3

Building Performance

Building performance observations were made based on estimated wind speeds and flood water levels to determine whether buildings performed as designed and to identify appropriate mitigation measures. Building age, function, and construction are considered when observing building hurricane damage to generate an overall summary of building damages and performance.

3.1 Wind Hazard Observations

The majority of wind-related damages observed during the 2004 hurricane season were observed and documented for Hurricanes Charley and Ivan. Wind-related damage associated with Frances and Jeanne, though significant and widespread, was difficult to document because of overlapping damage paths. Wind-related damage to critical and essential facilities is documented for Hurricane Frances. In general the type of wind damage observed was similar across the paths of all four hurricanes.

Key Observations

Building structural capacities appeared to have improved since Hurricane Andrew (1992) because of stronger building codes and better enforcement, resulting in less structural damage overall even from intense hurricanes such as Hurricane Charley. Buildings designed to codes and standards that were revised after Hurricane Andrew in 1992 performed better than the older building stock. It is important to note that only Hurricane Charley produced winds that were at or above the current design requirements of the FBC and the International Building Code/International Residential Code (IBC/IRC) used in Alabama. Except for Hurricane Charley's landfall area, the wind damage was caused by wind speeds that in many cases were 20–40 mph lower than the current design level wind speeds specified in the applicable codes.

Winds primarily damaged building envelope components and accessory structures. Building envelope failure (specifically roof coverings, roof mounted equipment, soffits, wall coverings, and unprotected glazing) led to widespread damage to building interiors throughout the paths of the hurricanes. During Hurricane Frances, which had wind speeds well below design levels, the long duration of the winds caused fatigue and subsequent damage to some building envelope systems.

SUCCESS STORY: SANIBEL SCHOOL ON SANIBEL ISLAND

The Sanibel School was designed and constructed to the 2001 FBC and as such, sustained only minor damage from Hurricane Charley (loss of gutters and some wind-driven rain issues). Dedicated on August 10th, just a week prior to the landfall of the storm, Sanibel School likely experienced wind speeds around the level of Category 2 winds. Although these winds were below the 130 mph (3-second gust) design wind speed for the site, the building performed very well and opened on time with no loss of function.

In general, many critical and essential facilities did not perform as well as intended. Although most damage was to facilities built before current code standards, the structural and envelope systems of some newer critical and essential facilities also failed.

The majority of building damage was caused by: (1) insufficient wind resistance of building envelope systems which allowed wind-driven water infiltration into buildings, resulting in contents damage and loss of function; and (2) impact of windborne debris (primarily related to Hurricane Charley). The performance of buildings observed by the MAT varied depending on their location in the wind field, the age of construction, and implemented hazard mitigation efforts (if any).

Wind induced damage and failures to building structures and components occurred where there was a break or discontinuity in the load path. Although significant design improvements ensure a continuous load path in the structural systems of buildings, the observed damage indicates that the requirements and guidance relative to load path for non-structural components and cladding elements still needs improvement.

Structural Performance

The MAT observed limited structural damage to residential structures, including site-built structures and post-1994 U.S. Department Housing and Urban Development (HUD) code-manufactured homes, as well as commercial structures throughout the wind field of all four hurricanes. Worth noting is the limited damage observed throughout the path of Charley, especially in the areas where code level winds occurred. A larger portion of structural failures occurred to the older buildings and to pre-1994 HUD code-manufactured housing. No structural failures were observed to structures designed and constructed to the wind design requirements of the 1997 Southern Building Code (SBC), the 2001 FBC, the 2000 IBC/IRC (in Alabama) or ASCE 7 (national design standard). There were isolated instances where newer structures sustained structural damage; partial failures occurred where design or construction was not code compliant. The following are overall observations of the structural performance grouped by structure type.

- **Wood frame.** New wood frame houses built in accordance with FBC 2001 and the 2000 IRC performed well structurally, including those located in areas that experienced winds of up to 150 mph (3-second gust) in Charley. For each structure, load path was accounted for throughout the structure, including the connection of the roof deck to supporting trusses and rafters. Loss of roof decking on newer homes was rare.

