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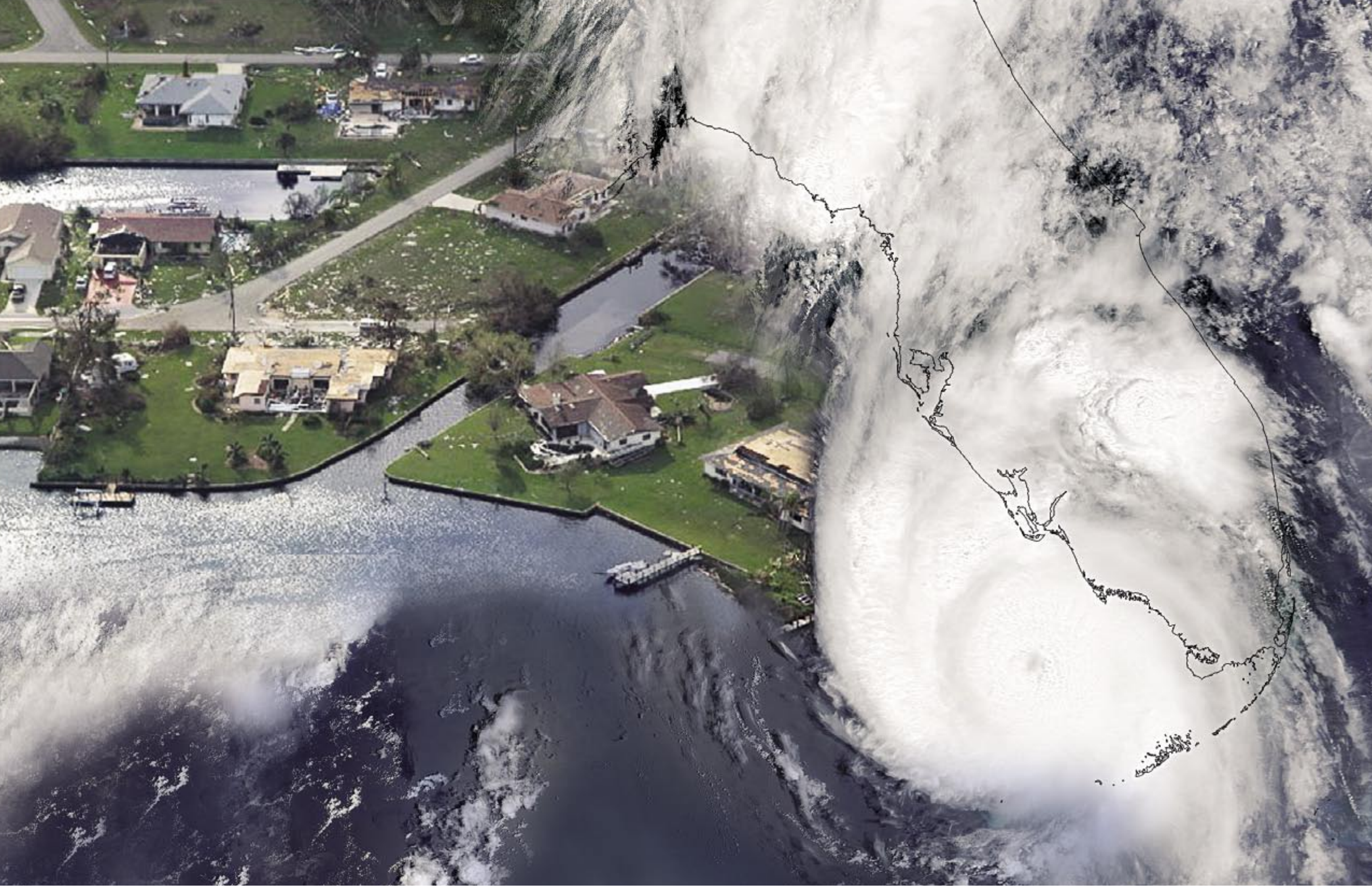

Mitigation Assessment Team Report

Hurricane Charley in Florida

Observations, Recommendations, and Technical Guidance

FEMA 488 / April 2005

FEMA

Florida Department of Community Affairs

In response to Hurricane Charley, the Federal Emergency Management Agency (FEMA) deployed a Mitigation Assessment Team (MAT) to evaluate and assess damage from the hurricane and provide observations, conclusions, and recommendations on the performance of buildings and other structures impacted by wind and flood forces. The MAT included members of FEMA Headquarters and Regional engineering staff, and code enforcement officials, as well as experts from the design and construction industry. The conclusions and recommendations of this Report are intended to provide decision-makers information and technical guidance that can be used to reduce future hurricane damage.

