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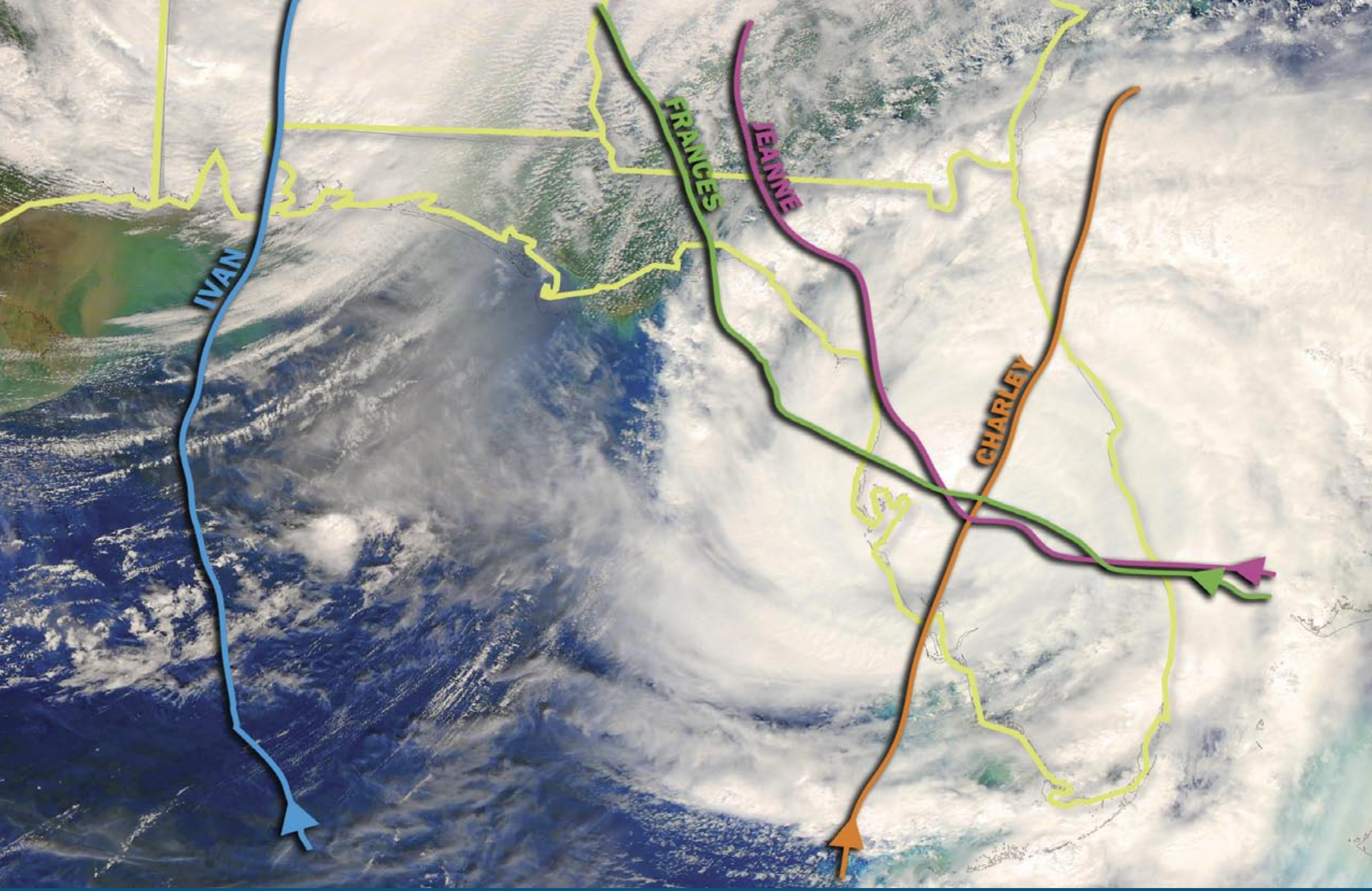

Summary Report on Building Performance

2004 Hurricane Season

FEMA 490 / March 2005

FEMA

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U.S. Department of Homeland Security

FEMA

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Executive Summary

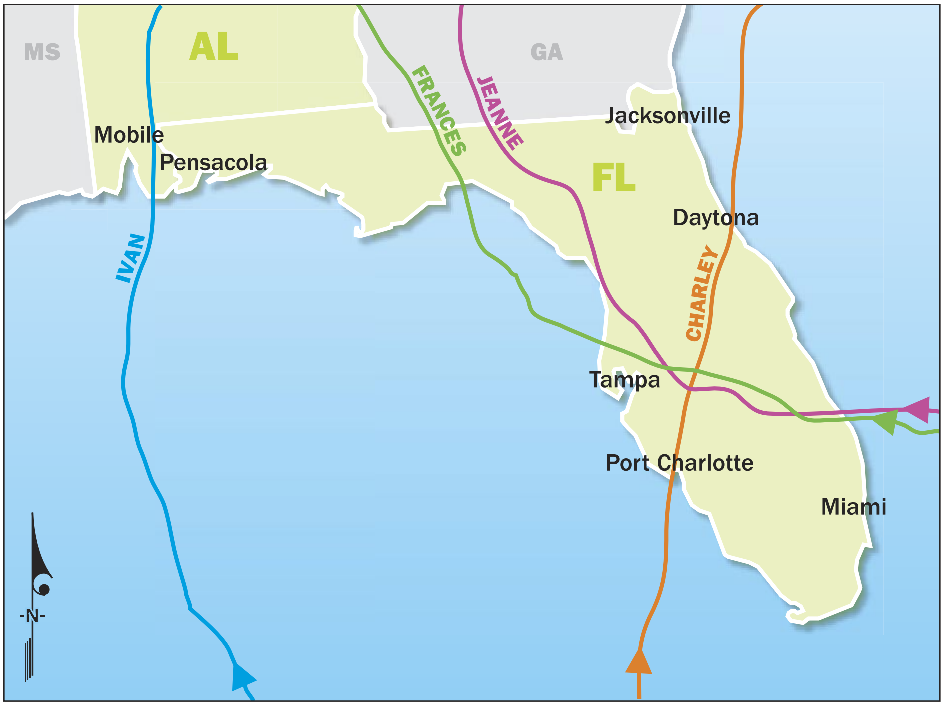
The nation will remember 2004 as a record-setting year in terms of presidential disaster declarations and administered disaster aid. In 2004, President Bush issued 68 disaster declarations of which 27 were due to hurricanes. Time and again the U.S. was impacted by hurricane force winds and waves that damaged cities and small towns in 15 states, Puerto Rico, and the U.S. Virgin Islands.

Of all the regions that endured the hurricane season, the State of Florida bore the brunt of the record-setting storms as Hurricanes Charley, Frances, Ivan, and Jeanne tested the federal and state fortitude in disaster response and recovery. Communities were devastated as wind and water damage from the four storms battered residential, commercial, industrial, and public facilities. Disaster assistance totaling more than $4.4 billion was approved for Floridians, and to date, 1.24 million storm victims have applied for federal and state assistance (FEMA 2005b). The financial impact of the season will likely exceed $20 billion, according to preliminary loss estimates from the Insurance Services Office's Property Claim Services (PCS).

The four hurricanes that struck Florida in 2004 were all significant events; however, the hurricanes were each distinctive in terms of their wind and water action and resulting damages. The first of these, Charley (designated a Category 4), was the first design level wind event to strike the U.S. mainland since Hurricane Andrew (1992) and caused more wind damage than flood damage. Frances (Category 2) and Jeanne (Category 3), while not as strong as Charley, were still very damaging hurricanes resulting in additional wind damage. Hurricane Ivan delivered not only strong winds (Category 3), but also caused significant flood damage to buildings and other structures, even those built above the 100-year flood elevation.

The impact of the four hurricanes was intensified by their back-to-back occurrence; three of the hurricanes followed similar paths or had overlapping damage swaths (refer to Figure 1 Storm Track Map). Frances and Jeanne followed almost identical paths across Florida from the east coast (around Port St. Lucie) to the west coast (north of Tampa area). These two very wide storms crossed the path of Charley (which

Figure 1. Storm Track Map



traveled west to east) in central Florida creating an overlap of impacted areas in Orange, Osceola, Polk, and Hardee counties. As a result of these overlapping impact swaths, damage resulting from the later hurricanes (Frances and Jeanne) was difficult to distinguish from earlier damage caused by Charley. For instance, roofs that failed during Frances or Jeanne may have been weakened or damaged by Charley and more prone to failure. For this reason, most of the recommendations and conclusions contained in this report are based on observations made after Hurricanes Charley and Ivan and are supported by observations made after Hurricanes Frances and Jeanne.

Following Hurricanes Charley and Ivan, the FEMA Mitigation Assessment Teams (MATs) performed field observations to determine how well buildings in Florida and Alabama performed under stresses caused by the storms' wind and water impacts. A Rapid Response Data Collection Team performed field observations after Hurricane Frances that focused on critical and essential facilities; however an assessment was not performed after Jeanne, because Jeanne and Frances impacted a similar region. Overall, the MAT observed building performance success in structural systems designed and built after Hurricane Andrew. This Summary Report focuses on the ongoing need for improvement in building performance.

Primary Observations

Wind

- Most of the wind damage was preventable. The winds primarily damaged building envelope systems which, upon failure, allowed wind-driven rain to enter building interiors causing not only loss of function, but millions of dollars of damage to building contents due to the rain and subsequent mold growth. Based on observations of wind damage after Hurricanes Charley, Ivan, and Frances, the most consistent failures were:
    - **Roof covering failures** allowed water to penetrate throughout building interiors and in some cases led to structural failures.
    - **Mechanical and electrical equipment** failure left holes in roofs (allowing wind-driven rain into building interiors) and significantly impacted the function of the buildings (i.e., communications equipment needed for 911 response was blown off roof).
    - **Soffits,** which are architectural elements at roof overhangs, frequently failed and allowed significant amounts of wind-driven rain to enter otherwise undamaged buildings.
    - **Window and door** failure exposed buildings to the damaging effects of wind-driven rain. Broken windows and doors allowed internal building pressures to increase rapidly which sometimes led to structural roof and wall failures.
- Where design level winds were experienced, current building code provisions appeared to adequately address the design of the structural building systems, as there was overall little wind damage to these systems except to older buildings which were not constructed to current code.
- Many critical and essential facilities, including shelters, did not perform as well as intended. Significant loss of function occurred due to largely preventable failures in building envelope performance from high winds during Charley, Frances, and Ivan. For example, in Charlotte County, over a half-dozen fire stations, three hospitals, numerous police stations, and the County Emergency Operations Center (EOC) were badly damaged. Some of these facilities were unable to provide essential functions in the days, weeks, and

sometimes months following Hurricane Charley. Hurricanes Frances and Ivan, both of which had wind speeds below the design-event, caused significant damage to building envelopes of critical and essential facilities. Many of these failures were a result of the age of the facilities (not built to current standards) and lack of proper maintenance.