- **Manufactured housing.** Manufactured housing performance was a function of unit age and of the regulations under which they were constructed and installed. In high wind areas, pre-HUD standard homes were mostly destroyed beyond repair. Pre-1994 HUD standard homes performed variably, but the vast majority of these homes located in the path of Charley were damaged significantly even though the wind was less than the current design wind speeds. While post-1994 HUD standard homes performed well structurally, these units sustained damages related to building envelope and accessory structure failures. Improved performance of post-1994 manufactured housing was observed, however the MAT also found widespread damage caused by the failures of improperly designed and constructed attached accessory structures, such as carports and screen rooms. When these attached structures failed, they often tore away siding, roof covering, roof decking, and the exterior walls of the units to which they were connected.

Manufactured housing that had structural damage resulting from accessory structure failure.

- **Concrete/Masonry.** Reinforced concrete and reinforced masonry structures performed well. Failures occurred when roof structural systems were inadequately connected to the top of the concrete walls or frames and in URM structures. URM buildings, especially older ones, fared poorly (including designated critical and essential facilities).
- **Steel-framed.** No structural failures were observed for steel-framed buildings.
- **Pre-engineered metal.** Pre-engineered buildings, usually designed to satisfy the minimum standards, often performed poorly. Poor performance was observed mostly in older buildings where corrosion of structural elements and exterior panels had occurred. Very few pre-engineered metal buildings designed to resist high winds were observed during the assessment. Of the small sample observed, all survived with minimal cladding damage and without structural failure with the exception of the public shelter in Arcadia.

Accessory Structures

Significant damage to accessory structures occurred throughout the paths of the hurricanes. Most of the accessory structures observed were associated with residential dwellings and many were attached to the primary residence. Generally, these structures were aluminum screen enclosures (typically observed as pool enclosures) and aluminum porches or carport structures. Not only did the accessory structures themselves fail, but in many cases the failure of the accessory structure led to damage to the primary residence at the point of attachment. In several instances, pieces of the failed accessory structures became windborne debris, damaging the primary residence with which it was associated as well as neighboring residences.

Building Envelope

As building structural capacities have improved because of stricter building codes and better enforcement, the performance of the building envelope is becoming increasingly important. The building envelope includes exterior doors, non-load bearing walls, wall coverings, soffits, roof coverings, windows, shutters, skylights and exterior-mounted mechanical and electrical equipment.

Based on building performance observed during the 2004 hurricane season, the five building envelope components that, in many cases, continue to perform poorly are: roof systems (of greatest concern is mortar-set tile roof systems), exterior mechanical and electrical equipment, soffits, windows, and doors (unprotected glazing), and wall cladding (especially exterior insulation finishing systems – EIFS). The failure of, or damage to, one or more of these systems allowed rainfall to enter buildings, which resulted in significant damage to building interiors and contents. Building envelope failure and rain water intrusion were also key reasons for widespread loss of building function, most notably in critical and essential facilities.

Building envelope failure allows an increase in the internal air pressure of a building and allows wind-driven rain to enter the building. Increased internal pressure can also lead to structural damage. Infiltration of water weakens gypsum board ceilings, causing them to collapse, and destroys building contents. Mold bloom can quickly occur in hot humid climates if a building is not dried out immediately.

Roof Coverings

The performance of roof coverings during the 2004 hurricane season continued to raise concerns. While improved performance was observed, damage to roof coverings continues to be the leading cause of building performance problems during hurricanes.

Variation in roof system performance was primarily related to installation and attachment methods, with the failure of mortar-set tile roof systems observed most frequently. Failure of roofing components (i.e., edge flashings, copings and gutters/downspouts) frequently contributed to roof covering failures.

