognizing the differences in performance levels, Miami-Dade and Broward Counties created and adopted a new *South Florida Building Code* that incorporated many of the observed hurricane resistant features and added entirely new requirements. The most significant change was the requirement that the building envelope resists wind-borne debris. As ASCE 7 internal pressure coefficients indicate, allowing wind to build up inside a structure increases the negative pressures the envelope components must resist; thus, breaches in the building envelope lower the failure threshold. The use of large and small impact testing for all exterior envelope components provides a methodology to address breaches caused by flying debris. Large missile resistance was required for all exterior envelope elements in the first 30 feet above grade. Small missile resistance was required for all elements above 30 feet.

In the large missile test, a 9-pound, 2x4 stud (approximately 8 feet long) is fired at the window, shutter, or wall system at a speed of 34 miles per hour. For the small missile testing, ten $^5/_{16}$-inch-diameter steel balls (initially small gravel was specified) are shot at the test specimen at 50 miles per hour. In both the small and large missile tests, the test specimen must resist cyclic forces similar to hurricane winds for over 3 hours, and this occurs after two or more impacts to the specimen. Furthermore, the test must be repeated on three samples. While the glass may crack during testing, there can be no cracks more than $^1/_{16}$-inch wide and 5 inches long through which air can pass. While this test procedure was rigorous and unique at the time, it is now standardized as ASTM E1886 and ASTM E1996, and codified in the *International Building Code* (IBC). An abundance of building envelope products exist that comply with this standard.

South Florida's Unique Code Provisions

There is one important distinction between the impact requirements of the IBC versus those used in South Florida. The impact requirement in the IBC is based on ASCE 7's statement that glazed openings must be protected in wind-borne debris regions. In South Florida, all building envelope components must be impact resistant, including exterior wall systems. Glazing is not a relevant

factor. For buildings utilizing popular Exterior Insulation and Finish Systems (EIFS), it is worth noting that the major manufacturers have developed impact resistant solutions for this requirement.

While glazed openings may present a more obvious susceptibility to breaches from windborne debris, lightweight exterior wall systems consistently fail during high wind events. The use of impact resistant wall systems provides not only a level of protection from windborne debris but also provides a higher level of confidence in the actual wind resistance of the system since it has passed a battery of wind and impact tests.

Other significant changes were incorporated into the building code after Hurricane Andrew. While many are only applicable to residential construction, the requirement for minimum ⅝-inch plywood roof decks and the prohibition of using oriented strand board (OSB) affects many commercial projects as well. Plywood roof deck connections are also required to use nails; the use of staples is forbidden.

Since the proper design and bracing of wood gable ends above masonry walls seems to be misunderstood by many in the residential marketplace, gable ends of masonry walls are simply prescriptively required to be full height. The common practice of stopping the masonry wall at the low eave height and filling the gable with wood framing and nominal bracing is prohibited.

Many of these changes were initially resisted by the building industry due to costs, but the most important provision, the missile impact testing requirements, were adopted by Palm Beach County in 1995 and Monroe County in 1997. Despite the continued resistance from builders, the new *Florida Building Code* (FBC) adopted these impact provisions in the first edition published in 2001. This new FBC incorporated missile impact testing for all Florida counties in windborne debris regions, while separately specifying all South Florida's original changes for Miami-Dade and Broward County. The Miami-Dade and Broward County provisions were officially named the High Velocity Hurricane Zone (HVHZ) provisions and are applicable only to those two counties. The HVHZ continues to be the only region that requires impact resistance of the entire building envelope, not just glazed openings.

In 2004, Hurricanes Charley, Frances, and Jeanne all made landfall in Florida. The following year, Hurricanes Katrina and Wilma also made landfall in Florida. This increased storm activity initiated more changes in the building code. Since there had been significant construction under the new codes, researchers were able to study the damage from these storms and evaluate the effectiveness of the new codes, identifying additional mitigation measures that were needed.

Due to observed uplift failures of roof tiles, especially at the eaves, eave tiles now require a metal clip tying the leading edge to the roof deck. Excessive failures were also observed at hip and ridge tiles; thus, special adhesives or mechanical fastening are now required rather than simply using a bed of mortar. Field testing of the installed hip and ridge tiles became mandatory after installation to assure minimum uplift requirements were satisfied.

Glass debris during Hurricane Wilma prompted a change to the glazing requirements. The sacrificial exterior lite of glass in some small missile resistant systems had no specific requirements, but breakage of this glass created large and damaging debris. The code was modified to require the use of safety glass for this exterior lite to minimize the effect of any resulting debris.