DESCRIPTION OF FLOOD ZONES

Zones X, B, and C. These zones identify areas outside of the Special Flood Hazard Area (SFHA). Zone B and shaded Zone X identify areas subject to inundation by the flood that has a 0.2-percent probability of being equaled or exceeded during any given year. This flood is often referred to as the 500-year flood. Zone C and unshaded Zone X identify areas above the level of the 500-year flood.

V Zone. The portion of the SFHA that extends from offshore to the inland limit of a primary frontal dune along an open coast, and any other area subject to high-velocity wave action from storms or seismic sources. The Flood Insurance Rate Maps (FIRMs) use Zones VE, V1-30 to designate these Coastal High Hazard Areas. The SFHA are subjected to inundation to the flood that has a 1% chance of being equaled or exceeded during any given year. This flood is referred to as the 100-year flood.

Coastal A Zone. The portion of the SFHA landward of a V Zone in which the principal source of flooding is storm surge, not riverine sources. Coastal A Zones may therefore be subject to wave effects, velocity flows, erosion, scour, or combinations of these forces. The forces in Coastal A Zones are not as severe as those in V Zones but are still capable of damaging or destroying buildings or inadequate foundations. A Zone areas are subject to breaking waves with heights less than 3 feet and wave run-up with depths less than 3 feet. It is important to note that FIRMs use Zones AE, A1-30, AO, and A to designate both coastal and non-coastal SFHAs. The SFHA are subjected to inundation to the flood that has a 1% chance of being equaled or exceeded during any given year. This flood is referred to as the 100-year flood.

For NFIP flood zone definitions, refer to 44 CFR 64.3.

- Lack of a continuous load path in the structural systems of older buildings led to structural failures. Un-reinforced masonry (URM) load bearing wall buildings performed poorly, as did older wood frame buildings, because neither building type had adequate connections between structural members to transfer wind loads from the roof system to the foundation.

Flood

- Flooding associated with Hurricane Ivan significantly damaged structures including those built above the regulatory 100-year flood elevation, especially in back bay areas.
- Damage caused by significant wave action, which is typically anticipated and experienced in V Zones, also occurred in Coastal A Zones.
- Multi-family residential structures located in areas outside the 100-year floodplain (as designated on the FIRMs in Zones B, C, and X and which are not required to have deep foundations) were severely impacted by erosion, causing the shallow foundations to fail, resulting in total collapse of the buildings.
- Flooding and wave action significantly damaged utilities, enclosures, stairs, and accessory structures located under the first floor of elevated buildings.
- Walkway sections and piles from docks and marine structures, along with other damaged materials, added to the debris

in high flood levels causing severe damage throughout the inland bays.

- Buildings with first floor elevations lower than required by current minimum standards were observed to sustain more damage from wave action, debris impact, and flood waters than buildings built beyond the standards.

Primary Recommendations

Wind

1. The performance of building envelope systems in high wind events requires attention. Design guidance and code changes are needed as described in this report.
2. The performance of critical and essential facilities/shelters in high wind events must be improved. The MATs proposed stricter design requirements, as outlined in this document. Communities and states need to develop and implement mitigation retrofit programs and take advantage of FEMA's mitigation programs: the Pre-Disaster Mitigation and the Hazard Mitigation Grant Program.
3. Emphasize best practices for schools and shelters as described in FEMA 424, *Design Guide for Improving School Safety in Earthquakes, Floods, and High Winds*, FEMA 361, *Design and Construction Guidance for Community Shelters,* and in the latest codes and standards governing wind resistant designs.

Flood

The primary recommendations based on damages observed after Ivan are:

1. Re-evaluate the hazard identification/mapping approaches in Coastal A/V Zones.
2. Re-evaluate the storm surge modeling methodology.
3. Require V Zone foundations for new construction in Coastal A Zones subject to erosion and/or wave heights greater than 1.5 feet. Require deep pile or column foundations in coastal areas mapped as Zone B, C, or X, where erosion is possible.
4. Elevate the bottom of the lowest horizontal structural member above the Base Flood Elevation (BFE) in Coastal A Zones, as is currently required in V Zones.

5. Emphasize best practices as described in FEMA 55, *Coastal Construction Manual* and in the latest codes and standards governing flood resistant design.
6. Use Hurricane Ivan tide levels, inundation limits, and areas subject to wave effects as proxies for reconstruction guidance.
7. Use flood and corrosion resistant materials below the BFE as recommended by American Society of Civil Engineers (ASCE) 24-05 and the *Coastal Construction Manual* (FEMA 55).

1 Purpose and Background

The purpose of this document is to summarize the observations, conclusions, and recommendations that were obtained during post-disaster assessments sponsored by the FEMA Mitigation Division in response to Florida's 2004 hurricane season. More than ten rapid response teams and two Mitigation Assessment Teams (MATs) were deployed to document observations and provide recommendations.

The rapid response data collection teams focused on coastal high water marks, inland wind effects, residential and commercial building performance, critical and essential facility performance, and mitigation program effectiveness. The MATs assessed damage to the built environment and relied on the perishable data, such as high water marks, collected by the rapid response teams to quantify flood and wind effects of the hurricanes.

The MATs are composed of national experts in hazards (wind and flood), coastal processes, and buildings codes. The experts are engineers, architects, policy makers, code specialists, and building officials. MATs are sent out after disaster events for which the damage summaries and subsequent conclusions and recommendations are likely to have national implications. Assessment and documentation of the performance of buildings constructed to the Florida Building Code (FBC) has national significance because the State of Florida enacts some of the most stringent coastal construction codes and regulations for wind and flood. Therefore, if buildings built in accordance with Florida's codes and regulations perform well, then the FBC stands as a good model for other coastal communities. However, if new building envelopes are damaged by a wind or flood event that is below the design level event in the FBC, then this indicates a significant problem for many coastal communities because even the most restrictive code in use is inadequate.

Building codes and standards, and floodplain regulations are adopted and enforced to regulate construction in at-risk areas. In Florida, the Standard Building Code (SBC), and the South Florida Building Code—both with local amendments—were used to regulate construction in Florida until early 2002 at which time the Florida Building Code (FBC) 2001 Edition was adopted statewide. The FBC is administered by the Florida Building Commission and governs the design and construction of residential and non-residential (commercial, industrial, essential/critical facilities) structures. The FBC 2001 is based on SBC; however, Florida has completed updates to the 2001 Edition and will release a 2004 Edition of the code for adoption in July 2005. The 2004 edition is based on the International Building and Residential Codes (IBC and IRC).

In Alabama, which adopts building codes on a statewide basis only for state-owned buildings; jurisdictions have traditionally adopted editions of the SBC, however, the City of Orange Beach adopted the 2003 IBC in the summer of 2004 and the City of Gulf Shores adopted it as an emergency measure after Hurricane Ivan. Other affected communities, such as those in unincorporated Baldwin County, still enforce the SBC.

For flood hazards, FEMA establishes by regulation the minimum floodplain management requirements that communities must adopt and enforce in order to participate in the NFIP (44 CFR Section 64.3). These requirements are the basis for the other codes and standards that are used to regulate floodplain construction. FEMA studies the impacts of hurricanes and tropical storms on coastal buildings to determine if its minimum requirements are effective in reducing flood damages. If problems are identified through a MAT or other evaluation, they can be addressed through regulatory changes to the NFIP, proposing changes in building code requirements, or through technical guidance and training.

MATs were deployed after Hurricanes Charley and Ivan for the following reasons:

- **Hurricane Charley MAT (FEMA 488).** A MAT was deployed in Florida to observe the first major design level wind event to strike the U.S. mainland since Hurricane Andrew. The MAT assessments illustrate the progress made in building performance and highlight needed improvements.

- **Hurricane Ivan MAT (FEMA 489).** A MAT was deployed in Florida and Alabama in response to a code level flood event with near code level winds. This storm allowed for evaluation of both the building code and flood ordinances and regulations governing coastal construction. When significant flood events occur—such as those associated with Hurricane Ivan where flood levels exceeded the 100-year flood elevations—it is important to assess and evaluate the accuracy of the models used to analyze and prepare the flood maps as well as the accuracy of the existing maps (if conditions have changed since the maps were developed).
- **Hurricane Frances Hazard Mitigation Technical Assistance Program Report.** Following Hurricane Frances, a team of structural and building envelope experts was deployed to assess damage to critical and essential facilities to help determine the extent of damage, the mode of failure, and what types of eligible mitigation projects could minimize damage to these buildings in the future.
- **Hurricane Jeanne High Water Level Report.** To document the severity of riverine flooding after Hurricane Jeanne, a field study was conducted to collect and survey riverine and coastal high water marks in affected Florida counties.

This summary document consolidates and presents the findings of the MATs and the supporting tasks and provides guidance to state and local governments to improve the reconstruction process and advise policy-makers during their upcoming Legislative and State Building Code update cycles. This Summary Report describes building performance for hurricane winds (Charley, Frances, and Ivan) and hurricane-related flooding (Ivan) in Florida and Alabama only, even though other states were impacted by the hurricanes. The conclusions presented in this report are based on the MAT's observations, evaluations of relevant codes, standards, and regulations, and meetings with state and local officials, building associations, contractors, and other interested parties. These conclusions are intended to assist the States of Florida and Alabama, communities, businesses, and individuals in the reconstruction process and to help reduce future wind and water damages promoting the economic well being of the nation.

2

Description of Hazard Events

To determine how well buildings performed, it is first important to understand the characteristics of the hurricanes, specifically their wind and water components at landfall.

2.1 Charley

Hurricane Charley made landfall on the Gulf Coast of Florida on August 13 as a very compact storm (refer to Figure 1, Storm Track Map). The hurricane eye had an estimated radius of maximum winds of 6 miles with hurricane force winds extending outward up to 25 miles from the center, and tropical storm force winds extended outward up to 85 miles (Figure 2, Hurricane Charley Wind Swath Map). The maximum recorded wind speed obtained for the storm at landfall from National Weather Service (NWS) weather station (Station PGD) before it failed was 112 miles per hour (mph), 3-second gust wind speed.