Tiles. Tile roof damage (both clay and concrete) occurred during Charley, Ivan, and Frances, but was most prevalent along the path of Hurricane Charley due in part to the large percentage of homes and buildings with tile roof coverings in Charlotte, Lee, and De Soto Counties. Tile damage from Hurricanes Frances and Ivan was also observed, both of which had much lower recorded wind speeds than Charley. Damage ranged from blow-off of hip and ridge tiles (which was very common even in areas with only moderate wind speeds) to large areas of blown off tiles (which was less common). The tile underlayments generally remained intact so even buildings with significant blow-off areas typically experienced little or no water infiltration from the roof (except in cases where the roof deck failed). Tiles located on ridges, hips, and edges of the roof were frequently a point of failure, especially when they lacked mechanical anchors.

In addition to the damage shown in this photo, this one-story roof lost virtually all of the hip and ridge tiles during Hurricane Charley. (Punta Gorda Isles)

Tiles or tile fragments were frequently the source of windborne debris and damaged nearby houses. In several cases, a neighbor's house sustained significant contents damage (by wind-driven rain entering through windows broken by flying roof tiles) even though their roof system did not fail. Additionally, tile roof systems themselves are prone to damage by windborne debris.

In general, the size of the blow-off area of tile roofs attached using mortar-set systems was much greater than for tile roofs attached using foam-set and mechanically attached systems. Failure on mortar-set roofs occurred from debonding from the mortar patties, debonding from the underlayment, and underlayment failure.

Hurricane Charley was the first hurricane to deliver near-design wind speeds to test the new foam-set attachment method for tiles (developed after Hurricane Andrew in 1992). Although large areas of blow-off were unusual for foam set roof systems, there were a large number of partially damaged foam-set roof systems with damages typically resulting from improperly sized and/or located foam paddies.

Asphalt Shingles. Although damage was observed on several new roofs, asphalt shingles installed within the past few years generally appeared to perform better than shingles installed prior to the mid-1990s. This was likely due to product improvements (adhesives) and less degradation of physical properties due to decreased weathering. On roofs with damaged shingles, almost all the shingle fasteners were located too high on the shingle. Additionally, where new roofs were installed on top of old roofs (without removing the underlying layer), large numbers of the overlay shingles were blown away, most probably due to the reduced fastener penetration into the roof deck.

Aggregate from the Indian River Memorial Hospital's roof (Vero Beach) broke several of the patient room windows (which were covered with plywood after Hurricane Frances).

Metal Panel Roofs. Although not as common as asphalt and tile roofs, numerous building types with metal panel roofs were observed. Systems where the panels acted as the deck and the roof coverings appeared to fail the most. 5-V Crimp panel systems typically performed very well.

Low-Slope Membrane Systems. Some failures of low slope roof systems (built-up roofs, modified bitumen, and single ply) were observed. However, the largest observed problem was lifting of gutters, edge flashings, and copings, which resulted in progressive failure of the membrane. Another common failure mode was membrane puncture caused by windborne debris. In several instances, roofing aggregate became windborne missiles and broke adjacent windows, thereby allowing wind-driven rain infiltration into buildings.

SUCCESS STORY: THE HOLMES REGIONAL MEDICAL CENTER (ROCKLEDGE)

Staff removed loose aggregate from the built-up roofs just prior to Frances' landfall, likely minimizing window breakage and thereby preserving the availability of patient rooms. Additionally, the aggregate surface of a portion of the upper roof had been previously re-roofed in a manner that encapsulated the aggregate, preventing aggregate blow-off.

Exterior Mechanical and Electrical Equipment Damage

The hurricanes resulted in many instances of damage to mechanical and electrical devices mounted on the exterior of buildings. Failure of this equipment resulted in rain water intrusion to building interiors and facility loss of function. Of most concern were the many failures and resulting loss of function associated with critical and essential facilities along the paths of the hurricanes.

Damaged equipment on commercial and critical/essential facilities included heating, ventillating, and air conditioning (HVAC) units, exhaust fans, relief air hoods, rooftop duct work, communications equipment and lightning protection systems (LPS). Equipment attached to these buildings was often essential to the operation of the facility. Equipment failed as a result of non-existent or inadequate anchoring. Displaced equipment frequently left large openings through the roof or punctured the roof membrane allowing rain water to infiltrate the building.

