1 B.2 **Hurricane Andrew 20 years later: What have we learned?**

Timothy P. Marshall*, Kenneth Gilvary, and Justin Kestner
Haag Engineering Co.

## I. INTRODUCTION

Hurricane Andrew struck south Florida on August 24, 1992 and went on to strike Louisiana on August 26th. The following week, the lead author conducted aerial and ground surveys in both states. Additional, detailed inspections performed on hundreds of specific buildings during the next several months revealed a number of common problems in building construction that increased the degree of damage. Some residences had poor attachment of rafters or trusses to the tops of walls which led to loss of entire roof structures. Roof trusses not laterally braced had collapse. Scissor trusses were especially problematic as they had high centers of gravity and toppled relatively easily. Gable ends were not secured properly to resist lateral wind pressures and fell either outward or inward. Loss of roof decking was common where fasteners missed the underlying framing members. Roof tiles and asphalt shingles, with little or no attachment, became airborne. Windows and doors that were not impact resistant were more susceptible to being breached by flying debris, leading to additional building damage due to internal pressures and rainwater entry. FEMA (1992) recognized these and other problems and developed recommendations to improve building performance.

Since 1992, the Florida Building Code (FBC) has been upgraded to fortify buildings against hurricane winds. Improvements have included better attachment of roof framing to walls. Various adhesives have been introduced to better secure roof decking to the rafters and to bond tiles and asphalt shingles. Impact resistant doors, windows, or use of corrugated steel shutters now are required in Wind-borne Debris Regions (WBDR).

Hurricanes Charley (2004) and Wilma (2005) showed that problems remained at the basic level with regard to attachment of roof coverings and use of materials such as roof gravel, three-tab asphalt shingles, and vinyl siding, which became wind-borne debris. This paper will discuss certain improvements in building construction in south Florida since Hurricane Andrew and indicate areas where further improvement is needed.

*Corresponding author address: Timothy Marshall, Haag Engineering Co., 4949 W. Royal Lane, Irving, TX 75063. Email: timpmarshall@cs.com.

## 2. HURRICANE ANDREW DAMAGE SURVEY

The lead author conducted aerial and ground surveys after Hurricane Andrew in Florida and Louisiana. The purpose of the surveys was to document wind speeds and water levels in the storm path, and to evaluate the performance of various building types. Many anemometers became inoperative during the hurricane. Thus, sustained (one-minute) winds and 3-second wind gusts (at 10m in open terrain) were estimated by the degree of damage to buildings in order to develop wind speed maps (Figs. 1a and 1b). The highest winds in south Florida were found to occur just east of Leisure City and Homestead at 60 gusting to 70 ms$^{-1}$ (135 gusting to 155 MPH). Heavily populated areas along I-95 from Princeton to Florida City had winds of 55 gusting to 65 ms$^{-1}$ (125 gusting to 145 MPH). Wind speeds in southern Louisiana were much lower, in the 35 gusting to 45 ms$^{-1}$ (80 gusting to 100 MPH) range from Jeanerette to Morgan City. Storm surge levels also were measured using a level and rod from known benchmarks and topographic maps (not shown).

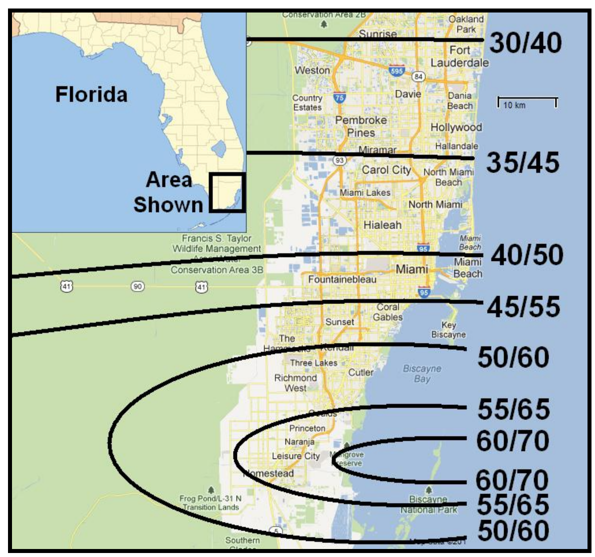


Figure 1a. Sustained (one-minute) winds and 3-second wind gusts estimated from the degree of building damage in south Florida after Hurricane Andrew. Wind speeds are in meters/second.