About the Cover

The photograph on the cover shows damage in Charlotte County, Florida, caused by Hurricane Charley on August 13, 2004. (Photograph courtesy of the Florida Division of Emergency Management and the State Emergency Response Team.) Superimposed on this photograph is an image of Hurricane Charley captured on August 13, 2004, at 12:35 p.m. Eastern Daylight Time by the Moderate Resolution Imaging Spectroradiometer (MODIS) sensor aboard the National Aeronautics and Space Administration's (NASA's) Terra satellite. At the time the image was taken, Charley was rapidly gaining strength and would reach Category 4 status just 90 minutes later. Maximum sustained winds at 2:00 p.m. were at 145 miles per hour (mph), and Charley was moving toward the north-northeast at 20 mph.

(IMAGE COURTESY OF NASA AND THE SPACE SCIENCE AND ENGINEERING CENTER, UNIVERSITY OF WISCONSIN-MADISON.)

MITIGATION ASSESSMENT TEAM REPORT

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Executive Summary

Hurricane Charley made landfall on Friday, August 13, 2004, at Mangrove Point, just southwest of Punta Gorda, Florida, The hurricane crossed the barrier islands of Cayo Costa and Gasparilla with wind speed estimates from the National Hurricane Center (NHC) of 150 miles per hour (mph) measured as 1-minute sustained wind speeds (over open water). In its *Tropical Cyclone Report, Hurricane Charley, 9-14 August 2004* (NHC, October 2004), the NHC categorized the storm at landfall as a Category 4 hurricane as measured by the Saffir-Simpson Hurricane Scale. The storm traveled the width of the state from west coast to east coast in approximately 7½ hours. It struck the Orlando International Airport with wind speeds of nearly 105 miles per hour (mph), and went back out over open water near Daytona Beach.

On August 19, 2004, the Federal Emergency Management Agency's (FEMA's) Mitigation Division deployed a Mitigation Assessment Team (MAT) to Florida to assess damages caused by Hurricane Charley. This report presents the MAT's observations, conclusions, and recommendations in response to those field investigations.

Several maps in Chapter 1 illustrate the path of the storm, the wind field estimates, the impact on people and infrastructure, and the depth of storm surge along the path. The width of the high-wind field was very narrow even though hurricane force winds affected some portion of the Florida peninsula from Punta Gorda to Daytona Beach. There was little storm surge or coastal flooding because of the narrow size of the storm and the translational speed with which it came ashore and crossed the state.

The hurricane is believed to have been a design wind event (the wind speeds equaled or exceeded those delineated in the current version of the Florida Building Code [FBC]) for a narrow area from the point of landfall on the west coast inland for 120 miles. The design wind speed for Charlotte County (Punta Gorda) per the FBC is 114 to 130 mph (measured as a 3-second peak gust). The actual measured wind speed near Punta Gorda was 112 mph (3-second peak gust) and measured speeds in other parts of the state suggest that Charley was a design wind event. The storm created a very small area affected by storm surge and most damage was not caused by flooding from storm surge, waves, or erosion.

Florida Building Code Changes

The State of Florida adopted a new building code that went into effect in March 2002, the 2001 Edition of the FBC. The 2001 FBC is modeled after the 1999 edition of the Standard Building Code (SBC) and the South Florida Building Code and retained many of the county-specific wind speed and debris designations used in these codes. The FBC uses the wind design methods specified in the American Society of Civil Engineers (ASCE) 7-98, improves the requirements for wind resistance of components and cladding (C&C), and requires impact resistance glazing or shutters in windborne debris regions. The 2001 FBC, in combination with legislative statutes, will continue to regulate construction in Florida until the 2004 Edition of the FBC becomes effective in the summer of 2005.

Prior to the adoption of the FBC in 2002, the state administered the 1997 Edition of the SBC, with Florida-specific amendments and the South Florida Building Code. Although the codes addressed wind design issues, the wind pressure determined by formula in the SBC is less than the wind design pressure determined by the FBC in many applications, thus understating what the design level wind pressure should be.