A large HVAC package unit was blown off this curb during Hurricane Charley. Note the loose LPS conductors this side of the curb. This school had significant damage from several pieces of rooftop equipment that blew off the building roof. (Port Charlotte Middle School)

Soffits

Widespread soffit damage was observed throughout the areas impacted by hurricanes, resulting in unnecessary rain water intrusion into building interiors. Soffits are architectural non-structural covering and cladding that enclose overhangs at the edges of roofs. Soffits failed by both downward and upward pressure. Where soffits were lost, rain water was driven over exterior walls sections, into wall cavities and attic spaces, and ultimately into the main portion of the building.

Soffit damage on the third story of a multi-family building. (Captiva Island)

Soffit failure led to many instances of significant damage to building interiors.

Doors

Normal width swinging doors performed well with only small numbers of failures observed. Failures of large doors, such as rolling or sectional garage doors, and apparatus bay doors at fire stations, were more common. Failure of an exterior door has two important effects. First, failure can cause an increase in internal pressure, which may lead to exterior wall, roof, interior partition, ceiling or structural damage. Second, wind can drive rain water through the opening, damaging interior contents and leading to mold development. Interior building damage resulting from door failures is generally preventable if doors and tracks that connect roll up doors to walls are strengthened and reinforced.

Failure of three of six new doors on a fire station in Charlotte County resulted in the loss of the entire roof structure over the apparatus bay during Hurricane Charley.

New wind- and debris-impact resistant doors typically performed much better than the older doors. Improved performance follows the application of minimum criteria for debris resistance as specified in the FBC.

Windows and Shutters

Preventable damage to building contents occurred in buildings located in "windborne debris areas", (as identified in the 2001 FBC and ASCE 7), where glazing was not impact resistant or protected by shutters. Glazing failure resulted in damage to building interiors and, in some cases, resulted in structural failure in older buildings.

Significant window damage was observed in manufactured housing parks after Hurricane Charley. This is likely due first, to the lack of manufactured housing regulations that require window protection in windborne debris regions (even though this is required of all other one- and two-family site-built dwellings) and second, because of the presence of many non-engineered and poorly construct-

SUCCESS STORY:
CHARLOTTE COUNTY SOUTH ANNEX BUILDING

In anticipation of Hurricane Charley, the Annex building was retrofitted with new galvanized metal shutters at a cost of $10,000. With the shutters in place, the Annex sustained only minimal damage as Charley blew in winds of 125 mph. The $10,000 investment is minor when compared with a taxpayer savings of over half a million dollars, which would have been the cost to replace the broken windows of the building, had the shutters not been installed. Employees and the community also avoided losses in time-off from work and interruption of services, which would have accompanied lengthy hurricane damage repairs. Just two days after Charley, with minor repairs still in progress, the South Annex was open for business.

ed accessory structures that failed and became sources of windborne debris (even in areas outside of defined windborne debris regions).

Significant window damage was also observed on many commercial buildings and critical/essential facilities throughout the area impacted by the hurricanes, especially in buildings with many windows (such as hotels, offices, and hospitals). The Charley and Ivan MATs and the Frances rapid response assessment teams all documented instances at hospitals where broken windows resulted in loss of function.

Most shutters and laminated glazing systems observed on buildings performed well. Damage and failures occurred when non-rated shutter systems were used; when they were not properly installed; or when they did not have the strength to withstand high winds or the impact of large windborne debris.

Wall Coverings

Wall covering damage was observed throughout the hurricane-impacted area. In residential and light commercial applications, the most common damage was to the vinyl siding systems; some instances of brick veneer failures were also observed after Hurricane Ivan. Failure of vinyl siding was most commonly observed in manufactured home parks; upon failure, the underlayment (either asphalt-saturated felt or housewrap) was also often blown away and wind-driven rain entered the wall cavity and initiated mold growth. Significant failures were observed on buildings with EIFS and stucco. Much of the failed vinyl siding became windborne debris damaging nearby structures.

