Facing the Storm

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When properly designed, detailed, and constructed, structural steel offers an excellent solution for buildings subjected to high hurricane winds.

THE RULES CHANGE WHEN YOU'RE IN HURRICANE COUNTRY. ASCE 7-05 *Minimum Design Loads for Buildings and Other Structures* requires that all buildings along the Atlantic and Gulf Coast be designed for wind loads produced by hurricane storms. This requirement applies as well to Hawaii, Puerto Rico, Guam, the Virgin Islands, and American Samoa.

The wind speed map shown in ASCE 7's Figure 6-1 gives wind speed contours for the 3-second gust wind speed ranging from 90 mph all the way to 150 mph for a storm magnitude having a nominal return period (MRI) of 50 to 100 years. The commentary to the standard (Table C6-5) shows that these design wind speeds along most of the coastline correlate to an "ultimate" hurricane wind level ranging from a Category 3 to a high Category 4 storm as defined by the Saffir-Simpson scale used by the National Hurricane Center. A designer can be assured that a steel building frame and the building envelope will perform well during these violent storms, provided all serviceability and strength limit states are addressed during the design phase, and proper construction techniques are followed.

Main Wind Force Resisting System

All steel buildings properly designed according to these requirements are expected to have their lateral load resisting systems remain essentially undamaged. The 2005 AISC specification (AISC/ANSI 360-05) covers all the necessary strength limit states for the lateral load resisting frame members and their connections to ensure excellent performance under these storm events. Indeed these frames will remain essentially elastic with little or no need for structural repair after a major storm. However, the engineer must pay close attention to key serviceability limit states as well. Chief among these is building drift and confirmation that unintended stiffness from collateral building elements—such as interior masonry walls placed "hard" against the steel frame—is not compromising building sway by introducing torsion in the overall building. Such accidental torsion is known to increase lateral frame forces and deflections over what is calculated in design.

It is necessary that an analysis model of the main wind force resisting system (MWFRS) be assembled that accurately predicts the internal forces in the structure from load combinations obtained from ASCE 7. This model should include the effect of leaning columns—i.e., "pin-ended" columns carrying gravity load that are not part of the MWFRS. Internal forces from this model are used to assess all limit states required in the specification.

It is suggested that building drift—deflection of one story relative to an adjacent story (Δ) divided by the story height (L)—be determined using a second-order analysis model of the MWFRS, based on a serviceability load combination that includes the nominal wind load as required by the building code. While not explicitly a building code requirement, wind drift limits such as $\Delta/L < 0.0025$ are common to protect the building partitions and cladding from the potentially damaging effects of building sway during hurricanes. Braced frames are a good choice in hurricane zones, because a strength-based design often provides the necessary drift control at no extra cost. For taller structures, a combination of braced and moment frames provides a synergistic benefit to both frame types and affords an economical solution for strength and drift.

One sometimes overlooked design requirement is attachment of untopped metal roof decks to the roof purlins and walls. It is critical that roof decks be attached to resist the extremely high uplift wind pressures experienced during hurricanes, especially at building edges and corners. It has long been known that hurricane tie-down straps are very effective in preventing separation of the roof and walls in residential and commercial structures having bearing walls. The roof deck not only protects the building from the exterior weather, but also often serves as a horizontal diaphragm to distribute wind loads at the roof level to the MRWRS. Compromise of this function can lead to significant damage to the building and its contents. It is not uncommon for edge and corner roof pressures to reach magnitudes of 125-150 psf or more. The designer is reminded to follow the attachment requirements

Hurricane Jeanne approaching Florida. Image by NOAA.

of Factory Mutual and/or Underwriters Laboratory, which contain strict guidelines for purlin spacing and proper attachment to resist the roof uplift forces from hurricanes.

The Building Envelope

While proper design of the MWFRS is essential to good performance of the building structure during powerful gulf coast storms, protection of the building envelope is equally critical and considerably more problematic. Experience from observation of building damage from these storms shows most damage occurs because some portion of the building envelope has been breached. There are several causes for this. Attachment of the roof deck has already been mentioned, but other elements, such as proper adherence of the roof membrane, flashing, gutters, parapets, windows, doors, rooftop vents, rooftop equipment, and other portions of the exterior cladding, are equally critical to protecting the building from damage. These attachment details are all too often poorly conceived in the design phase and woefully executed in the construction stage, leading to failure and breach of the building envelope. Many post-hurricane assessments reveal that the MWFRS remains undamaged but extreme losses are incurred due to wind and water infiltration.