According to reports from the NWS, the center of Charley crossed the barrier islands of Cayo Costa and Gasparilla as a Category 4 hurricane on the Saffir-Simpson scale with maximum sustained winds of 149 mph. After crossing the Florida barrier islands, Charley moved up Charlotte Harbor before making landfall at Mangrove Point, just southwest of Punta Gorda, Florida. Communities around Charlotte Harbor including Punta Gorda and Port Charlotte were impacted with sustained winds estimated at 125–130 mph (1-minute) and gust winds upward of 155 mph (3-second) in built-up areas. Hurricane force winds (with 3-second gust winds as high as 105 mph) in built-up areas of Orlando continued to cause damage across the peninsula of Florida until Hurricane Charley exited into the Atlantic Ocean near Daytona Beach, still categorized as a hurricane.

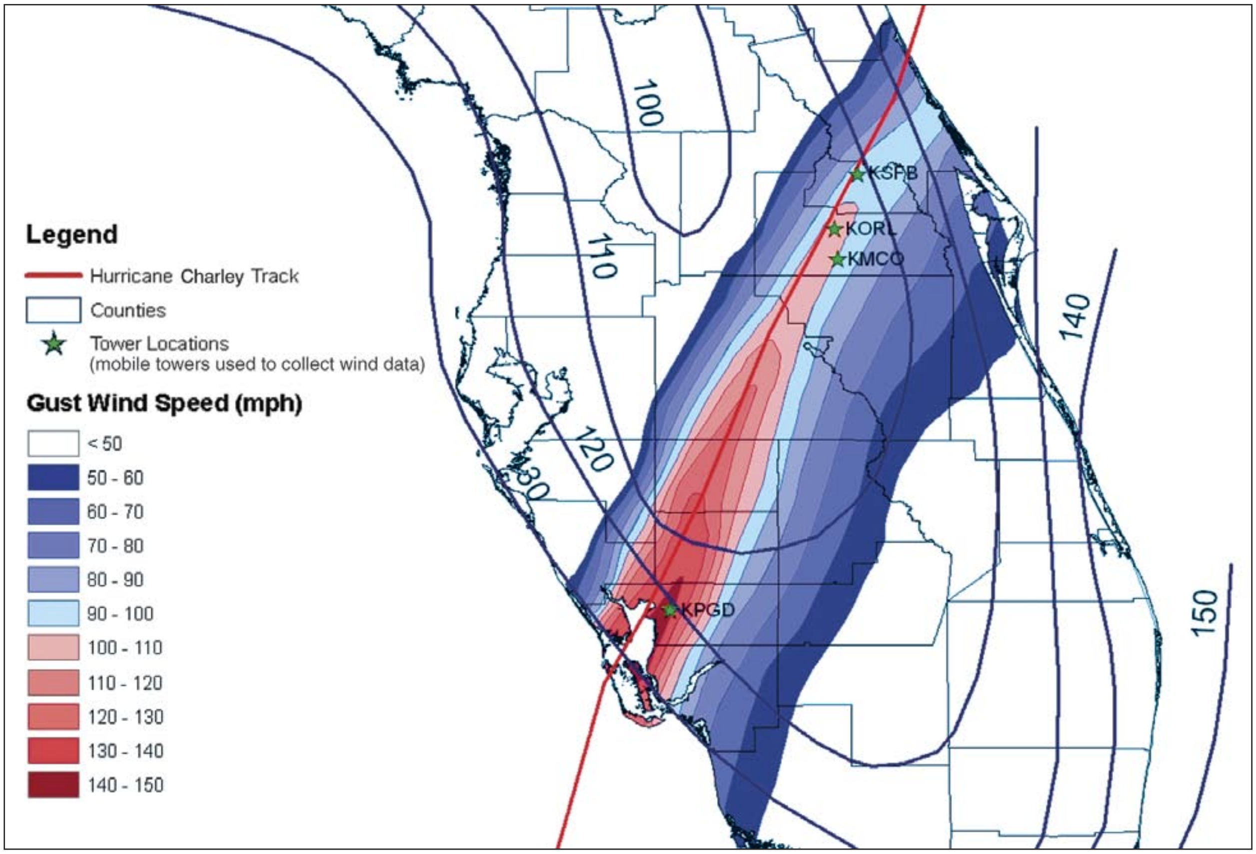


Figure 2. Hurricane Charley Wind Swath Map

The storm surge from the hurricane was significantly smaller than originally predicted due to the storm's compact size and the northeastward turn it made just prior to landfall. Although the storm was reported to have some Category 4 winds, the hurricane did not generate water levels typical of a Category 4 hurricane, which are often in the range of 10 to 14 feet. Instead, high water elevations along the open coast from Naples north to Ft. Myers Beach and Sanibel Island were 5 to 8 feet. Inland bays, including areas near Port Charlotte and Punta Gorda, measured up to 1.5 feet.

2.2 Frances

Hurricane Frances was the second of four deadly hurricanes that swept through the State of Florida during the 2004 season, just weeks after Hurricane Charley left its catastrophic mark. Frances struck a wide stretch of Florida's east coast early September 5 as a Category 2 hurricane on the Saffir-Simpson scale according to the National Hurricane Center (NHC) (refer to Figure 1, Storm Track Map).

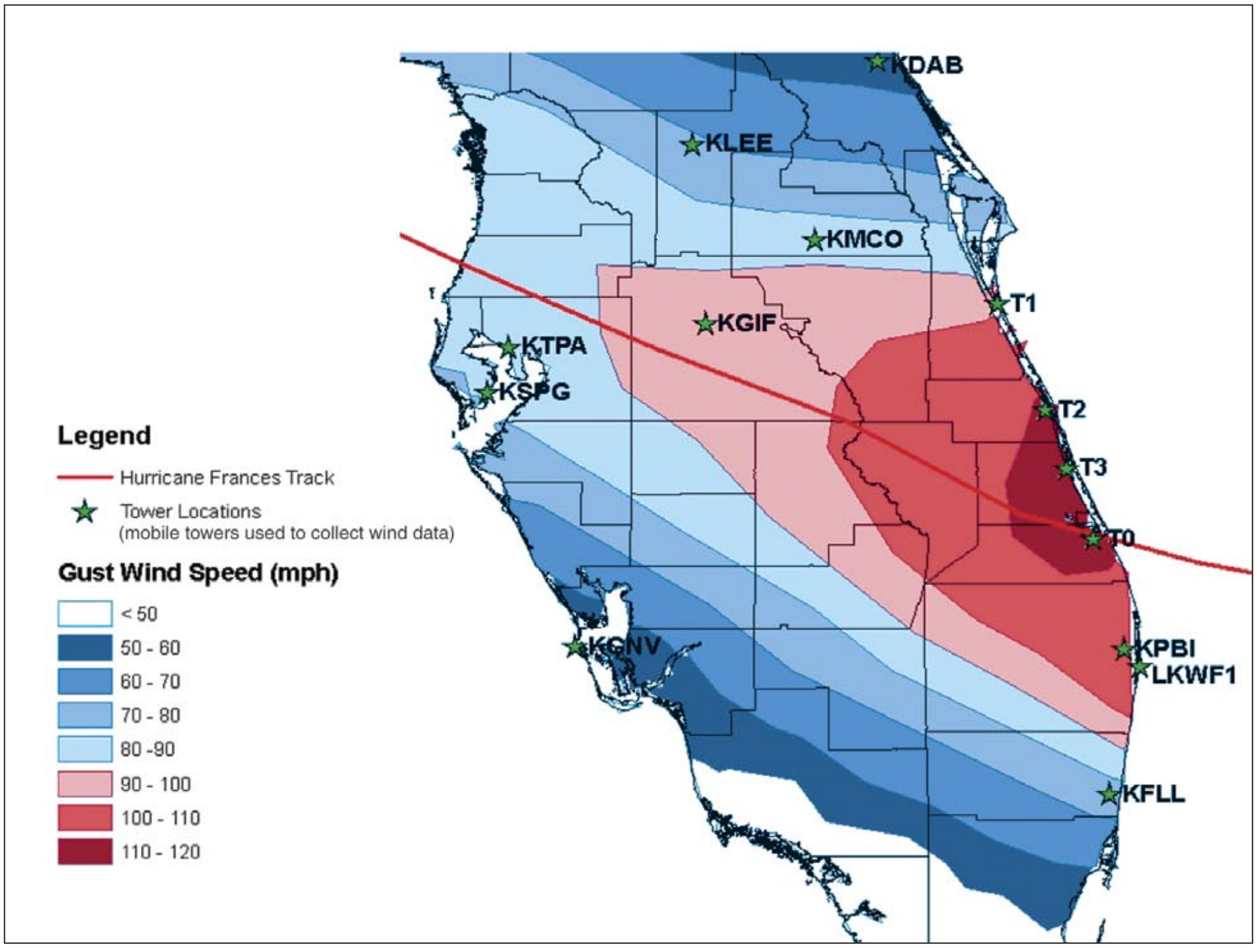


Figure 3. Hurricane Frances Wind Swath Map

Hurricane Frances hit Florida with reported maximum sustained winds of over 105 mph and storm surges over 5 feet. The highest 3-second gust winds measured by the Florida Coastal Monitoring Program during Hurricane Frances were 112 mph at an open-exposure site south of Fort Pierce. Hurricane-force winds extended outward up to 75 miles from the center, and tropical storm-force winds extended outward up to 205 miles (Figure 3, Hurricane Frances Wind Swath Map). Frances made landfall near Sewall's Point, Florida, on September 5 as a Category 2 storm, and moved west across the central Florida peninsula while weakening to a tropical storm. Hurricane Frances' unusually long duration, a result of its slow forward speed, significantly impacted the functions of critical facilities because of building "fatigue".