Example of wall cladding failure. The building had synthetic stucco installed over molded, expanded polystyrene insulation and gypsum board. The gypsum board blew off during Hurricane Ivan.

3.2 Flood Hazard Observations

Key Observations

The majority of flood-related damages observed during the 2004 hurricane season were associated with Hurricane Ivan. The storm's arrival was concurrent with high tide, a condition that maximized storm surge flooding which was estimated at 10 to 16 feet above normal high tide levels. Extreme storm surge conditions occurred along 90 miles of the Alabama-Florida Gulf shoreline, extending 5 miles west and 85 miles east of the hurricane's track. Flood levels in many bays and sounds exceeded the mapped BFEs on published FIRMs by several feet. Damage to buildings in mapped Coastal A Zone areas from flood-borne debris and wave action was extensive and in some cases was characteristic of damages that would be expected in mapped V Zones. Additionally, many buildings in mapped C Zones sustained significant flood-related structural damage as a result of erosion and scour, which is anticipated in V Zones. The current maps that show C Zones are not based on existing conditions along the coast.

Foundations and Structures

Flood-related structural damage was observed along the Gulf coast from Gulf Shores, Alabama, to Pensacola Beach, Florida, along the intracoastal waterway, and along the shorelines of Escambia Bay. Structural damage occurred to residential structures (single and multi-family) and commercial structures from a combination of significant storm surge elevations, wave action, and debris impacts. The most extreme cases were building failures due to erosion of supporting soil under buildings with shallow foundations.

A multi-family condominium collapsed after Hurricane Ivan due to erosion of supporting soil under the shallow foundation.

Shallow Foundations

Several multi-family buildings constructed on shallow foundations in areas along the Gulf coast were severely damaged due to erosion and scour. Many of these buildings were originally constructed in Zones B, C, or X, which did not require deep foundations, but now would require deep foundations if the flood zone was determined from the current methodologies and coastal conditions.

Several structures were completely torn off their pile foundations during Hurricane Ivan as a result of significant flood depths, waterborne debris impacts, and lack of connections.

Pile Foundations

In coastal areas, structures built on pile foundation systems along the inland bays and the open coast of the Gulf performed well except for shallow-embedded pile systems on barrier islands that sustained significant erosion. Relatively few pile failures were observed of newer, post Hurricane Opal (1995) homes. Two condominium buildings along the Gulf Coast were reconstructed with deep-pile foundation systems after Hurricane Georges (1998); both buildings experienced beach erosion during Ivan similar to that of Hurricane Georges, but the building damage from Ivan was not catastrophic. Losses to the condominiums were generally limited to lower level damage from the erosion of sand and from storm surge elevations that exceeded lowest floor elevations. Pile foundation performance along inland bays and sounds varied depending on how well they were constructed (i.e., fasteners/straps).

Slab-on-Grade Foundations

Residential slab-on-grade foundations in Coastal A Zones experienced substantial damage or complete destruction when flood elevation levels exceeded the elevation of the top of the slab. Many slab-on-grade houses that sustained significant flood damage were older homes constructed prior to FIRM publication located outside the designated floodplain.

Flood water from Hurricane Ivan exceeded the required elevation of the top of the lowest floor supported by the stem wall foundation for this house leading to severe damage caused by waves and debris impact.

Stem Wall Foundations

In general, stem wall foundations performed well against storm surge and wave and debris impacts. However, some buildings were significantly damaged due to the elevation of the finished floor being lower than the flood levels.

Pier Foundations

Pier foundations typically performed poorly. These foundation systems were typically unreinforced and associated with pre-FIRM structures. Some reinforced piers failed due to lack of structural capacity to withstand wave and debris loads on the buildings.

High flood levels during Hurricane Ivan and lack of structural capacity to withstand waves and debris loads caused this reinforced pier foundation to fail.