Recognizing these risk factors, a building design team would be well advised to consider the following precautionary steps in designing a building envelope for hurricanes:

1. Design all portions of the building envelope for component-and-cladding forces contained in ASCE 7-05. Even better, undergo a wind tunnel study on critical projects where the budget can afford it. Wind tunnel studies are known to be more accurate in predicting the magnitude and distribution of hurricane wind pressures than the analytical method in the standard.
2. Properly detail all elements of the building envelope to resist these forces. This takes an experienced architect and cladding designer familiar with detailing for hurricanes. Attachment requirements suggested or required by Factory Mutual and Underwriters Laboratory should be followed where guidance exists for the considered materials. Sources of information can be found in the Factory Mutual *Research Approval Guide* and the FMRC Data Sheet I-28, "Wind Loads to Roof Systems and Roof Deck Securement." Information can also be found in the UL publication *Roofing Systems and Materials Directory*.
3. Consider engaging the services of a cladding and/or roofing consultant experienced in the design and installation of building envelope components and systems.
4. Consider performing a full-scale cladding test in a recognized testing facility on important projects. Guidelines for such testing can be found in publications by the National Association of Architectural Metals Manufacturers (NAAMM). Of particular interest are the NAAMM *Curtain Wall Design Guide Manual* and NAAMM standards 501.1 and 501.4; the latter two cover testing curtain walls for wind pressure and racking from wind drift. The test assembly of the actual full scale curtain wall system is usually done by field installation teams that are used in the construction of the actual building.
5. Consider designing for debris impact of cladding elements using recognized test methods (ASTM E 1886 and E 1996). This is important because observation from hurricane damage shows that flying "missiles" are often responsible for breaches to the building envelope.
6. Consider the use of storm shutters and/or missile-impact-resistant glazing to protect doors and windows.
7. Carefully monitor and observe the actual construction and installation of the roof and cladding. Sadly, experience has shown that, despite a well-conceived design, faulty construction oftentimes is the root cause of failures in the building envelope.

The building structural engineer can play an important role in this process because of his or her knowledge and understanding of wind pressures, wind load resistance, and load path distribution through the building.

The Role of Structural Steel and AISC

AISC has published a series of design guides to assist structural engineers in designing steel buildings for most strength limit states required by the AISC specification. *Steel Design Guide 3: Serviceability Design Considerations for Steel Buildings* addresses appropriate serviceability limit states for hurricane storms. A new design guide on cladding attachment that specifically addresses the attachment of all types of cladding systems to steel building frames, is under review and will soon be published. This guide will be very useful to designers concerned with attachment of cladding systems to resist hurricane winds. AISC's Steel Solutions Center, staffed with knowledgeable and friendly engineers, is available by telephone, fax, e-mail, and the Internet, and is ready to assist designers in all aspects of structural steel design, including designing for hurricane storms.

Structural steel is an ideal building material to consider for resistance to hurricane winds. It is strong, light, durable, adaptable to all types of buildings, readily available, easily fabricated, erected quickly, and economically competitive. Adherence to proper design details regarding high wind pressures and good construction standards is key to successful performance.

Still Standing

Designing steel buildings for hurricanes requires careful consideration of key strength and serviceability limit states for both the lateral load resisting system and the entire building envelope. Hurricane loads for both the MWFRS and all component-and-cladding elements found in the exterior building envelope can be determined from Section 6 of ASCE 7-05. Attention to drift control will prevent the structure from racking under hurricane winds and protect cladding and interior partitions from damage.

Attachment of all parts of the building envelope to resist hurricane force winds is key to preventing breach of the building envelope and opening up the building to wind and water damage, often the biggest problems encountered when designing for hurricanes. Conformance to attachment requirements found in Factory Mutual and Underwriters Laboratory is very important to satisfactory performance. The design team should consider a wind tunnel study, a cladding consultant, exterior wall testing, and careful construction observation on large, important projects that can afford them. Following these suggestions will go a long way to ensuring that a building will stand strong in hurricane-force winds. MSC

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