Recent changes to regulations and statutes governing the manufacture and installation of manufactured housing include closer spacing of tie-downs and requirements that additions are to be free-standing and self-supporting, with only the flashing attached to the main unit (unless the added unit has been designed to be structurally attached to the existing unit). Further, the regulations state that all additions must be constructed in compliance with state and locally adopted building codes. This portion of the manufactured housing regulations is important in the context of understanding the damage that was caused by this event.

Damage Assessment Observations

Because Hurricane Charley was a design level wind event, the resultant storm damage provides valuable evidence about the effectiveness of building codes and design practices as they address design guidelines for high winds. For buildings built prior to the adoption of the current codes, judgments were made about how the observed damage was reflective of the code to which the building was constructed, and the quality of construction or the inspection process that followed construction. Consideration also was given to the type and use of buildings. Many buildings that were expected to function for critical/essential services were severely damaged by the hurricane and lost function for significant periods of time after the event.

Generally speaking, the structural systems of buildings designed and constructed to the 2001 FBC performed as expected and thus there was little to no damage to the structural systems of these buildings. For older buildings, a number of damage observations were pervasive:

- Design wind loads used were often too low, resulting in a design that was not sufficient for the winds encountered, thus creating some roof and framing damage
- Fasteners for roof sheathing were often too small or spaced too far apart and led to loss of roof panels
- Small or missing strapping used to anchor the roof structure to the walls was often observed
- Unreinforced masonry walls often lacked a continuous load path and led to wall damage and failure
- Lack of a continuous load path at the connection between the walls to the foundations was often observed
- Structural design often did not account for unprotected glazing, leading to structural failures due to increased internal pressures
- Unprotected glazing, leading to interior damage from wind and wind-driven rain was often observed
- Corrosion of ties or fasteners used to attach siding to the wall structure was often observed
- Corrosion of anchors or connectors that attach the building to the foundations or tie structural elements together was often observed
- Improper elevation of habitable space and utilities relative to flood risks was often observed

- Degradation of building elements and connections due to material deterioration, termite infestation, or lack of proper preventive maintenance was often observed

The MAT noted substantial damage to building envelopes and accessory structures on many different types and ages of buildings. The most common damage included:

- Roof coverings blown off
- Soffits blown away, allowing water to enter buildings
- Unprotected glazing, leading to interior damage from wind and wind-driven rain
- Siding blown off buildings, including exterior insulation and finish systems (EIFSs)
- Garage doors blown in or out, allowing wind inside garages and often causing significant structural damage to the garages
- Metal roof and wall panels blown off pre-engineered metal buildings
- Rooftop mounted equipment blown off roofs or severely damaged
- Carports and accessory structures attached to manufactured homes blown off, creating additional debris

The damage to building envelopes allowed wind to enter buildings in many cases, causing property loss, and/or the loss of some component, which then allowed rain water to enter the buildings, causing additional non-structural damage.

This damage indicates that insufficient attention has been given to selecting materials or components of the building envelope that will meet the building code requirements for wind and water resistance. Further, many products do not have test protocols that provide verification that they can meet design loads. Materials are often selected based on criteria other than "disaster resistance." In spite of new codes and education related to the enforcement of and construction to meet the new codes, not enough attention is paid to building envelopes.

A significant number of critical and essential facilities (including fire stations, police stations, hospitals, and schools and other buildings used as shelters) were damaged. The damage was primarily to building envelopes (e.g., large rolling and sectional doors on fire stations or roof coverings on hospitals or schools). Some of the damage to these elements caused subsequent damage to the buildings. There were a few catastrophic failures (i.e., fire stations that lost their entire roof structure, rendering the facilities unusable for their intended functions, and collapse of a wall and portion of the roof of a building where 1,400 people were gathered to seek shelter from the hurricane).

Recommendations

The recommendations in this report are based solely on the observations and conclusions of the MAT, and are intended to assist the State of Florida, local communities, businesses, and individuals in the reconstruction process and to help reduce damage and impact from future natural events similar to Hurricane Charley. The general recommendations presented in Section 8.1 relate to policies and education/outreach that are needed to ensure that designers, contractors, and building officials understand the requirements for disaster resistance construction in hurricane-prone regions.

Buildings constructed in accordance with the 2001 FBC (and those that had been mitigated to resist high-wind loads) were observed to perform substantially better than typical buildings constructed to earlier codes, but their performance was not without exception. Proposed changes to codes and statutes are presented in Section 8.2.