Roof Top Mechanical Equipment

Building breaches not only cause increased wind pressures on cladding elements, but they also allow water infiltration which significantly affects losses in terms of dollars and business interruption. Another primary source of building breaches occurs at the roof level with damaged roofing systems. Often, the roof damage is a result of poorly supported mechanical equipment tumbling across a roof and tearing the roofing system. Once torn, the system loses its design resistance as wind gets under the system and the failure propagates. Proper design and detailing of rooftop equipment is critical to the sustainability of a building when subjected to extreme winds. Depending on the project and the size of the specific piece of equipment, rooftop dunnage may be engineered by the Engineer of Record or placed by a subcontractor and never actually engineered to resist wind loads. The extent of damage from rooftop equipment led to more research to address the issue. Subsequently, ASCE 7-05 introduced increased horizontal wind loads for rooftop equipment based on research in the wind engineering community. Further research provided the data for ASCE 7-10 to address uplift loads on rooftop equipment, as this was not previously addressed.

Unfortunately, while ASCE now addresses these equipment loads, their use is limited in practice. Rooftop equipment must be properly fastened to engineered supporting elements and the equipment housing must be designed to remain intact, or the equipment itself will be tossed about the roof causing the same damage. Applying proper design requirements to the manufacturers' housing caused such a lack of equipment availability in Florida, the FBC has removed the requirement for the higher loads on the equipment itself. For reliable performance during and after an extreme wind event, roof top equipment must be properly addressed by the Engineer of Record through appropriate delegation and review procedures.

Building Code Evolution

Building codes addressing the design of hurricane resistant structures have significantly changed and been enhanced over the past few decades due to continued research.

Building Code or Standard	Envelope Protection
IBC, Building - 2015 Edition	Impact protection for **glazed openings** in wind-borne debris regions.[1]
FBC, Building - 5th (2014) Edition High Velocity Hurricane Zone Provisions	Impact protection for **all exterior envelope elements** in wind-borne debris regions.[1]
ICC/NSSA Standard for the Design and Construction of Storm Shelters ICC 500-2014	Impact protection for **all exterior envelope elements** with higher missile velocities & higher testing safety factors.

[1]Wind-borne debris regions are areas of high wind velocities, defined specifically in ASCE-7-10, Section 26.10.3.1.

Table 2. Code comparison of building envelope protection.

Unfortunately, much of this research is conducted in the field during the aftermath of a hurricane or tornado. Because building codes are a balance between science, engineering, economics, and politics, shortcomings in codes are often realized but not addressed until the damage is repeated or particularly catastrophic.

A more recent example of a local building code being strengthened after extreme wind events is in Moore, Oklahoma. A devastating EF5 tornado strike in 1999 raised awareness, but it took EF4 strikes in 2003 and 2010, then devastating EF4 and EF5 strikes in 2013, before the political will existed to strengthen the local building codes. While the Moore building code enhancements are significant, they are simply prescriptive requirements for residential construction addressing some common failure mechanisms and fall short of requiring that homes be engineered to resist extreme winds. In South Florida, a professional engineer (or Registered Architect) is required to structurally design all buildings, including residential homes, a unique requirement in the residential construction industry.

For commercial or residential projects, simply engineering the structures to resist wind speeds similar to those used in South Florida provides a resilient structure with a much lower probability of failure during an extreme wind event. Designers in tornado-prone regions have significant code provisions that may be referenced and utilized to provide clients and communities with buildings that are more sustainable than would otherwise be provided using only local building codes.

Enhancing the building code is an evolutionary process. In the coming years, more communities will adopt specific residential design features and maybe even higher design wind velocities for all buildings, but more wind events will show that the changes are not enough. Once building structures and roofs are able to resist a reasonably significant wind event, we will then see less excessive damage from building breaches and cladding failures. Eventually, higher design wind speeds and impact protection for exterior cladding elements will seem appropriate for many buildings in tornado-prone regions.

Until then, structural engineers need to lead the way in designing more sustainable structures. An understanding of the various code provisions available that provide criteria for resisting extreme wind events is essential. *Table 2* provides a simplified summary showing the significant levels of wind mitigation provided in several readily available code documents.

While enhanced design specifications are not always appropriate for a project, the structural engineer is best positioned to evaluate a client's objectives and determine whether they should be considered. While most of these advancements in wind mitigation can address building elements outside the primary structural frame, the structural engineering of these elements is crucial to a building sustaining an extreme wind event with minimal damage. In some regions, it may be an expansion of scope, but structural engineers bring added value to building owners and architects if they introduce wind sustainability concepts that exceed minimum building code requirements with minimal economic impact.▪