The hurricanes of 2004

An overview of FEMA’s findings and recommendations for roof system performance

by Thomas L. Smith, AIA, RRC
Between Aug. 13, 2004, and Sept. 25, 2004, Hurricanes Charley, Frances, Ivan and Jeanne made landfall in Florida. (Ivan also hit the eastern coastal areas of Alabama.) In response, the Federal Emergency Management Agency (FEMA) deployed Mitigation Assessment Teams (MATs) following Charley and Ivan to determine how well buildings performed following the hurricanes. The MATs were composed of national experts in hazards (wind and flood), coastal processes and building codes. They are deployed after disaster events for which damage summaries and subsequent conclusions and recommendations are likely to have national implications.

In addition, a Rapid Response Data Collection Team performed field observations after Hurricane Frances. This team focused on critical and essential facilities, such as hospitals and schools.

The observations, conclusions and recommendations of the Charley and Ivan MATs are presented in FEMA publications 488 and 489, respectively, and can be obtained at no cost from FEMA. The two reports include more than 45 pages and 55 photos pertaining to roof system and rooftop equipment performance. Following is an overview of the reports.

**Storm characteristics**

Hurricane Charley was the first design-level hurricane to strike the U.S. mainland since Hurricane Andrew in 1992. Of the four hurricanes, Charley delivered the highest wind speeds. In portions of the area where it made landfall, the wind speeds were near current design-level speed. Charley made landfall in the Port Charlotte and Punta Gorda areas, continued inland near Orlando and exited into the Atlantic Ocean near Daytona Beach. It caused building damage all along its track. Fortunately, the hurricane was compact—the eye had an estimated radius of maximum winds of 6 miles (9.6 km). Therefore, the damage swath was quite narrow, and flooding was minimal.

Frances made landfall near Sewall’s Point, and the storm exited into the Gulf of Mexico north of Tampa. Its wind speeds were well below current design speeds. However, Frances had an unusually slow forward speed. As a result, there was considerable rain and it took a long time for the storm to move out of Florida. Although the wind speeds were not high, a large number of buildings along Florida’s east coast from West Palm Beach to the Kennedy Space Center experienced envelope damage. Fatigue associated with the slow-moving storm likely influenced the magnitude of damage.

Although wind-driven rain was able to enter many buildings through broken glazing, damaged soffits and other areas, leakage from damaged roofs caused a majority of interior water damage.

**Generalizations**

Historically, poor building envelope performance is the leading cause of damage to buildings and their contents in weak-to moderate-intensity hurricanes. The hurricanes of 2004 were no exception.

In contrast to the building envelope damage, few structural problems were observed with buildings designed and constructed according to recent building codes, even in areas affected by Hurricane Charley. Damage to roof coverings and rooftop equipment was the leading cause of building performance problems.

**Critical facilities**

Critical and essential facilities are needed to lead and manage response and/or recovery operations during and after an
event. In general, these facilities did not perform significantly better than commercial-use buildings. As a result, the operations at many critical and essential facilities were hampered or shut down after the hurricanes. A variety of roof systems were used on the facilities observed, including built-up, modified bitumen, single-ply, metal, asphalt shingles and tiles. Problems were observed with each of these types of coverings.

The 2004 hurricanes demonstrated the importance of elevator penthouses. If water leaks into a penthouse because of roof or wall problems or through relief air or air intake vents, the elevator equipment is vulnerable to damage. At one hospital, metal wall panels were blown away and water destroyed the elevator control equipment. Four nursing floors were evacuated, and patients were moved to other hospitals. Loss of elevator service caused by penthouse envelope problems also was observed at a few other facilities.

The Florida Building Code (FBC) and International Building Code (IBC) require critical and essential facilities to be designed with loads 15 percent higher than those used for ordinary buildings. This load increase is the only special wind-related requirement for such buildings. However, from 2004 observations, as well as observations from previous hurricanes, it is clear greater attention is needed for these important buildings. FEMA 424, “Design Guide for Improving School Safety in Earthquakes, Floods and High Winds,” is a resource that can be used. Although intended for schools, most of the guidance can apply to other types of critical and essential facilities. The document has specific recommendations pertaining to roof systems and rooftop equipment in hurricane-prone regions.

Rooftop equipment

Poor performance of rooftop equipment often led to damaged roof coverings and/or resulted in large openings through roofs that allowed water infiltration.

For example, a school suffered failed goosenecks. At this roof, there was some minor lifting of a metal edge flashing and the roof membrane was punctured in one area, but otherwise the roof system performed well. Although the wind speeds at this location were not severe, several goosenecks blew away. The goosenecks were connected to the curbs with only two small screws. Although the curb opening was small, a significant amount of water was able to enter because of the long duration of rainfall. Because of widespread building damage in the area, emergency repairs had not been made at the time of the observation, which was five days after the storm made landfall.