Specific recommendations for improving the performance of the building structural system and envelope, and the protection of critical and essential facilities (to prevent loss of function) are provided in Chapter 8. Implementing these specific recommendations in combination with the general recommendations of Section 8.1 and the code recommendations of Section 8.2 would significantly improve the ability of buildings to resist damage from hurricanes. Recommendations specific to structural issues, building envelope issues, critical and essential facilities, and education and outreach have also been provided.

As the people of Florida rebuild their lives, homes, and businesses, there are a number of ways they can minimize the effects of future natural hazards, including:

- Continue to design and construct facilities to at least the minimum design requirements in the 2001 FBC and the 2004 FBC (after it becomes effective in the summer of 2005)
- Involve a structural engineer/design professional/licensed contractor in the design and planning if buildings (both residential and commercial) are being renovated and remodeled for structural and building envelope improvements

- Assure code compliance through increased enforcement of construction inspection requirements such as the Florida Threshold Inspection Law, the International Building Code (IBC) Special Inspections Provisions, or the National Fire Protection Association (NFPA) 5000 Quality Assurance Requirements
- Perform follow-up inspections after a hurricane to look for moisture that may affect the structure or building envelope

Furthermore, improvements can be made to forecasting, tracking, and responding to hurricanes. Specifically, the following recommendations are provided for State and Federal government agencies:

- The government should place a high priority on and allocate resources to hardening, providing backup power and data storage to the National Oceanic and Atmospheric Administration's (NOAA's)/National Weather Service's (NWS's) surface weather monitoring systems, including Automated Surface Observing Systems (ASOSs) located in hurricane-prone regions.
- The government should place a high priority on continuing to fund the development of several different tools for estimating and mapping wind fields associated with hurricanes and for making these products available to the public as quickly as possible after a hurricane strikes.

Additional recommendations and mitigation measures for design professionals, building officials, contractors, homeowners, and business owners are presented in Chapter 8, including:

- Improving the performance of building structural and envelope systems through proper design of the continuous load path
- Proper design of structural attachments and additions to manufactured homes
- Improving quality control and inspections
- Retrofitting existing residential and commercial buildings from the roof decks to the foundations
- Improving the performance of critical and essential facilities (including shelters)
- Improving design and construction guidance
- Improving public education and outreach

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1 Introduction

On August 19, 2004, the Federal Emergency Management Agency's (FEMA's) Mitigation Division deployed a Mitigation Assessment Team (MAT) to Florida to assess damages caused by Hurricane Charley. This report presents the MAT's observations, conclusions, and recommendations in response to those field investigations.

Chapter 1 provides an introduction, a discussion of the event, historical information, and background on the MAT process. Chapter 2 presents a discussion on the codes, standards, and regulations that affect construction in Florida. Chapters 3 through 5 provide a characterization and discussion of the observed damages to residential, commercial, and critical/essential buildings from Hurricane Charley. Chapter 6 presents observations regarding damages and loss of function to critical and essential facilities in the counties impacted by the hurricane. Chapters 7 and 8 provide the conclusions and recommendations, respectively, that are intended to help guide the reconstruction of hurricane-resistant communities in Florida and all hurricane-prone regions. Chapter 7 also contains examples of mitigation successes. Additional information related to the specific technical issues is presented in the appendices. Appendix A contains the references for the report, and Appendix B is a list of acknowledgments. Appendix C defines the acronyms and abbreviations used in the report. Appendix D contains FEMA *Hurricane Recovery Advisories No.1 (Roof Underlayment for Asphalt Shingle Roofs), No. 2 (Asphalt Shingle Roofing for High-Wind Regions)*, and *No. 3 (Tile Roofing for Hurricane-Prone Areas)*. Appendix E provides information on the history of hurricanes in southwest Florida.

Appendix F contains guidance and statute requirements for design and construction of Enhanced Hurricane Protection Areas (EHPAs) from Florida's State Emergency Shelter Program (SESP).