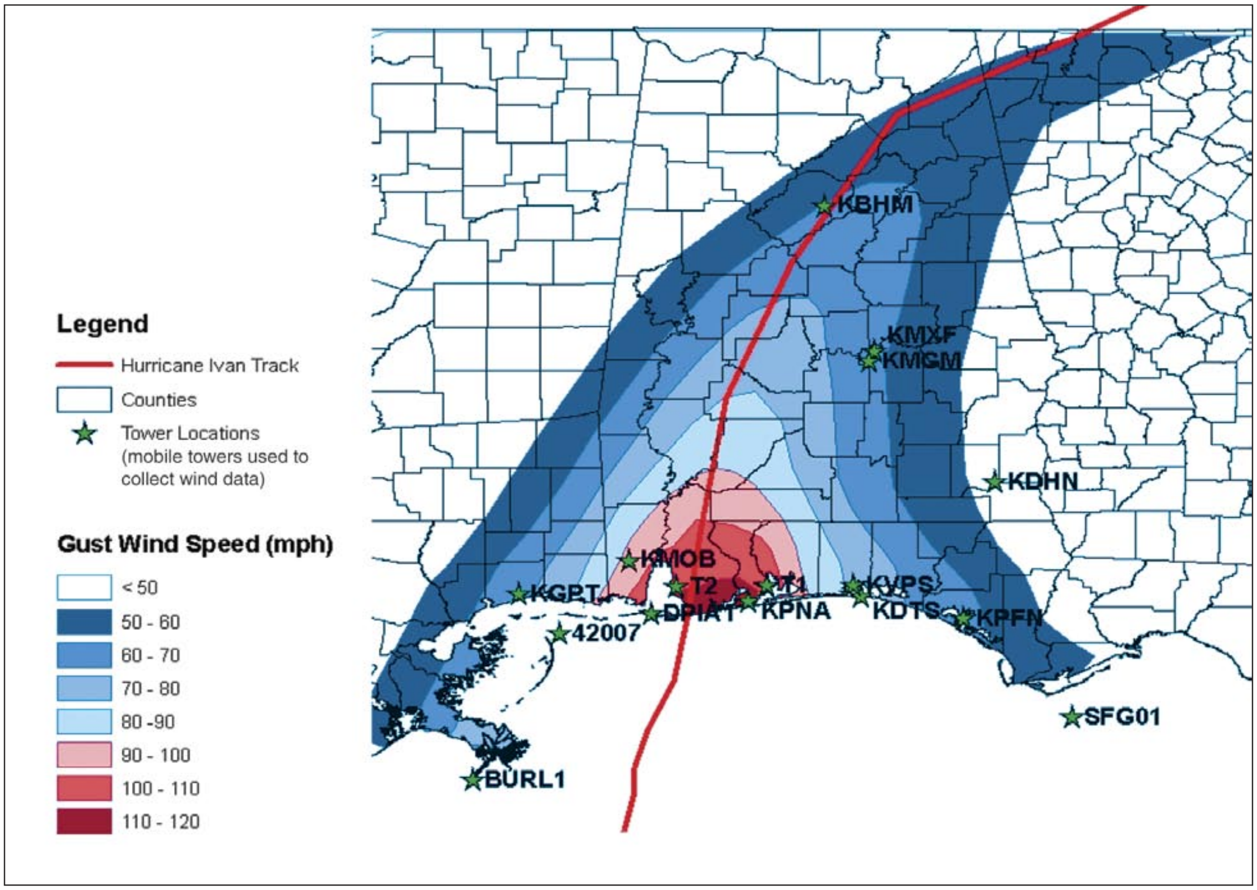


Figure 4. Hurricane Ivan Wind Swath Map

2.3 Ivan

Hurricane Ivan made landfall on September 16 as a Category 3 hurricane, according to the NHC, with estimated maximum sustained winds of over 100 mph and with wind gusts of up to 120 mph, torrential rains and coastal storm surge, and large battering waves of up to 16 feet in inland bays, and up to 19 feet along the open coast and inland bays (Figure 4, Hurricane Ivan Wind Swath Map). The hurricane's strongest winds were located east-northeast of the storm center. This aspect, coupled with the higher, on-shore directed winds, associated storm surge and accompanying breaking waves, resulted in much of Ivan's destructive impact on the Florida Panhandle coast and Gulf Shores, Alabama.

Many of the barrier islands exposed to Hurricane Ivan's strongest winds and storm surge are low lying and were washed over by storm surge. Coastal storm surge flooding crossed the barrier islands, undermined buildings and roads, and opened new island breaches. In addition to the storm surge, breaking waves eroded dunes and battered structures. The storm's arrival was concurrent with high tide, which exacerbated storm surge flooding.

2.4 Jeanne

Hurricane Jeanne made landfall as a Category 3 hurricane on September 25 at Hutchinson Island, just east of Stuart, Florida. The storm's landfall location was only about 2 miles north (3 km) from Sewall's Point, where Hurricane Frances struck Florida just 3 weeks earlier. According to the NHC, Jeanne's eye diameter at the time of landfall was approximately 60 miles, its maximum winds were 120 mph over a very small area north of the center of circulation, and movement was west-northwest at approximately 9 mph (Figure 5, Hurricane Jeanne Wind Swath Map). Storm surge of 3.8 feet above normal tide levels was measured near Port Canaveral, Florida, about an hour after Jeanne made

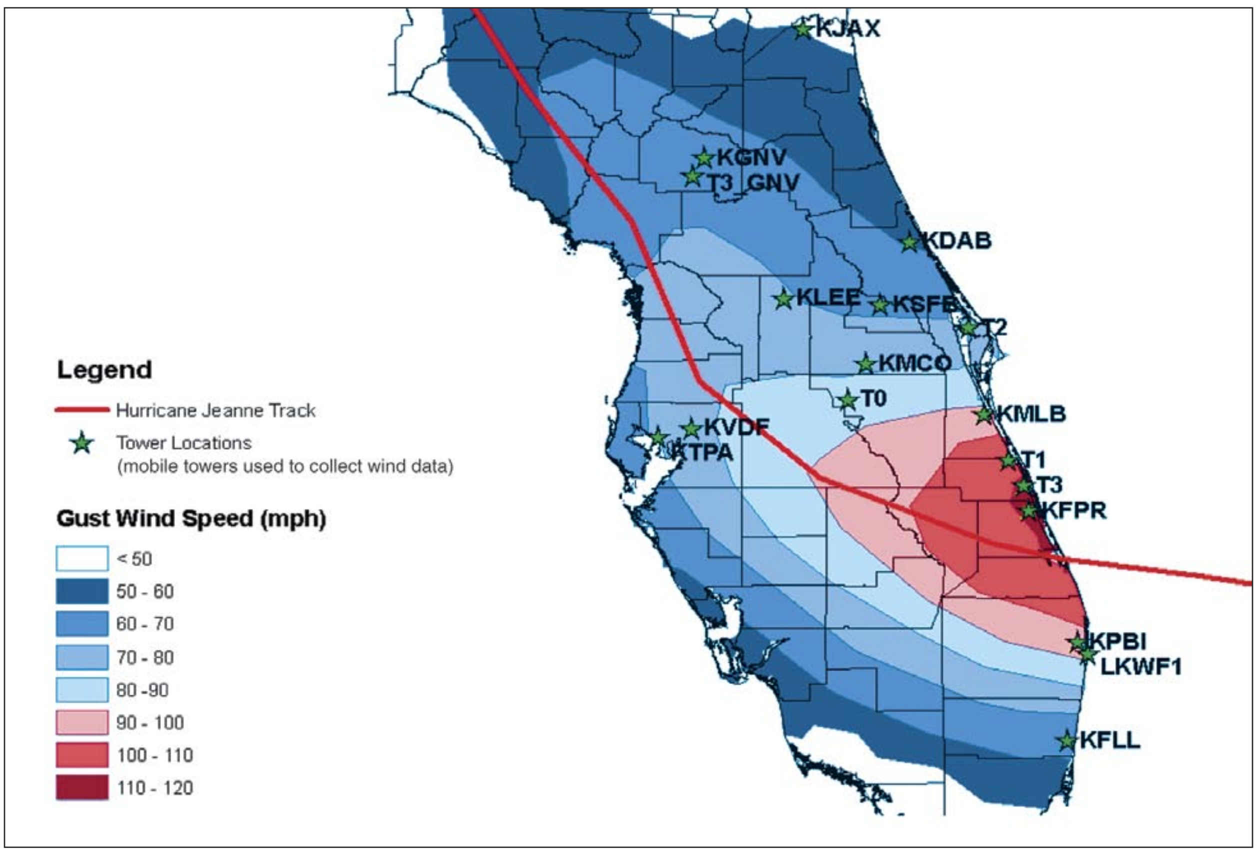


Figure 5. Hurricane Jeanne Wind Swath Map

landfall. The maximum storm surge was estimated to be 6 feet above normal tide levels.

2.5 Cumulative Hurricane Damages

Alabama and Florida residents braced for impact and endured the aftermath of four hurricanes in August and September 2004, large events separated by a brief pause of just days. Intensifying the rapid-fire hurricane strikes was the track similarity shared by Frances and Jeanne, and the overlapping zone of effects among Frances, Jeanne, and Charley. Though Hurricane Ivan tracked through the Gulf of Mexico and hit Alabama, the storm brought severe wind and water effects to Florida as well as Alabama. Though varied in degree, the hurricanes each resulted in wind and water damage to commercial, residential, and public facilities, as well as vegetation, agricultural crops, and infrastructure such as utilities and roadways. Though the wind swaths, flood levels, and tracks of the hurricanes are easily mapped, the boundary of damages associated with each event is not so easily drawn. Field observations were difficult to perform before the next hurricane struck. As such, the overlapping hurricane events and track similarities led to a succession of damages that is almost easier to consider cumulatively than separately.

The outlay of resources to disaster communities can put into perspective the degree of sustained damages (FEMA, 2005b):

- More than 548,000 citizens were assisted in FEMA Disaster Recovery Centers throughout Florida.
- Approved aid for Public Assistance (public facilities) disaster damages surpassed $604 million (FEMA, 2005c).
- Approved aid for Individual Assistance disaster damages surpassed $1.16 million (FEMA, 2005b).
    - Nearly 1.24 million victims applied for federal and state assistance.
    - Almost 877,000 housing inspections were completed.
    - FEMA provided more than 15,600 temporary housing units to hurricane victims.
- An estimated 53 million cubic yards of debris was cleared.
- More than 33,000 NFIP claims were received.

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.

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.

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.

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.

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)

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.

**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.

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 constructed 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.

Conclusions and Recommendations

4

The following conclusions and recommendations are based on the most significant damages observed by the MATs and Rapid Assessment Teams deployed after Hurricanes Charley, Frances, and Ivan. Additional conclusions and recommendations are included in the individual reports for these hurricanes. The following sections outline the most significant conclusions and recommendations. Detailed recommendations are included in four matrices presented at the end of this Summary Report.

4.1 Wind-Related Conclusions and Recommendations

Houses built in accordance with the FBC 2001 or the IBC 2000/2003 generally avoid most wind-related structural issues. At this time, improvements must focus on preventing rain water intrusion and protecting the building envelope. Protection of the building envelope is important in minimizing losses to building contents.

General

NOAA/NWS Monitoring System

None of the Automated Surface Observing System (ASOS) and other systems that were impacted by the strongest winds of Hurricane Charley (as far inland as Orlando) continued to report wind information throughout the storm. Assessment of structure and infrastructure performance is keyed to wind speed estimates experienced throughout the area of impact. Based on performance during Hurricane Charley, National Oceanic and Atmospheric Association (NOAA)/NWS surface wind and weather monitoring systems in areas of the U.S. threatened by hurricanes must be hardened and provided with backup power and better data storage.

Hurricane Classification

Building performance across the paths of the hurricanes varied significantly by location in the wind swath area. The categorization of a storm by a single hurricane classification has limited use in post storm assessment. Wind field estimates and wind speed swath maps (refer to Figures 2–5 for examples) are critical to properly assess storm events and their implications for building design, construction, and code development.