Photo 2 shows a large heating, ventilating and air-conditioning unit that crushed two unoccupied vehicles. It was 30 feet (9 m) long, 10 feet (3 m) wide and 8 feet (2.4 m) high. It blew off a medical office building that was less than a year old. Although it reportedly weighed 18,000 pounds (8165 kg) and was attached to its curb with 16 fasteners, the unit was blown from the roof. As it tumbled across the roof, it tore the membrane in several locations. There was extensive interior water damage. The winds in this area were estimated to be 85 mph to 95 mph (38 m/sec to 42 m/sec) peak gust.

At a hospital, the mechanically attached single-ply membrane on the fourth-floor roof of the nursing tower was severely damaged. Although the deck was reinforced concrete, water was able to leak into the building. The entire fourth floor had to be evacuated.

Photo 1 shows a hospital that suffered glazing damage. Three of the eight intensive-care rooms were taken out of service during the hurricane because of broken windows. Although some glazing damage may have been caused by the gutters blown from an upper roof, a majority of the damage was caused by aggregate blown from the hospital’s built-up roofs. Glazing damage caused by aggregate blow-off was observed at several hospitals.
Exhaust fan cowlings were a common problem. Blown-off fan cowlings can tear roof membranes, break glazing and cause injury. FEMA 424 provides guidance for job-site installation of cowling anchor cables.

Detached lightning protection system conductors were observed on many roofs. And detached conductors often punctured roof membranes. Not only are loose conductors capable of damaging roof coverings, but when the conductors become detached, they no longer provide the intended lightning protection.

(For more information, refer to the Proceedings of the 12th International Roofing and Waterproofing Conference on CD-ROM. It is available on shop.nrca.net or by calling (866) ASK-NRCA [275-6722].)

Other types of rooftop equipment damage included rooftop ductwork and equipment screens around mechanical equipment that were blown away, collapsed antenna (which sometimes caused roof covering damage) and satellite dishes that were blown from roofs.

A common satellite dish attachment method was to anchor the dish to a pole mounted to a large metal pan that was loose-laid over the roof membrane. The pan then was weighed down with concrete masonry units. This attachment method was found to be inadequate in high-wind areas.

Membrane systems

There were two common problems observed with built-up, modified bitumen and single-ply systems—membrane lifting and peeling because of failure of metal edge flashings. In many instances, the metal edge flashing failure was caused by gutter blow-off.

Unfortunately, there is virtually no guidance for gutter wind-resistance design. This issue is not addressed by ANSI/SPRI ES-1, "Wind Design Guide for Edge Systems Used with Low Slope Roofing Systems," FM Global’s Loss Prevention Data Sheet 1-49, FBC or IBC.

Development of a gutter wind design guide is critically needed.

In the Port Charlotte/Punta Gorda area, the edge flashing failure often was exacerbated by how the flashing integrated with the membrane. Rather than installing the metal flashing over the membrane and then stripping in as recommended by NRCA, the metal was installed underneath the membrane. When the metal is underneath rather than on top of the membrane, the metal is not capable of clamping down the membrane’s edge. When unclamped, the membrane is more susceptible to lifting and peeling.

The other common problem was membrane puncture from windborne debris. During hurricanes, a large quantity of debris blows through the air. As wind speed increases, the quantity, size and speed of debris increases. Even small tree limbs can puncture tough membranes such as modified bitumen. This is a difficult problem to avoid unless a roof is armored with heavy concrete pavers. Another option is to incorporate a secondary membrane below the insulation as discussed in FEMA 424. With this approach, the outer membrane remains vulnerable to puncture, but the secondary membrane may prevent water from leaking into a building.

Aggregate blow-off also was a common problem on aggregate-surfaced roofs. Although the roofs from which the aggregate was blown were not damaged by the aggregate loss, the aggregate often broke glazing.

Asphalt shingles

Although damage was observed on several new roofs, in general, it appeared shingles installed during the past few years performed better than those installed before the mid-1990s. The enhanced performance was attributed to product improvements (greater bond strength of the self-seal adhesive and greater adhesive surface area) and less degradation of physical properties because of limited weathering time.

Photo 3 shows shingles that were damaged by the aggregate loss, the aggregate often broke glazing.
installed about two months before the hurricane struck. They were installed with six nails per shingle, but the nails were about 1 ½ inches (38 mm) above the nail line. Nail placement was a commonly observed problem. The starter course also was installed incorrectly—this, too, was a common problem. The self-seal strip on this roof was continuous but quite narrow—the shingles overshadowed by the importance of bonding.

Another common problem was with hip and ridge shingles, which typically had nails installed too high. However, more important, the self-seal strips provided virtually no bonding. Usually, only one or two small areas are bonded together. Bonding is inhibited along the hip and ridge because of planar irregularities and difficulties in getting trim shingles to conform to field shingles.