Hurricane Charley was categorized as a Category 4 hurricane on the Saffir-Simpson Hurricane Scale by the National Hurricane Center (NHC) in its *Tropical Cyclone Report, Hurricane Charley, 9-14 August 2004* (NHC, October 2004), with 150 miles per hour (mph) estimated 1-minute sustained wind speeds (over open water). As the storm made landfall on the barrier island of North Captiva, surface winds could not be measured, but best available data indicate wind speeds were at or below this wind speed. On the east side of Charlotte Harbor, the MAT estimated the hurricane struck the Port Charlotte/Punta Gorda area as a strong Category 3 or borderline Category 4 hurricane with 1-minute sustained winds of approximately 125 mph to 130 mph, and maximum 3-second peak gust winds of 155 mph to 165 mph. Because of the limited amount of surface data and frequent failures of instruments, a significant amount of uncertainty surrounds wind speed estimates at specific locations and information about the storm's winds is still being analyzed by various modelers. However, there is reasonable agreement on the maximum wind speeds at landfall. The wind and flood data included herein reflect the best available estimates at the time of release of this report.

Hurricanes are classified into different categories according to the Saffir-Simpson Hurricane Scale. Table 1-1 gives the categories of the Saffir-Simpson Hurricane Scale along with their respective wind speeds, presented as 1-minute sustained wind speeds and as 3-second peak gust wind speeds, as well as their respective wind pressures. A "major hurricane" is a term utilized by the NHC for hurricanes that

Table 1-1. Wind Speeds of the Saffir-Simpson Hurricane Scale

Strength	Sustained Wind Speed (mph)*	Gust Wind Speed (mph)**	Pressure (millibars)
Category 1	74 – 95	90 – 119	>980
Category 2	96 – 110	120 – 139	965 – 979
Category 3	111 – 130	140 – 164	945 – 964
Category 4	131 – 155	165 – 194	920 – 944
Category 5	>155	>194	<920

* 1-minute sustained over open water ** 3-second peak gust over open water

reach maximum 1-minute sustained surface winds over open water of at least 111 mph (96 knots), the threshold velocity for a Category 3 hurricane. A more complete discussion of preliminary wind speed estimates based on surface wind measurements and computer modeling is provided in Section 1.2.

1.1 Hurricane Charley – The Event

According to the NHC, on August 10, 2004, Hurricane Charley developed from a tropical depression to a tropical storm. Charley was upgraded from a tropical storm to a hurricane on August 11, and tracked west-northwest across the Caribbean, impacting Jamaica and Cuba. This report will discuss and present observations of the damage along the path in some of the hardest impacted areas of Captiva and North Captiva Islands, and the cities of Port Charlotte, Punta Gorda, and Arcadia.

1.1.1 Summary of Winds

The National Weather Service (NWS) and the NHC reported Hurricane Charley made landfall on the Gulf Coast of Florida on Friday, August 13, 2004, just before 4:00 p.m. (Eastern Daylight Time, EDT) when the center of Charley crossed the barrier islands of Cayo Costa and Gasparilla at 3:45 p.m. as a Category 4 hurricane with estimated winds of 150 mph (1-minute sustained over open water) (NHC, October 2004). After crossing the barrier islands, Charley moved up Charlotte Harbor before striking Mangrove Point, just southwest of Punta Gorda, at 4:35 p.m. By 5:30 p.m., the center was 5 miles west of Arcadia (De Soto County) and, at 7:30 p.m., was 4 miles west of Lake Wales (Polk County). At approximately 9:15 p.m., the storm hit the Orlando International Airport. By 11:30 p.m., the hurricane was back over open water, having exited the Florida peninsula near Daytona Beach. By 2:00 a.m. EDT, the center was over the Atlantic about 45 miles north-northeast of Daytona Beach, with maximum sustained winds reported to be 85 mph (1-minute sustained over open water) after having moved across Florida with an average forward translation speed of near 20 mph. Figure 1-1 is an infrared satellite image of Hurricane Charley just prior to landfall.