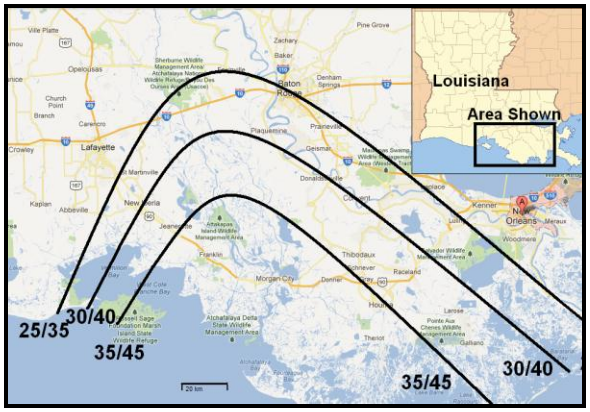


Figure 1b. Sustained (one-minute) winds and 3-second wind gusts estimated from the degree of building damage in southern Louisiana after Hurricane Andrew. Wind speeds are in meters/second.

### 3. GENERAL BUILDING PERFORMANCE

All building types sustained wind-caused damage. These included metal buildings, wood-framed and masonry residences, manufactured homes, commercial and warehouse facilities, high-rise office buildings, and condominiums. Of all building types, manufactured homes and wood-framed residences sustained the most severe damage. According to Dade County officials (see Mafi, 1993), Hurricane Andrew destroyed approximately 97 percent of manufactured homes in the county but only 11 percent of single-family homes. Major damage occurred to 43 percent of single-family homes in Dade County.

#### 3a. Manufactured Housing

Safety standards for manufactured home construction developed by the Department of Housing and Urban Development (HUD) sometimes are called "HUD standards." At the time of Hurricane Andrew, HUD required that manufactured homes placed in hurricane regions (Wind Zone II) be designed and installed for a lateral wind load of 1.2 kPa (25 psf) and an uplift load of 0.72 kPa (15 psf). This would be equivalent to a wind speed of about 45 $ms^{-1}$ (100 mph). Of course, winds in Dade County exceeded this wind speed during Hurricane Andrew, and the destruction of manufactured homes was widespread. Close spacing of manufactured homes in parks contributed to shredding of neighboring homes due to flying debris (Fig. 2).

In Florida and Louisiana, we found that most manufactured homes had been anchored to the ground with stakes or augers. However, anchors either pulled out of the ground or the galvanized metal straps attached to the anchors broke. Anchorage failure led to vaulting or rolling of the homes. Where floor platforms remained intact, failures occurred where the walls were stapled or strapped to the wall bottom plates. Roof trusses also failed where stapled to the wall top plates.

Figure 2. Typical shredding of manufactured homes at a mobile home park in south Florida as a result of Hurricane Andrew.

#### 3b. Wood-framed residences

There were certain subdivisions in Dade County, Florida where residences sustained substantial structural damage. Close inspection revealed a number of inherent construction deficiencies which rendered the residences more susceptible to wind damage than normally would be expected. In many instances, we found inadequate strapping of walls to top plates and top plates to roof trusses. These deficiencies resulted in the loss of most of or the entire roof (Fig. 3). Absence of horizontal bracing between manufactured trusses caused trusses to rotate or fall over like a "row of dominoes" when roof decking was removed (Fig. 4). We found entire sheets of roof decking with asphalt shingles still attached (Fig. 5). Close examination revealed that fasteners had missed the trusses, leaving deck sheets unattached. Ladder-rake details at gable ends were prone to rocking back and forth in the wind, leading to loss of the roof deck (Fig. 6). Wolfe et al. (1993) and Cook (1993) also recognized these and other shortcomings in residential building construction after surveying the damage caused by Hurricane Andrew.

Figure 3. Loss of roof trusses due to inadequate strapping. Straps were nailed to the sides of the trusses instead of being wrapped completely around them.


Figure 4. Rotation of wood trusses due to a lack of lateral bridging or blocking.

Figure 5. An entire sheet of oriented strand board (OSB) decking with shingles still attached. The roof deck had not been attached properly to the trusses.

Figure 6. Ladder-rake detail at a gable end which rocked back and forth during the hurricane resulting in the loss of roof decking.

Internal pressure contributed to the loss of roofs and walls when windows and doors were breached (Fig. 7). Resultant wall openings caused additional positive pressures against the leeward and side walls. Garage doors failed either by buckling and/or detaching from the tracks. In some instances, door tracks pulled away door frames as they were not anchored properly.

Figure 7. Damage to a wood-framed house from Hurricane Andrew. Note the breached windows and doors which allowed internal pressure to push side and back walls outward.