Structural

To minimize damage or prevent failure of older buildings (both residential and commercial), mitigation actions that create a continuous load path from the roof deck to the foundation must be undertaken. Specific recommendations are included in Matrix #2, Building Code and Regulations Recommendations.

Accessory Structures

Historically and typically, aluminum structures have had little rigorous engineering applied to them because they have been regarded as auxiliary and even expendable structures. As such, the widespread failure of these structures observed after the 2004 hurricane season was anticipated.

Connection detail failures and inadequate bracing were frequently the initiation points for the ultimate failure of accessory structures indicating that, in general, designers, installers, and building department personnel may not be sufficiently knowledgeable about the design and construction of wind resistant aluminum structures. Attention is generally given to the size and spacing of members, but not to connection details. Revised guidance associated with Table 2002.4 (FBC 2001), prepared by the Aluminum Association of Florida (AAF) should be used until the adoption of the 2004 version of the FBC. Specific recommendations relating to accessory structures and attachment are cited in Matrix #1, Design and Construction Recommendations.

Building Envelope

Poor building envelope performance resulted in extensive property damage and substantial loss of function. Poor performance was a function of both inadequate wind resistance and damage from debris impact.

- Inadequate resistance to large wind pressures on building envelopes (particularly roof systems and soffits) and rooftop equipment was responsible for much of the damage incurred by the hurricanes.
- Windborne debris, especially during Hurricane Charley where wind speeds in some areas were 120 mph 3-second gust and greater, caused significant envelope damage.

Recommendations to improve building envelope performance include: modifications to building codes, Florida statutes, and regulatory requirements (refer to Matrix #2); specific recommendations by building envelope element (Matrix #1); and additional/new guidance materials and public education (Matrix #3, Public Outreach Recommendations).

Building Codes, Florida Statutes, and Regulatory Requirements

Buildings built in accordance with older codes are typically vulnerable to envelope and equipment damage because older codes had inadequate criteria or no criteria at all. Where buildings were designed and constructed to newer codes (FBC or IBC/IRC), some of the observed failures were due to failure to comply with code provisions in the design and/or construction phases. Other failures were the result of installing materials and systems that cannot perform under high-wind loads (i.e., the use of inadequately secured soffit panels). Because these elements are not considered "structural elements," their design and construction is often overlooked during design, construction, and code enforcement. Therefore, improvements are needed in the design requirements of codes themselves and with code enforcement. Specific code change recommendations are included in Matrix #2.

Building Envelope Systems

Certain building envelope components reported on in previous MAT reports continue to be initiation points for substantial interior damage and/or progressive failure. The following elements require additional guidance and design; specific recommendations by element type are included in Matrix #1.

- **Roof systems.** Many roof coverings of all types continue to fail at unacceptable rates during hurricane events, even when wind speeds are below design levels. Failure is due to the age of the coverings (coverings that were never considered for their ability to resist what is now understood as design level wind loads), debris impact, and design and construction related issues. Inadequate attention has typically been given to edge flashing, coping, and gutter/downspout design and installation despite their roof area locations, which are subject to the highest wind pressures.

- **Exterior Mechanical and Electrical Equipment Damage.** Displacement or damage to these units resulted in loss of function associated with the damaged units and, in many cases, loss of function of the occupied space serviced by the equipment. Rooftop and ground level equipment is not receiving the design, installation, or code compliance needed.
- **Soffits.** In numerous buildings, wind-driven rain intruded into areas where soffits were displaced or lost. Widespread loss of soffits was observed in residential construction.
- **Wall Covering.** Wall coverings continue to be an initiation point for progressive failures leading to interior contents damage or pressurization of the building.
- **Doors.** As building performance has improved and resolved many of the large structural issues, increased attention can be focused on doors and wind-driven rain infiltration. Weatherstripping and vestibules are recommended to minimize interior damage from wind-driven rain.
- **Windows and Shutters.** The required protection of windows and glazed doors in areas within the ASCE 7 windborne debris region appeared justified based on the amount of observed windborne debris from Hurricanes Charley, Frances and Ivan. The FBC windborne debris provisions in the panhandle should be changed to match those in ASCE 7. Most shutters observed on buildings performed well. Many homes and businesses that experienced only contents damage could have prevented these losses if their building envelope openings were protected.

4.2 Flood-Related Conclusions and Recommendations

The most severe flood-related damages experienced during the 2004 hurricane season were associated with Hurricane Ivan. Several general conclusions were drawn based on damage observations by the MAT.

General

Flood levels several feet higher than the mapped BFEs on the FIRMs were recorded. Several reasons could account for this: Ivan may have been a storm with a higher return period than the 100-year event shown on the FIRMs; there may have been changes in the topography over the 20 to 25 years since the storm surge modeling was initially performed; or older storm surge modeling methodologies may have failed to produce accurate estimates. Recommendations based on these observations are:

- **Re-evaluate the hazard identification/mapping approaches in Coastal A/V Zones.** Re-evaluate the methodology to determine flood zones and flood elevations in coastal high hazard areas to address the inconsistencies of observed damages versus anticipated damages based on mapped flood zones. Flood hazard mapping procedures and methodologies in coastal areas (especially on barrier islands and on mainland, open coast shorelines) may need revision to capture anticipated future coastal conditions (for instance, the possible effects of multiple storm events and long-term erosion).
- **Re-evaluate the storm surge modeling.** Re-analyze the storm surge modeling, which provides the storm surge elevations for the mapping analysis, because of significant changes in the barrier islands since the modeling was first performed.
- **Reconstruction Guidance.** Use Hurricane Ivan tide levels, inundation limits, and areas subject to wave effects as proxies for reconstruction guidance until such time as new, up-to-date regulatory studies and maps can be prepared and adopted.

Structures and Foundations

Pile Foundations. Although pile foundations generally performed well, their performance varied depending on the level of detail followed during building construction. Additionally, flood-borne debris contributed significantly to the structural damages that were observed by creating unanticipated loads on pile foundations. Recommendations to address these issues are presented in Matrix #1.

Shallow Foundations. In areas subject to coastal erosion and scour, shallow foundation damage was extensive and the structural failures dramatic. The most extreme cases were building failures due to erosion of supporting soil under shallow foundations. Shallow foundations are not appropriate for supporting structures in coastal areas subject to scour and/or erosion and should not be permitted. Specific foundation design measures related to barrier island construction and bay/sound shoreline area construction are provided in the Matrix #1.

General recommendations on the foundations are:

- **Elevate the bottom of the lowest structural member above the BFE for Coastal A Zones.** Damages to lowest floor elevations were widespread in the flood damaged areas. All new construction (including substantially improved structures and replacement of substantially damaged structures) in Coastal A Zones should be elevated with the bottom of the lowest horizontal structural member at the base flood level.
- **Freeboard.** Require freeboard for all structures in all flood hazard zones with the amount varying with building importance and anticipated exposure to wave effects. Recommendation is based on ASCE 24-05, which addresses freeboard and elevation requirements for flood resistant materials and equipment. Specific recommendations are provided in Matrix #2.
- **V Zone standards.** Require V Zone foundations for new construction in Coastal A Zones subject to erosion, scour, and/or wave heights greater than 1.5 feet. Require deep pile or column foundations in areas mapped as Zone B, C. or X, where erosion and/or scour are possible.
- **FEMA 55 *Coastal Construction Manual.*** Emphasize best practices contained in FEMA's *Coastal Construction Manual* and in the latest flood resistant codes and standards.

Accessory Structures and Construction Features Beneath Elevated Structures

Accessory structures such as stairs and enclosures built beneath elevated buildings were totally destroyed. Most of this damage is preventable by limiting the construction of these enclosures and other systems built beneath elevated buildings. Not only are the enclosures, stairs, utilities, and other systems severely damaged, but they become a significant source of flood-borne debris, as were docks and piers. Once dislodged by storm surge, wave action, or wind, these features can act as obstructions and create unanticipated loads on the foundations and increase the potential for structural failure. Refer to Matrix #1 for specific recommendations related to these structures.

To discourage construction that results in this type of damage, flood insurance claims payments for stairs and building access structures should be limited to a reasonable fraction of the policy limit and claim procedures should be modified to ensure flood insurance policy ratings are correct, particularly with regard to enclosures and obstructions.

4.3 Critical and Essential Facilities/Shelters, Conclusions and Recommendations

Poor performance of numerous critical/essential facilities and shelters occurred in the fall of 2004 during Hurricanes Charley, Frances, Ivan, and Jeanne. The building damage these facilities sustained during the hurricanes led to significant, yet avoidable, loss of function.

Many essential and critical facilities (excluding shelters) were housed in older buildings and most apparently were not mitigated to resist known hurricane wind risks. If these critical and essential operations were housed in buildings constructed to current code (which provides levels of protection from wind and in some cases to windborne debris), some of these buildings could have then remained operational. Alternatively, many of these facilities could have remained operational if key areas of the buildings had been mitigated or retrofitted for wind and windborne debris design requirements for their locations as specified in the current code. Code improvements are also needed. The current practices for designing, constructing, retrofitting/mitigating, and maintaining critical/essential facilities can be improved.

In addition, the continuity of critical facilities needs to be ensured. In some cases this means designing beyond the existing code minimums (e.g., remove or replace roof-top aggregate). A vulnerability assessment should be performed to assess the building performance and utilities that service critical facilities. This would provide the building owner a better understanding how the building will be impacted during a storm and how the operations will be impacted by limited utility services. As an example, electrical service may provide power to lift stations for sewage; if the building were used as a shelter and electrical service is disrupted during a storm, backup systems would likely be required, but certain portions of the building may not need to be operational.

The performance of buildings used as hurricane shelters also varied widely. Performance varied from numerous successes to an instance of a partial building collapse. Although only minor injuries were reported, large numbers of people within shelters were traumatized because of poor building performance or perceived poor performance when comfort issues were compromised. In Charlotte and Lee Counties in

Florida, shelters used during Hurricane Charley were located within the storm surge inundation zone for a Category 3 hurricane; luckily, due to the compact size of the hurricane, typical storm surge was not generated and the shelters were not flooded; however, if typical surge had occurred, this shelter would have been flooded.

To achieve building performance during hurricanes that will preserve the facility function, the following are recommended in addition to the specific recommendations provided in Matrix #2 and Matrix #4, Critical and Essential Facility Recommendations.