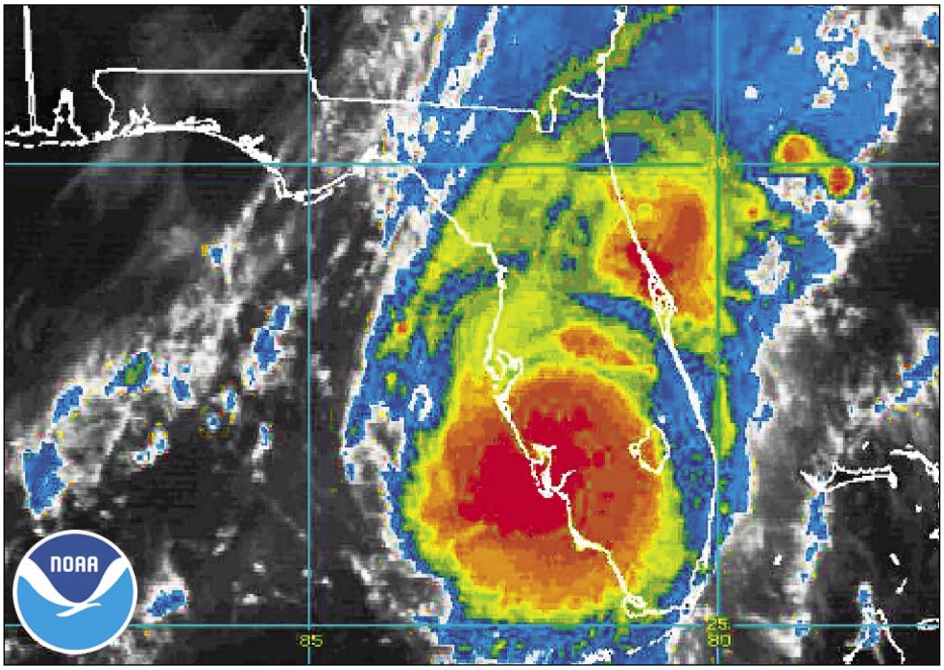


Figure 1-1.
Infrared satellite image of Hurricane Charley making landfall on the southwest Florida coast on August 13, 2004

(NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION [NOAA])

Very few wind speed measurements were obtained for Charley that reflected the actual strength of the storm as it made landfall and moved across Florida. This was due to the small number of weather stations near the point of landfall and the variable performance of stations remaining on-line and recording data during the hurricane. All wind speed data were obtained from the measuring stations and confirmed in the October 2004 NHC report unless otherwise noted. Notable wind speeds recorded and verified from Hurricane Charley were obtained at the following locations:

- Around the time of landfall:
  - 112 mph (3-second peak gust) in Punta Gorda (with a 87-mph, 2-minute sustained wind speed)*
  - 87 mph (3-second peak gust) at the Cape Coral Airport (SOURCE: FLORIDA COASTAL MONITORING PROGRAM [FCMP])

(*Note: NWS reported that the anemometer used to measure wind speeds stopped recording just before the height of the storm at Punta Gorda, NHC, October 2004.)

- Over land, before exiting into the Atlantic Ocean:
  - 105 mph (3-second peak gust) at the Orlando International Airport**
  - 92 mph (3-second peak gust) at the Sanford Airport just northeast of Orlando**

- 83 mph (3-second peak gust) at the Daytona Beach Airport (with a 69-mph, 1-minute sustained wind speed)**
- 87 mph (3-second peak gust) at Ormond Beach (with a 68-mph, 1-minute sustained wind speed)**

(**Note: NWS reported that the anemometer used to measure wind speeds stopped recording before the height of the storm at the Orlando International and Sanford Airports, NHC, October 2004.)

Figure 1-2 shows the approximate extent of tropical storm winds (39- to 73-mph, 1-minute sustained wind speed) and hurricane force winds (greater than 74-mph, 1-minute sustained wind speed) for Hurricane Charley. These wind contours are based on a combination of actual wind readings and meteorological data evaluated by the NOAA H-wind model shortly after Charley made landfall. Additional information regarding the wind field and gradation of winds along the path of the hurricane are presented in Section 1.2.