Accessory Structures and Construction Features Beneath Elevated Structures

Extensive damage to enclosures, utilities, and accessory structures located beneath elevated buildings occurred due to storm surge, wave, and debris impacts. Not only were these systems totally destroyed, but the resulting debris damaged other materials and systems attached above the flood levels (i.e., siding). Damage to docks and piers was extensive, which also led to a significant source of flood debris that threatened to damage landward structures.

3.3 Implications of Poor Building Performance

At the Martin Memorial Hospital (Stuart, Florida) wall panels blew off the elevator penthouse during Hurricane Frances. Rain water entered the elevator equipment room damaging much of the equipment. The falling panels punctured the main roof and at least one of the lower roofs. Because of rain water infiltration and lack of elevator service, floors 2 through 6, which contained 75% of the hospital's beds, were inoperative. Many patients were relocated to other hospitals until the penthouse walls were re-sheathed and new elevator equipment was installed.

When a building performs poorly as a result of natural disasters, the impacts transcend the cost of repair to include the human cost associated with damaged homes and businesses and their oftentimes sentimental contents. Community safety can be jeopardized if critical/essential facilities, such as fire stations or emergency shelters, cannot function due to disaster damages. The following summarizes the impacts of poor building performance on a community level.

Residential Buildings

The primary impacts of residential building performance failures are economic damages, displacement, and human suffering. Economic costs include repairing or replacing damaged homes and their contents. Loss of personal possessions and relocation during reconstruction are common outcomes of residential damage.

Commercial/Industrial Buildings

Damage to commercial and industrial buildings typically results not only in the need for reconstruction and repair but also in loss of function. The loss of function can impact an entire community if the building houses a large company, multiple offices, or a vital business (i.e., bank or supermarket). Additionally, if businesses are unable to operate, large segments of a community may be without work and income for significant periods of time.

An emergency roof (shown) was installed after Hurricane Charley blew the mechanically attached PVC membrane roof covering off the concrete deck of the Fawcett Memorial Hospital.

Critical and Essential Facilities

Critical and essential facilities are needed to lead and manage response and recovery operations after an event. These facilities include EOCs, police and fire stations, hospitals, schools, and shelters. In general, buildings that function as critical and essential facilities did not perform to the level expected. Critical and essential facilities throughout the area impacted by the four hurricanes sustained significant loss of function. The most common loss of function was caused by failure of building envelope components, allowing wind-driven rain to damage the interior. The poor performance of the buildings hampered the ability of the responders to provide assistance to communities. In many cases, service functions were returned within a few weeks of the hurricane through repair of equipment, and through dispatching and operations support provided from other facilities. Long term impacts are being experienced and cannot be remedied until severely damaged facilities are repaired or replaced. Many of the hospitals impacted by the hurricanes sustained some loss of function due to building envelope damage.

The Charlotte County Sheriff's Office/County EOC, located in a pre-engineered metal building, was significantly damaged and completely taken offline. Despite having openings protected with shutters, the building failed by loss of roof panels (failure of roof clips) and loss of metal wall panels. These failures allowed damaging amounts of rain and debris to enter the facility resulting in closure of the building. The county was aware of the weakness of this facility, and prior to Charley, had begun the design process for a new county EOC facility that would meet statewide Enhanced Hurricane Protections Areas (EHPA) requirements and guidelines not used in the design of the existing structure.

- Numerous fire and police stations were heavily damaged by Hurricane Charley. Many of them could not respond immediately after the hurricane.
- Primary causes of damage to hospitals were rain water intrusion due to roof covering (typically initiated by metal edge flashing failure) and roof top equipment failure and window damage from roof aggregate. This damage to building envelopes led to extensive internal damage in key hospital areas such as emergency rooms, intensive-care units, and general use areas.
- All the observed shelters prevented loss of life, which is their primary role. However, many of the shelters sustained damage and loss of function.
- A new shelter experienced a partial building collapse during Hurricane Charley when design and construction requirements for EHPA were apparently not properly followed and implemented.
- Many schools sustained significant interior water damage.

This school building experienced several building envelope problems, which allowed water intrusion, but it did not disrupt operations. Damage and disruptions may have been worse if design wind speed conditions had been experienced.