3b. Concrete masonry residences.

In general, residences constructed with concrete masonry units (CMU) performed better than wood-framed structures. However, problems occurred where bond beams at the tops of walls were not tied properly to the walls. Non-reinforced walls toppled due to combined effects of lateral wind pressure and internal pressure. Khan and Suaris (1993) found similar failures in residences constructed with concrete masonry. In particular, they found several homes with horizontal cracks in mortar joints below the bond beams where there had been inadequate attachments of the beams to the walls. These bond beams had tried to resist uplift forces that had been applied to the roofs.

Homes constructed with CMU still had the same problems with roof coverings as did wood-framed residences. Problems included roof decking not being attached to the trusses. Gable ends were prone to being blown inward or outward because they were not secured properly to the roof framing (Fig. 8).

Figure 8. Gable end fell outward because it was not attached to the roof trusses.

Asphalt shingles, especially the three-tab variety, were prone to being torn away by the wind. The tabs acted as "flaps" which flopped back and forth in the wind until the tabs broke loose. In some instances, shingles had been secured with staples driven so hard that the crowns cut into or penetrated the shingles. This caused the shingles to be removed in large mats or chunks. Felt underlayment tore away to expose the roof deck. Subsequent rains caused extensive water damage to interior finishes and furnishings (Figs. 9 and 10).

Numerous homes lost concrete and/or clay tile roof coverings. In many instances, the tiles were not attached to the roof substrate, although attempts had been made to secure the tiles with mortar placed on the underlayment. These mortar "patties" rarely bonded to the tiles (Fig. 11). When the mortar did bond to the tiles, tile loss resulted in holes being torn in the underlayment allowing rainwater penetration. Tiles nailed to wooden battens also performed poorly. In many instances, the tiles lifted over the fastener heads leaving the nailed battens intact. In these instances, fastener heads were smaller than manufactured nail holes in the tiles.

Figure 9. Loss of the asphalt shingle roof covering led to rainwater penetration and caused extensive interior damage.

Figure 10. Close-up view of roof decking showing lost asphalt shingles and underlayment. The shingles had been installed with staples.

Figure 11. Removal of concrete tiles where an attempt had been made to secure the tiles with mortar.

### 3d. Metal buildings

Large metal buildings and aircraft hangars were particularly susceptible to collapse due to their large surface areas. According to Dean (1993), one reason for metal building collapses was that the 1988 FBC did not take into account the higher wind loads experienced at wall and roof corners. Overhead doors also played a role in increasing building damage by allowing wind to enter the buildings as the doors failed. Dean indicated that many metal building manufacturers did not sell overhead doors. Thus, doors were supplied by the builders, leaving questions about the types of doors and their installation.

At Tamiami Airport, steel framed hangars collapsed when columns failed at welded plate connections or pulled out of the foundations (Figs. 12 and 13). However, smaller metal buildings fared much better, especially if their large doors faced directions opposite the oncoming wind.

Figure 12. Failure of a steel-framed building at the column bases.

Figure 13. Failure of a welded base plate connection at the base of a column in a metal building.

## 4. BUILDING CODES

The South Florida Building Code (SFBC) first was adopted by the Board of County Commissioners in Dade County on October 29, 1957. Revised editions were published annually or biannually. In 1988, the SFBC was scheduled to be updated every three years. wait was the 1988 edition of the SFBC that was in effect at the time of Hurricane Andrew. The Basic Design Wind Speed in the SFBC was deemed to be 54 $ms^{-1}$ (120 MPH) at 9.1 m (30 feet) above the ground (SBFC, 1988). However, the SFBC did not designate the time interval (i.e. whether that was a one-minute sustained wind, fastest mile, or three to five second gust). The 1991 Uniform Building Code (UBC, 1991) specifies a basic design wind speed of 50 $ms^{-1}$ (110 MPH) at 10 m (33 feet) as a "fastest mile" speed for south Florida. The fastest mile is defined as the fastest mile of wind that passes a stationary point, a calculated quantity.

Building codes are MINIMUM requirements for construction interpreted and enforced by local building officials. Unfortunately, many builders use the building code as the goal, not a minimum requirement.

After Hurricane Andrew, Broward and Dade Counties passed more stringent building codes which became effective on September 1, 1994. The new building codes provided stricter requirements for the attachments of roof systems, opening protection, and fastening of roof sheathing. Higher wind resistance requirements were added for wall and roof corners. Use of storm shutters was optional prior to Hurricane Andrew, but the new code requires shutters in certain high wind areas that must meet certain impact resistance requirements set forth in Testing Application Standard (TAS) 201-94.