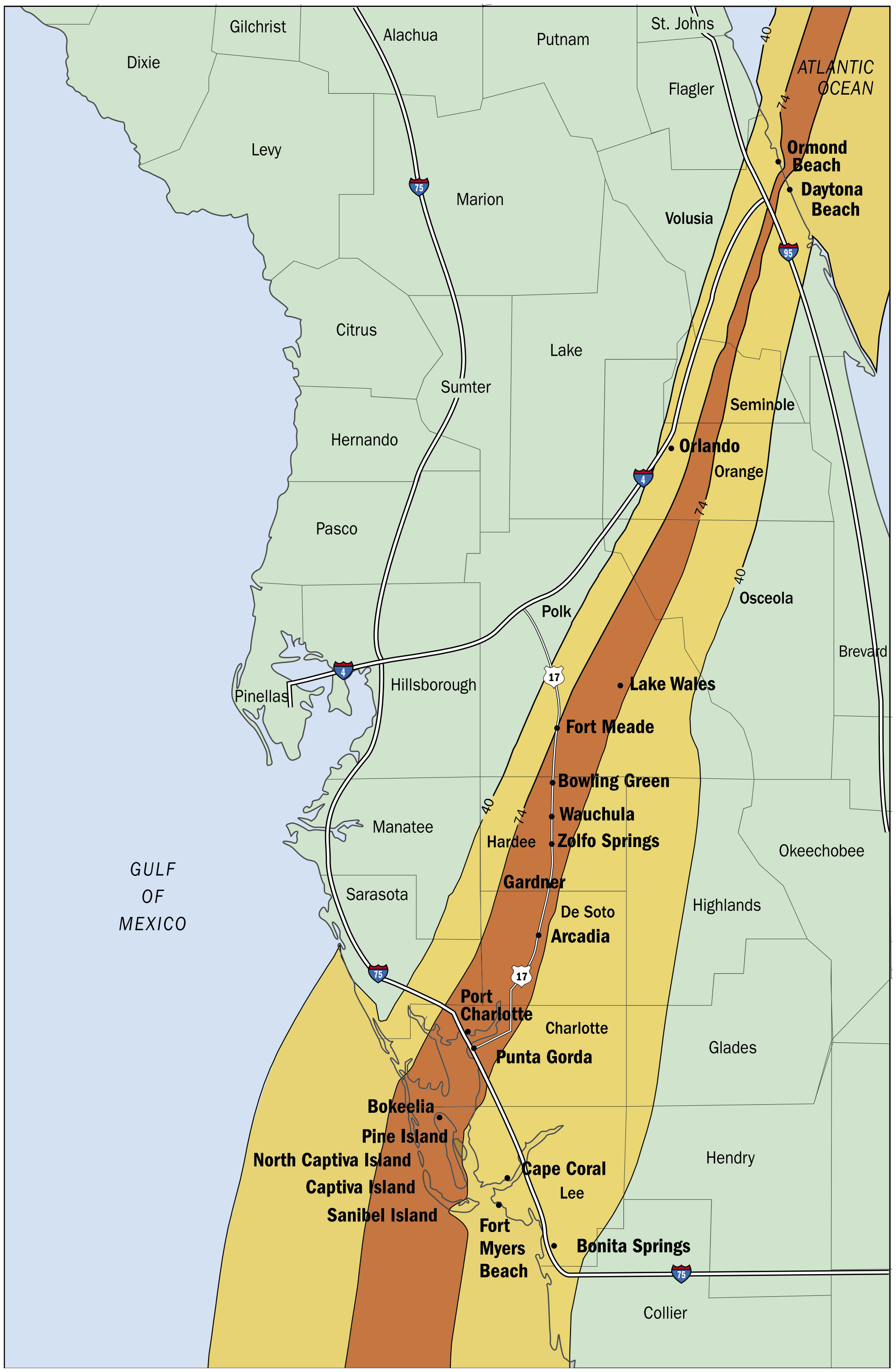
1.1.2 Summary of Storm Surge

As a result of the compact size of Charley and the unexpected eastward turn the hurricane made prior to landfall, the storm surge was not as high as originally predicted by the NHC. The hurricane came ashore as a very narrow, but major hurricane. The radius of the hurricane's eye was estimated to be 6 miles (12 miles in diameter). Hurricane force wind gusts extended outward up to 25 miles from the center; tropical storm force wind gusts extended outward up to 85 miles.

The coastal high water marks were surveyed throughout the impact area. Coastal high water marks along the south-facing Sanibel Island shore were 6 to 8 feet above sea level (asl) (North America Vertical Datum [NAVD] 88). This elevation increased to about 7 to 9 feet asl on the west-facing shore of North Captiva Island. A breach, referred to as "Charley's Gut," was cut across North Captiva Island and was estimated to be 1,500 feet in width. Storm surge elevations along Fort Myers Beach were 5 to 7 feet.