- **Expand the use of the critical/essential facility designation.** Buildings other than those defined by ASCE 7 Table 1 may be vital in the response or recovery after a hurricane, or they may house functions that need to remain operational during or after an event. For example, damage to a medical office building, though not necessarily a Category III or IV building, could adversely affect the hospital functions. Additionally, skilled nursing homes, Alzheimer's units, and perhaps independent living or assisted living facilities could benefit from this designation.
- **Prioritize the critical and essential facilities.** Although all critical and essential facilities are important, some are more critical than others. Buildings sheltering large numbers of people (e.g., greater than 1,000) and buildings that have regional importance (e.g., a county EOC or regional hospital) should be designed, constructed, and maintained more conservatively than normal critical and essential facilities. Existing critical and essential facilities should also receive the highest priority for mitigation (retrofit). Designers should also remember that codes and standards recommend the minimum design requirements for facilities (even critical and essential facilities). Designers should implement known best practices for high-wind design above the minimums required.

4.4 Design Guidance and Public Education Recommendations

Design and Construction Guidance

Many building component failures observed during the 2004 hurricane season were the result of the failure to implement well-established basic construction practices. Designers and contractors need additional guidance to understand wind-resistance issues and to provide methodologies and best practices when code guidance is vague or unclear or does not exist. Based on the MATs' observations, specific design, testing, and construction guidance is needed for the several areas listed below. Detailed recommendations are included in Matrix #3:

Design Guidance

- Roof coverings, gutters, and downspouts
- Rolling and sectional doors
- Soffits
- Rooftop equipment
- Other exterior devices and equipment such as pool equipment, swing sets, and storage sheds
- Electrical and communications equipment

Testing Guidance

- Test methods: Most of the methods used to test envelope assemblies are static tests, which are inadequate for some assemblies. The development and application of dynamic tests are recommended.

Construction Guidance

- Manufacturer's instructions: There were numerous instances of significant deviation from manufacturers' installation instructions. Manufacturers need to ensure adequate instruction (bilingual instructions would be advantageous) and training.

Public Education and Outreach

Much has been learned in the past three decades regarding practices that need to be implemented to achieve good building performance during strong hurricanes. Although improvements are still needed with respect to design guides, test methods, building codes, and construction/inspection practices, many designers, manufacturers, building officials, and contractors did not fully implement the current state of knowledge (e.g., FEMA 55, FEMA 361, FEMA 424, ASCE 24-05) with respect to buildings located in hurricane-prone regions. A renewed, comprehensive educational effort is needed to avoid the hurricane building damage cycle, wherein buildings are constructed, damaged, repaired, or rebuilt—to a condition often no better than the initial damage—and then damaged again in a future weather event. Specific recommendations for the following audiences are included on Matrix #3.

- Building owners and homeowners
- Architects/engineers/consultants
- Building officials
- Contractors
- Manufacturers
- Associations

The greatest educational challenge is to get those in need to take advantage of educational materials that are available. To the extent possible, materials and seminars should be free or of minimal cost. To achieve this goal, governmental funding or private sponsorship may be necessary. However, the ultimate incentive likely lies with building owners and homeowners, and the decisions they make in selecting design and construction teams that will produce the best product for their dollar.

Matrix #1.
Design and Construction Recommendations

BUILDING COMPONENT	RECOMMENDATION	ACTION REQUIRED BY[1]
WIND HAZARD		
ACCESSORY STRUCTURES		
Attached & detached	Add additional anchors at corner post connections to concrete.	D, C
Attached & detached	Use AAF *Guide to Aluminum Construction in High Wind Areas* until FBC 2004 is adopted.	D
Attached & detached	Increase wind resistance of accessory structure walls parallel to primary building (e.g., tension cable, solid 'K' bracing).	D
Attached & detached	Provide lateral bracing in roof planes using rigid diagonal structural members.	D, C
Attached	Ensure attached building and primary building can withstand equal wind pressures.	D, C
Attached	Determine implications to primary building if attached structure collapses.	D, C
Detached	Determine ability to withstand windstorm events to reduce windborne debris.	D, C
BUILDING ENVELOPE		
Roof systems	Testing: Roof assemblies susceptible to dynamic loading should be dynamically tested to obtain realistic measure of their wind resistance. Higher safety factors should be used for those assemblies requiring dynamic testing, but for which dynamic test methods are not available.	D, C, G
Re-roofing	Tear off old roof (do not re-cover) in areas where basic wind speed is 110 mph or greater.	D, C
Re-roofing	Install additional sheathing fasteners if existing sheathing attachment is not in compliance with current building code.	D, C
Asphalt shingles	Ensure manufacturers' installation instructions are followed (i.e., starter strips and nail locations) and use Recovery Advisory Nos. 1 and 2.	D, C
Asphalt shingles	Re-evaluate attachment of factory-laminated tabs.	M
Metal panel roof system	Ensure that chalk-line clip locations for panels with concealed clips are not excessively spaced.	C
Metal panel roof system	Base uplift resistance on ASTM E 1592.	M, D
Metal panel roof system	Specify close spacing of fasteners at eaves, and hip, and ridge flashings.	D
Tile roof system	Use Recovery Advisory No. 3.	D, C
Tile roof system	Develop tiles with improved ductility via internal or backside reinforcement or bonding film in hurricane-prone regions (e.g., develop tile similar to laminated glass).	M

[1] Action required by: Designer (D), Contractor (C), Manufacturer (M), Government Official (G), Building Owner (O)

BUILDING COMPONENT	RECOMMENDATION	ACTION REQUIRED BY[1]
Tile roof (foam-set) system	For foam set tile, simplify number of installation options and clarify requirements.	M
Tile roof (foam-set) system	Modify training and certification programs to ensure that foam-set roof installers are adequately trained.	M, C
Tile roof (foam-set) system	Use a higher safety factor (e.g., 4) to account for application and testing issues.	M, D
Mechanically attached roof systems	FRSA/TRI re-evaluate use of safety factor of 2. Either develop dynamic test method or use existing test method with higher safety factor (e.g., 3).	M, D
Built-up roofs	Develop and codify technically-based criteria for aggregate surfacing on built-up and sprayed polyurethane foam roofs.	M, G
Edge flashings & copings	Comply with ANSI/SPRI ES-1 (2003). Use safety factor of 2 - 3.	D
Edge flashings & copings	Install edge flashings on top of membrane to clamp it down.	D, C
Edge flashings & copings	Place a bar over roof membrane near edge of flashing and coping to provide secondary protection.	D, C
Gutters & downspouts	Use professional judgment to specify and detail gutter uplift resistance.	D
Gutters & downspouts	Design Guidance: Develop design guide, test method, and code criteria for gutters, including attachment of downspouts.	M, C
Rooftop walkway pads	Research wind resistance of roof walkway pads.	M, G
Soffits	Design Guidance: Develop design guidance for attaching soffits, including design of baffles or filter media to prevent wind-driven rain from entering attics.	M, G
EXTERIOR EQUIPMENT		
General	For all exterior equipment, recommend safety factor of 3 due to uncertainties pertaining to wind load.	D
General	Design Guidance: Develop guidance and code criteria for attaching condensers and rooftop mechanical equipment (including ductwork).	D, G
General	Evaluate the need to better secure exterior devices, such as pool equipment and roof-mounted solar heaters.	D, C, O, CF
Cowlings	Anchor cowlings on exhaust fans to curbs using cables.	M, D, C
Access panels	Modify access panels attached by manufacturer to ensure secure attachment (see FEMA 424).	M, D, C
Lightning protection systems	Attach lightning protection systems, per FEMA 424.	M, D, C

[1] Action required by: Designer (D), Contractor (C), Manufacturer (M), Government Official (G), Building Owner (O)

BUILDING COMPONENT	RECOMMENDATION	ACTION REQUIRED BY[1]
Lightning protection systems	Design Guidance: Develop guidance and code criteria for attaching lightning protection systems. Anchor communication towers and satellite dishes.	D, C, M, G
Vinyl siding	Design Guidance: Develop design guidance for attachment.	M, G
EIFS	Design Guidance: Develop design guidance for attachment and re-evaluate existing test method.	M, G
DOORS		
Exterior doors	Specify wind-driven rain resistant weather-stripping at exterior doors (see FEMA 424).	D
Entrance vestibules	Design entrance vestibules in areas where basic wind speed is greater than 120 mph.	D
Rolling & sectional doors	Consider type, size, and spacing of door, frame, and frame fasteners to withstand wind loads. If frame is attached to wood blocking, then consider blocking attachment.	D, C
Rolling & sectional doors	Maintain adequate edge distances for frame fasteners.	C
WINDOWS AND SHUTTERS		
General	The window industry should re-evaluate current test procedures to better represent dynamic wind loading produced by hurricane and tropical storm winds.	D, C, M, G
General	Develop window assemblies that are more wind-driven rain water-resistant.	M
FLOOD HAZARD		
FOUNDATIONS AND STRUCTURES		
General	Design foundations and structures to withstand loads from flood-borne debris during a base flood event (100-year).	D
Foundations on barrier islands	Require V Zone foundations for new construction in Coastal A Zones subject to erosion, scour, and/or subject to wave heights of 1.5 feet or higher during a base flood event.	G
Foundations on barrier islands	Use pile or column pier foundations for A Zone areas not subject to erosion and not subject to 1.5 foot (or higher) wave heights to minimize flood-borne debris damage. Stem wall foundations may be appropriate for areas subject to shallow flooding, but foundation walls are not recommended.	D, C
Foundations on barrier islands	Require deep pile or column foundations in areas presently mapped as Zones B, C, or X, where erosion and/or scour is possible.	G
Foundations on barrier islands	Require use of self-supporting lowest floor system that will not collapse if undermined for high-rise construction in areas outside the V Zone.	G
General	Use flood and corrosion resistant materials below the BFE as recommended by American Society of Civil Engineers (ASCE) 24-05 and the *Coastal Construction Manual* (FEMA 55).	D, C

[1] Action required by: Designer (D), Contractor (C), Manufacturer (M), Government Official (G), Building Owner (O)

BUILDING COMPONENT	RECOMMENDATION	ACTION REQUIRED BY[1]
Foundations in bay and sound shoreline areas	Require V Zone foundations for new construction subject to erosion and/or scour in bay areas outside mapped V Zones.	G
Foundations in bay and sound shoreline areas	Require V Zone foundations for new construction subject to wave heights of 1.5 feet or higher in bay areas outside mapped V Zones.	G
Foundations in bay and sound shoreline areas	Use pile, column, or pier foundations for A Zone areas that are not subject to erosion, scour, or 1.5-foot (or higher) wave heights to minimize flood-borne debris damage. Stem wall foundations may be appropriate for areas subject to shallow flooding, but foundation walls are not recommended.	D, C
First floor elevation	Elevate all new construction (including substantially improved structures and replacement of substantially damaged structures) in A Zones with the bottom of the lowest horizontal supporting member above the base flood level. Freeboard for all structures in all flood hazard zones is desirable; the amount will vary with building importance and anticipated exposure to wave effects.	D, C
ACCESSORY STRUCTURES AND CONSTRUCTION BENEATH ELEVATED STRUCTURES		
Dock and Piers	Implement design requirements for docks and piers that minimize damage to other structures.	D