In October 2007, Florida adopted by statute (Rule 9B-3.0475) requirements to strengthen existing site-built, single-family residences to better resist hurricanes. Known as the Hurricane Mitigation Retrofits (HMR), these requirements later were adopted into the *Existing Building* volume of the 2007 FBC. Interestingly, some of these requirements were based on the value of the house. Key components of the HMR include:

- Use of a secondary water barrier. Originally, the HMR required the use of a peel and stick membrane, but this was revised to allow for other alternatives in April 2008 along with several other aspects of the HMR.
- Re-nailing of roof sheathing to the roof frame.
- Roof truss strapping to walls must be verified and added as needed for single family homes permitted prior to March 1, 2002 within the WBDR and with an insured or assessed value of \$300,000 or more. If the value of the home exceeds this amount, an additional 15% of the reroofing cost must be expended on roof to wall connections, including the cost of inspection.
- The addition of windborne debris protection (storm shutters or impact resistant glazing) on homes in the WBDR worth more than \$750,000 when a building permit of \$50,000 or more is applied for after July 1, 2008.

The FBC prescribes Wind-Borne Debris Regions (WBDR) where impact resistant glazing or storm shutters must be used for new construction or buildings that undergo major remodeling or retrofit; however, there is no requirement to upgrade other existing structures.

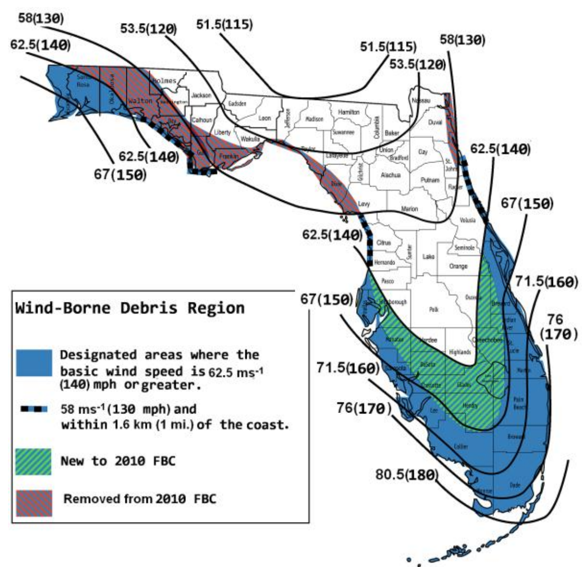


Figure 14. Changes to the Wind-Borne Debris Region in the FBC from 2007 to 2010 for residential (Type II) buildings. Wind speeds shown are 3-sec gusts in $ms^{-1}$ (mph) at 10m in Exposure C.

There have been changes in the WBDR regions between the 2007 and 2010 editions of the FBC (Fig. 14). For example in the 2007 FBC, the WBDR included Jacksonville Beach; however, the WBDR does not include Jacksonville Beach in the 2010 FBC. In addition, Category D exposure has been reintroduced which requires higher wind forces to be used for design in areas adjacent to water surfaces. Furthermore, wind speed values have increased slightly between the 2007 and 2010 FBC, shifting from Allowable Stress Design (ASD) wind speed to ultimate (i.e., strength design-level) wind speeds. Buildings now constructed in the middle and lower Florida Keys must meet or exceed 80.5 $ms^{-1}$ (180 mph) basic wind speed design requirements

Unfortunately, deficiencies remain in the FBC that need to be addressed. Roof gravel still is allowed outside the WBDR. Buildings that currently have roof gravel are allowed to remain regardless of location. Three-tab shingles and felt underlayment are allowed even in the WBDR. Vinyl siding, which hangs loosely on exterior walls, is still allowed.

## 5. SUMMARY

Hurricane Andrew served as a "wake-up call" to south Florida and demonstrated how poorly buildings can perform in high winds, if not constructed adequately. Since then, the FBC has been upgraded several times and enforcement has become stricter. The result has been better building construction. The FBC remains an exemplar code which other states prone to hurricanes should utilize when upgrading their building codes.

But increasing code requirements does not guarantee better constructed buildings. Subsequent weaker hurricanes like Charley (2004) and Wilma (2005) have shown problems remain at the basic levels with regard to attachment of roof coverings and prevention of breaching buildings by wind and rain. While there remains a variety of building materials having different resistances to wind effects, there remains no substitute for good workmanship.

## 6. ACKNOWLEDGEMENTS

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