Several re-covered roofs were observed where the newer layer of shingles blew off, yet the underlying shingles remained. Some of these problems may have been a result of nails that were too short, but a majority likely were a result of bonding problems. When re-covering, there is greater opportunity for substrate irregularity and bonding interference of new shingles.

In the Pensacola area, several roofs similar to Photo 4 were observed. The vertical lines of missing shingle tabs indicate installation via the racking method. When racked, end nails frequently are not installed. NRCA does not recommend the racking method.

Continuous ridge vent performance varied. Some vents performed well in high-wind areas, and other vents blew off when exposed to moderate winds. In one case, a portion of the ridge vent blew off, leaving a slotted opening through the roof. Although leakage because of shingle damage did not occur, a substantial amount of water entered the residence at the damaged vent. The damaged vent had been unprotected for 15 days at the time of observation. Currently, there is inadequate testing and design guidance regarding wind-resistant attachment of continuous ridge vents.

To assist in the rebuilding, FEMA issued three Hurricane Recovery Advisories pertaining to asphalt shingles and tiles (for more information, see “Enhancing wind resistances,” May issue, page 20). Those advisories have since been updated and incorporated into FEMA’s Home Builders Guide to Coastal Construction Fact Sheets (FEMA 499).

Metal panels

A variety of structural and architectural panels were observed. The most notable roof covering success was the 5-V crimp panels. Exposed fasteners are used with these panels. Although some 5-V crimp panel failures were observed (typically when fastened with nails rather than screws or when the substrate failed), these panels were found to be reliable performers even in areas struck by Charley’s high winds. An advantage of exposed fastener systems is that it is easy to determine fastener spacing after panel application (and, if deficient, additional fasteners can be readily installed).

Tile

In areas of lower wind speeds, tile blow-off typically was limited to hip, ridge and eave tiles. In areas with higher wind speeds, damage included field tiles as
shown in Photo 5. The size of the blow-off area of mortar-set systems typically was much greater than for tiles attached using foam-set or mechanically attached systems. On those roofs that lost large areas of tiles, the underlayment typically was not blown off. Therefore, many buildings with significant tile damage likely experienced little, if any, water infiltration from their roofs.

The roof shown in Photo 5 was on a recently constructed one-story residence. The tiles were screwed directly to the deck. Based on the March 1, 2003, addendum to the third edition of the Concrete and Clay Tile Installation Manual (published by the Florida Roofing, Sheet Metal and Air Conditioning Contractors Association and RoofTile Institute), this roof’s attachment was suitable for buildings with a mean roof height of 40 feet (12 m) in areas with a basic wind speed of 150 mph (67 m/sec). The estimated speed at this location was 125 mph to 140 mph (56 m/sec to 63 m/sec); therefore, the tiles did not perform as predicted. At a few other buildings, the manual’s predicted performance also was not achieved.

The 2004 storms provided the opportunity to evaluate the performance of foam-set tiles when exposed to high wind speeds. The foam-set method was developed after Hurricane Andrew in response to the widespread poor performance of the mortar-set systems. Nevertheless, several damaged foam-set systems were observed. All the damaged roofs that were examined closely were found to have significant workmanship deficiencies in foam application—either related to size and/or location of the foam paddies.

Hip and ridge tile blow-off was common even in areas with lower wind speeds. A majority of the observed hip and/or ridge tiles had been attached with mortar, but damage also was observed with foam-set hips and hips and ridges that were attached with nails to wooden ridge boards. FEMA 499 provides recommendations pertaining to enhanced attachment of hip and ridge tiles, as well as other recommendations.

**Recommendations**

Improved performance generally was observed on newer buildings. This was attributed to improved codes and standards, product and test method improvements, a more educated designer and contractor work force, and reduced detrimental effects of weathering.

The two MAT reports provide numerous recommendations pertaining to roof systems and include those related to design and construction, building codes, public outreach (including professional and trade associations, institutes and societies), and recommendations specific to critical and essential facilities.

In my opinion, significant advances have been made in the wind performance of roof systems since Hurricanes Hugo in 1989 and Andrew in 1992. However, there still is much to learn, and improved and new design guides and test methods are needed. Moderate and strong hurricanes offer enormous challenges to roof systems and rooftop equipment. Unless roof system design, product manufacturing and testing, construction and maintenance are approached with thoroughness, the probability of a roof system winning the battle with a hurricane is low. Conversely, with care, damage can be avoided or at least reduced to a level that is not devastating to building occupants.

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![Photo 5: This new mechanically attached tile roof lost several tiles.](image-url)

For contact information for FEMA and ways to access its reports and fact sheets, as well as additional photos, log on to www.professionalroofing.net. FEMA 489 and 499 may not be posted online until later this fall.