[1] Action required by: Designer (D), Contractor (C), Manufacturer (M), Government Official (G), Building Owner (O)

Matrix #2.
Building Code and Regulations Recommendations

WIND HAZARD	
BUILDING COMPONENT	**RECOMMENDATION**
BUILDING ENVELOPE	
Edge flashing and coping	**FBC Section 1503** (Weather Protection) should require compliance with ANSI/SPRI ES-1 for edge flashings and copings.
Gutters	**FBC Section 1503** (Weather Protection) **and IBC/IRC**: Develop and add criteria regarding uplift resistance of gutters.
Metal panel roof system	**FBC Section 1504** (Performance Requirements): Require compliance with ASTM E 1592 for testing the uplift resistance of metal panel roof systems.
Roof system	**FBC Section 1510.3** (Recovering vs. Replacement) **and IBC/IRC**: Require removal of existing roof covering down to the deck and replacement of deteriorated sheathing in areas where basic wind speed is 110 mph or greater. If existing sheathing attachment does not comply with loads derived from Chapter 16, then require installation of additional fasteners to meet loads.
Asphalt shingles	**FBC Section 1507.2** (Roof Covering Application) **and IBC/IRC**: Require compliance with UL 2390. Also require six nails per shingle and require use of asphalt roof cement at eaves, rakes, hips, and ridges where basic wind speed is 110 mph or greater (refer to Recovery Advisory No. 2).
Mortar-set tile roof system	**FBC Section 1507.4** (Clay and Concrete Tile) **and IBC/IRC**: Provide an alternative to the use of mortar to attach field tiles and hip/ridge tiles.
Built-up roof	**FBC Section 1508** (Roof Coverings with Slopes Less Than 2:12): Add technically-based criteria regarding blow-off resistance of aggregate on built-up and sprayed polyurethane foam roofs.
Ridge vents	**FBC Section 1503** (Weather Protection) **and IBC/IRC**: Add criteria regarding wind and wind-driven rain resistance of ridge vents. Attachment criteria require development, but TAS 110 could be referenced for rain resistance.
Soffit	**FBC/IBC/IRC:** Criteria regarding wind resistance of soffits should be added, and wind-load criteria for soffits require development. Wind-driven rain resistance of ventilated soffit panels should also be added. TAS 110 may be a suitable test method, modified as necessary.
WINDOWS AND SHUTTERS	
Shutters	**FBC Section 1606.1.4** (Protection of Openings): Add requirement to label shutters (other than wood) because without labels, building owner does not know if shutters are suitable.
Windborne debris region	**FBC:** Revise the Florida panhandle criteria to match ASCE 7.
Shutters	Revise Chapter 15C of the Rules and Regulations of Florida to provide window protection systems (and a strengthened structure around openings) on Zone II and Zone III units being installed in the windborne regions defined by Chapter 16 of the FBC.
EXTERIOR EQUIPMENT	
General	**FBC Section 1522.2** (Rooftop Mounted Equipment): Make applicable throughout the State of Florida for all wind speeds. Develop and add criteria that pertain to attaching lightning protection systems. Provisions also included in mechanical and electrical codes.

BUILDING COMPONENT	RECOMMENDATION
CRITICAL AND ESSENTIAL FACILITIES	
General	For hurricane shelters and EHPA, adopt wind speed recommended by Florida Department of Community Affairs (FL DCA) in the SESP and the ASCE 7-02/2001 FBC wind speed map design wind speed plus 40 mph using Performance Criteria 3. Currently this is a *recommended* best practice in the FL DCA shelter design guidance and in FBC Section 423, Part 24; change to a *requirement.* This criterion should be required by the SESP and should be used until the International Code Council's High Wind Shelter Standard is completed in 2006/2007 and available for adoption.
General	Minimum debris impact protection should be per ASTM E 1996 Category E for a 9-pound 2x4 (nominal) missile traveling at 50 mph. This criterion should be required by the SESP and should be used until the International Code Council's High Wind Shelter Standard is completed in 2006/2007 and available for adoption.
General	As an alternative to designing shelters to the SESP or ASCE criteria, design or retrofit buildings to be used as shelters to the design guidance provided in FEMA 361, *Design and Construction Guidance for Community Shelters.*
FLOOD HAZARD	
FOUNDATIONS AND STRUCTURES	
General	Adopt ASCE 24-05 for elevation requirements and flood resistant materials, equipment.
General	Re-evaluate the hazard identification/mapping approaches in Coastal A/V Zones (refer to glossary for definitions).
General	Re-evaluate the storm surge modeling methodology.

Matrix #3.
Public Outreach Recommendations

WIND HAZARD	
EDUCATION TOPIC	**OUTREACH METHOD**
BUILDING OWNERS AND HOMEOWNERS	
Plan and budget construction projects that incorporate natural hazard mitigation measures. Select design and construction teams knowledgeable in effective construction methods in hurricane-prone areas. Prepare and protect building prior to hurricane landfall. What to do after hurricane passes (building inspection for damage, emergency repairs, and drying out building interiors). Rebuild damaged structure in manner that protects against future damage. Inspect exterior connections and fasteners for wear, corrosion, and other deterioration. Educate building owners on how wind-driven rain water enters buildings, the resulting implications (loss of electricity, mold), and prevention methods.	✓ Tailor informational pamphlets to homeowners and building owners. ✓ Develop strategy to distribute information (e.g., standardized information sheets during sale of building). ✓ Enlist assistance of real-estate companies and organizations such as the Building Owners and Managers Association. ✓ Provide public service notices at start of each hurricane season. ✓ Develop informational materials on how wind-driven rain water enters buildings, the resulting damage, and prevention methods.
ARCHITECTS, ENGINEERS, CONSULTANTS	
Improve the technical proficiency of building envelope design. Provide adequate level of design details for connecting rooftop equipment, including mechanical, electrical and lightning protection. Share post-disaster building performance information to maximize the value of lessons learned.	✓ Prepare monographs for trade-wide distribution. ✓ Prepare web-based tutorials and seminars. ✓ Encourage colleges and universities to augment existing curriculum with hurricane-resistant design instruction.
BUILDING OFFICIALS	
Share post-disaster building performance information to maximize the value of lessons learned. Train building officials to identify structural weaknesses that may cause structure or building component failure during a hurricane (e.g., unbraced gable ends, missing truss bracing, truss' anchorage, window/door anchorage). Implement effective enforcement techniques to maintain a high construction quality.	✓ Conduct annual seminars for building officials and plan reviewers in coastal areas to share lessons learned. ✓ Implement hurricane disaster building inspection training program and "train the trainer" program.

EDUCATION TOPIC	OUTREACH METHOD
CONTRACTORS	
Educate contractors who construct building envelopes and install rooftop equipment on hurricane resistant fastening and anchoring systems. Educate contractors on how wind-driven water enters buildings, the resulting implications (loss of electricity, mold), and prevention methods.	✓ Develop and distribute visual tools such as instructional videos or DVDs. ✓ Conduct on-the-job training to highlight failures that occur when simple anchoring techniques are not applied. ✓ Encourage trade schools in hurricane-prone areas to augment their curriculum with courses on state-of-the-art hurricane-resistant construction.
MANUFACTURERS	
Educate manufacturers of building envelope materials and rooftop equipment on the performance of their products during hurricanes. Encourage manufacturers to provide special guidance for use of their products in hurricane-prone areas. Develop improved products and systems for hurricane-prone areas. Manufacturers should educate designers and contractors on their products.	✓ Develop and distribute informational notices to manufacturers.
ASSOCIATIONS, INSTITUTES, AND SOCIETIES	
Advocate hurricane-resistant design and construction to their membership.	✓ Develop educational materials for distribution to their members and industry.
FLOOD HAZARD	
BUILDING OWNERS AND HOMEOWNERS	
Educate building and homeowners in the risks of natural hazards and best practices for mitigating damages. Educate homeowners on the risk of constructing enclosures and accessory structures beneath the first floor and emphasize the significant damage that will result during a severe coastal flood event.	✓ Tailor informational pamphlets to homeowners and building owners.
ARCHITECTS, ENGINEERS, CONSULTANTS **BUILDING OFFICIALS** **CONTRACTORS**	
Share post-disaster building performance information to maximize the value of lessons learned. Emphasize best practices such as *Coastal Construction Manual* (FEMA 55). Emphasize importance of strong structure-to-beam connections to prevent structure detachment from the foundations while piles and beams are still intact.	✓ Prepare monographs for trade-wide distribution. ✓ Prepare web-based tutorials and seminars. ✓ Encourage colleges, universities, and trade schools to augment existing curriculum with hurricane-resistant design and construction instruction.

Matrix #4.
Recommendations Specific to Critical and Essential Facilities[1]

WIND HAZARD		
COMPONENT	**RECOMMENDATION**	**ACTION REQUIRED BY[2]**
GENERAL		
Detailing and notations on the building plans	Facility plans should delineate the facility area designed to function as a shelter or hardened area. Details of the shelter or hardened area and the envelope elements should be provided to ensure that the construction requirements are clearly understood by the builder and building official. Provide facility design criteria and maximum design pressures for the main wind force resisting system (MWFRS) and for components and cladding.	D, C, CFO
Material selection	Reinforced concrete roof deck and reinforced concrete and/or reinforced and fully-grouted concrete masonry unit (CMU) exterior walls are recommended. FEMA 424, *Design Guide for Improving School Safety in Earthquakes, Floods, and High Winds,* and FEMA 361, *Design and Construction Guidance for Community Shelters,* provide detailed guidance on material selection for structural and building envelope systems.	D, C, CFO
General	Develop additional criteria to help insure continuity of function. See FEMA 424 and FEMA 361.	CFO
General	Emphasize best practices for schools and shelters described in FEMA 424 and FEMA 361 respectively, and in the latest codes and standards for wind resistance (ASCE 7).	CFO
Design guidance	Develop a comprehensive design guide to complement FEMA 424 for mitigating existing facilities.	D, G
Perform vulnerability assessment	Perform vulnerability assessment to ensure continuity of operations. The assessment should evaluate the building performance and utilities that service critical/essential facilities so that the building owner understands impacts to the facility during a storm and operational impacts due to limited utility services.	CFO
STRUCTURAL		
General	Implement mitigation measures or structurally retrofit critical/essential facilities to design levels other than minimum code requirements for general use buildings. Do not house critical facilities in lightly engineered buildings such as pre-engineered metal buildings.	CFO, D
General	Educate designers: buildings designed to minimum EHPA requirements does not guarantee that building used as shelter will be properly designed and constructed to resist extreme wind events. Emphasize best practices for shelters described in FEMA 361.	D, C
General	Educate designers: American Red Cross 4496 provides a baseline for a shelter's integrity and performance, but meeting this criterion does not guarantee that the building will resist wind and windborne debris associated with hurricanes. Emphasize best practices for shelters described in FEMA 361.	D, C

[1] Refer also to other matrices
[2] Action required by: Designer (D), Contractor (C), Manufacturer (M), Government Official (G), Critical Facility Manager/Owner (CFO)

COMPONENT	RECOMMENDATION	ACTION REQUIRED BY[2]
General	Conduct special inspections for key structural items and connections to ensure performance of critical facilities.	CFO, C
General	Design critical and essential facilities with wind loads using an importance factor of 1.15 in accordance with ASCE 7. For some facilities, design using the 40-mph increase with importance factor of 1 (recommended for shelter EHPA design in FBC Section 423, Part 24).	D
General	Incorporate hazard mitigation peer review into design approval process to ensure that critical and essential facilities are adequately designed to resist extreme winds.	D
ACCESSORY STRUCTURES		
Detached	Strengthen the anchorage of structures and portable classroom buildings at schools.	D, C, G, CFO
BUILDING ENVELOPE		
General	Contract drawings and specifications for new construction and remedial work on existing building envelopes and rooftop equipment should undergo rigorous peer review, submittal review, field observation (inspection), and testing prior to construction.	D, C, G
General	Implement mitigation measures in buildings not built to current building codes to protect roof coverings, wall coverings, window and door systems, and rooftop equipment.	D, CFO
General	Conduct special inspections for key building envelope components to ensure performance of critical/essential facilities. Inspect roof top equipment twice a year. Inspect doors, windows, and wall coverings at 5-year intervals. Conduct special inspections of the entire facility (both structural and building envelope systems) after storms with wind speeds in excess of 90 mph 3-second gust winds.	CFO
Roof structure	Install hurricane clips or straps on inadequately connected roof beams and joists in those buildings that will be occupied during a hurricane.	C, CFO
Roof decks	Strengthen inadequately attached roof decks.	CFO
Roofing	Replace aggregate-surfaced roof systems with non-aggregate systems.	D, C, CFO
Roof system	Design roof system that will prevent water infiltration if roof is hit by windborne debris.	D
Edge flashings and copings	Install exposed fasteners to weak metal edge flashings and copings.	D, C, CFO
Gutters and downspouts	Install tie-down straps on gutters to avoid membrane blow-off.	D, C, CFO
Rooftop equipment	Anchor all rooftop equipment.	D, C, CFO

[2] Action required by: Designer (D), Contractor (C), Manufacturer (M), Government Official (G), Critical Facility Manager/Owner (CFO)

COMPONENT	RECOMMENDATION	ACTION REQUIRED BY[2]
DOORS		
Door	Design or mitigate to the 2001 FBC for the 120 mph (3-second gust) design wind speed.	D
Rolling and sectional doors	Purchase and install high wind-rated, sectional/rolling doors to protect against high wind.	D, CFO
Rolling and sectional doors	Ensure sectional rolling doors are properly installed and reinforced to prevent catastrophic door failure and building pressurization. Replace or retrofit existing doors that lack adequate resistance.	D, CFO
WINDOWS AND SHUTTERS		
Shutters	Install shuttering system on all exterior glazing that is not windborne debris resistant. Install power-operated shutters or laminated glass, or apply an engineered film system to the glazing and frame on upper-level floors,	D, C, CFO
Windows	Implement window protection systems to protect critical facilities from windborne debris.	CFO, D
FLOOD HAZARD		
FOUNDATIONS AND STRUCTURES		
General	Do not open shelters located in potential storm surge inundation zones until after the hurricane makes landfall.	G, CFO
General	Elevate new structures in floodprone areas to the 500-year (0.2% annual exceedance) flood level, or higher based on ASCE 24.	D, C, G, CFO

[2] Action required by: Designer (D), Contractor (C), Manufacturer (M), Government Official (G), Critical Facility Manager/Owner (CFO)

Acronyms

AAF	Aluminum Association of Florida
ANSI	American National Standards Institute
ASCE	American Society of Civil Engineers
ASOS	Automated Surface Observing System
ASTM	American Society for Testing and Materials
BFE	Base Flood Elevation
BPAT	Building Performance Assessment Team
CMU	Concrete masonry unit
EHPA	Enhanced Hurricane Protection Area
EIFS	Exterior Insulation Finishing Systems
EOC	Emergency Operations Center
FBC	Florida Building Code
FEMA	Federal Emergency Management Agency
FIRM	Flood Insurance Rate Map
FL DCA	Florida Department of Community Affairs
FRSA	Florida Roofing, Sheet Metal and Air Conditioning Contractor's Association, Inc.
HMTAP	Hazard Mitigation Technical Assistance Program
HUD	U.S. Department of Housing and Urban Development
HVAC	Heating, ventilation, and air conditioning
IBC	International Building Code
ICC	International Code Council
IRC	International Residential Code
LPS	Lightning Protection Systems
MAT	Mitigation Assessment Team
mph	miles per hour
MWFRS	main wind force resisting system

NFIP	National Flood Insurance Program
NHC	National Hurricane Center
NOAA	National Oceanic and Atmospheric Administration
NWS	National Weather Station
PCS	Property Claim Services
SBC	Southern Building Code
SESP	Statewide Emergency Shelter Plan (prepared yearly by the FL DCA Division of Emergency Management for the state of Florida)
SFHA	Special Flood Hazard Area
SPRI	Single Ply Roofing Institute
TAS	Testing Application Standard
TRI	Tile Roofing Institute
URM	unreinforced masonry

Glossary

100-year flood	The flood elevation that has a 1-percent chance of being equaled or exceeded each year.
100-year flood elevation	Elevation that flood waters would reach as a result of a 100-year flood.
ASCE 7	National design standard issued by the ASCE, Minimum Design Loads for Buildings and Other Structures, which gives current requirements for dead, live, soil, flood, wind, snow, rain, ice, and earthquake loads, and their combinations, suitable for inclusion in building codes and other documents.
ASCE 24-05	National ASCE standard, Flood Resistant Design and Construction, which outlines the requirements for flood resistant design and construction of structures in flood hazard areas.
Base Flood Elevation (BFE)	Elevation of the 100-year flood. This elevation is the basis of the insurance and floodplain management requirements of the National Flood Insurance Program.
Building envelope	The entire exterior surface of a building, including walls, doors and windows, which encloses or envelops the space within.
Cladding	A protective or insulating layer fixed to the outside of a building or another structure
Coastal A Zone	The portion of the SFHA landward of a V Zone in which the principal source of flooding is storm surge, not riverine sources. Coastal A Zones may therefore be subject to wave effects, velocity flows, erosion, scour, or combinations of these forces. The forces in Coastal A Zones are not as severe as those in V Zones but are still capable of damaging or destroying buildings or inadequate foundations. A Zone areas are subject to breaking waves with heights less than 3 feet and wave run-up with depths less

	than 3 feet. It is important to note that FIRMs use Zones AE, A1-30, AO, and A to designate both coastal and non-coastal SFHAs.
Critical/essential facilities	Facilities that, if flooded, would present an immediate threat to life, public health, and safety. Critical/essential facilities include, but are not limited to, hospitals, emergency operations centers, fire and police stations, water systems, and utilities.
Erosion	Process by which flood waters lower the ground surface in an area by removing upper layers of soil.
FBC 2001	FBC 2001, effective on March 1, 2002, regulates the construction, erection, alteration, modification, repair, equipment, use and occupancy, location, maintenance, removal and demolition of every public and private building, structure or facility or floating residential structure, or any appurtenances connected or attached to such buildings, structures or facilities in Florida.
Freeboard	The additional height of a structure above design high water level to prevent further damage.
Hurricane	An intense tropical weather system with a well defined circulation and sustained winds of 74 mph or higher.
Load path	The process of carrying vertical force in a building from the roof down to the soil.
Pier foundation	Vertical support member of masonry or cast-in place concrete that is designed and constructed to function as an independent structural element in supporting and transmitting both building loads and environmental loads to the ground.
Pile foundation system	Vertical support member of wood, steel, or precast concrete that is driven or jetted into the ground and supported primarily by friction between the pilings and surrounding earth. Piling often cannot act as independent support units and therefore are often braced with connections to other pilings.
Recovery Advisory No. 1	Issued by FEMA, this advisory recommends practices for use of roofing underlayment as an enhanced secondary water barrier in hurricane-prone areas.

Recovery Advisory No. 2	Issued by FEMA, this advisory recommends practices for installing asphalt roof shingles that will enhance wind resistance in high-wind, hurricane-prone areas.
Recovery Advisory No. 3	Issued by FEMA, this advisory recommends practices for designing and installing extruded concrete and clay tiles that will enhance wind resistance in hurricane-prone areas.
Saffir-Simpson Scale	Measures a hurricane's present intensity on a 1-5 scale to give an estimate of the potential property damage and flooding expected along the coast from a hurricane landfall. Wind speed is the determining factor in the scale. A Category 1 hurricane is the weakest, with winds from 74-95 mph, and a Category 5 hurricane is the strongest, with winds over 155 mph.
Scour	Process by which flood waters remove soil around objects that obstruct flow, water from rainfall or snowmelt.
Slab-on grade foundation	Type of foundation in which the lowest floor of the house is formed by a concrete slab that sits directly on the ground. The slab may be supported by independent footings or integral grade beams.
Soffit	An architectural element at the roof overhang.
Special Flood Hazard Area	Portion of the floodplain subject to inundation by the base flood.
Storm surge	Rise in the level of the ocean that results from the decrease in atmospheric pressure association with hurricanes and other storms.
TAS 110	Standard number 110-2000 of the FBC, which covers testing requirements for physical properties of roof membranes, insulation, coatings, and other roofing components.
Tropical storm	An organized system of strong thunderstorms with a defined circulation and maximum sustained winds of 39-73 mph.
V Zone	The portion of the SFHA that extends from offshore to the inland limit of a primary frontal dune along an open coast, and any other area subject to high-velocity wave action from storms or seismic sources. The FIRMs use Zones VE, V1-30 to designate these Coastal High Hazard Areas. V Zones are subject to breaking waves 3 feet or higher.

Zones X, B, and C	These zones identify areas outside of the SFHA. Zone B and shaded Zone X identify areas subject to inundation by the flood that has a 0.2-percent probability of being equaled or exceeded during any given year. This flood is often referred to as the 500-year flood. Zones C and unshaded Zone X identify areas above the level of the 500-year flood.

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