Charlotte Harbor is an estuary that is north of Pine Island and south of Port Charlotte. The Myakka River mouth enters from the west and the Peace River mouth enters from the east, approximately 1 to 1½ miles wide, respectively. Punta Gorda lies on the east shore where the Peace River enters the Charlotte Harbor estuary. High water mark observations along the Port Charlotte shoreline and up the lower Peace River showed that there was no significant storm surge. Water levels appeared to have remained within the normal range of the tide and possibly even below this level. Along Charlotte Harbor south of Punta Gorda to the Charlotte-Lee County line, water levels appeared to have been as high as 3 to 4 feet asl. Additional high water marks after the landfall of Hurricane Charley are presented in Table 1-2.

Figure 1-2. Extent of the hurricane and tropical storm force winds for Hurricane Charley as estimated by the NOAA H-wind model



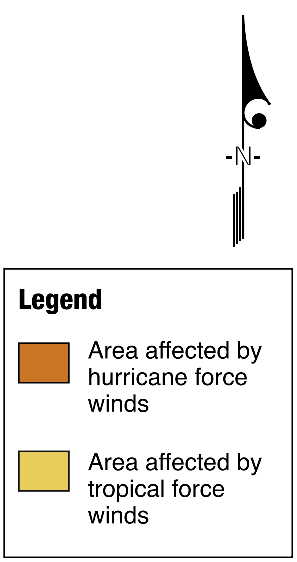


Table 1-2. Additional Storm Surge Depths Observed After Landfall

Location	Storm Surge (asl)
Gasparilla Island, just north of Cayo Costa Island	Estimated between 2 and 3 feet
Along Pine Island Sound, along the sound-facing sides of Captiva and Sanibel Islands	Estimated between 2 and 3 feet
Along the northwest shoreline of Pine Island	Estimated between 4 and 5 feet
Southern shoreline of Pine Island	No significant surge
Along the Caloosahatchee River, 3 to 9 miles upstream of the mouth	Estimated between 1 and 4 feet

1.1.3 Summary of Storm Damage

The effects of the storm were felt across the State of Florida (Figure 1-3) and up into the northeast, as Charley moved up the East Coast. In Florida, the storm caused at least 27 deaths and resulted in the evacuation of over 1 million residents and tourists. Over 2 million people were without power, some of whom remained without power for several weeks. According to the Insurance Services Office (ISO), 640,000 insurance claims were filed, with 605,000 of those in Florida; insured losses from the storm are estimated at $6.8 billion (ISO, 2004). A total of 25 Florida counties were declared under a “state of emergency” and, therefore, eligible for public assistance programs.

Charley took approximately 9 hours to traverse Florida. It was the strongest hurricane to make landfall in the state since Hurricane Andrew in 1992. Just under 36 hours prior to Charley’s landfall, Tropical Storm Bonnie struck the Florida Panhandle near Apalachicola. Not since 1906 have two hurricanes struck the State of Florida so close together and not since 1886 (in Texas) have four hurricanes made landfall in the same state in one year. (Hurricanes Charley, Frances, Ivan, and Jeanne all hit the State of Florida in 2004.) Additional information on the history of hurricanes in southwest Florida is provided in Appendix E.

CHARLEY: An overview

Total dead in Florida: At least 27

1.4 million people evacuated

Power knocked out to 2 million.

About 1,500 Florida National Guard members were activated and another 5,000 were called up. Federal "State of Emergency" was declared in 25 counties.

Elsewhere:

Cuba: At least four people were killed, and four others injured. At least 41 buildings in Havana collapsed. More than 200,000 people were evacuated in western and central Cuba.

Jamaica: One person was killed. Flooding left some roads impassable and submerged crops in the southern agricultural region.

North Carolina: Relatively little damage was reported, mostly in the northeastern corner of the state, as Charley weakened to a tropical storm. About 104,000 customers lost power, and there were scattered reports of flooded roads, damaged homes, and downed power lines.

South Carolina: Grand Strand resort area was evacuated and nearly emptied of 180,000 tourists and residents. About 65,000 customers lost power, including 32,000 in the Charleston area.

Other customers without electricity by county

Collier	80,000
Highlands	45,000
Brevard	25,000
Sarasota	16,000
Lake	11,498
Flagler	10,000
Hendry	2,000
St. Johns	2,000
Glades	1,000
Hillsborough	300

SOURCES: ESRI, GDT, ASSOCIATED PRESS, NATIONAL HURRICANE CENTER, U.S. CENSUS BUREAU, FLORIDA POWER & LIGHT, TAMPA ELECTRIC, PROGRESS ENERGY, AND THE ORLANDO UTILITIES COMMISSION

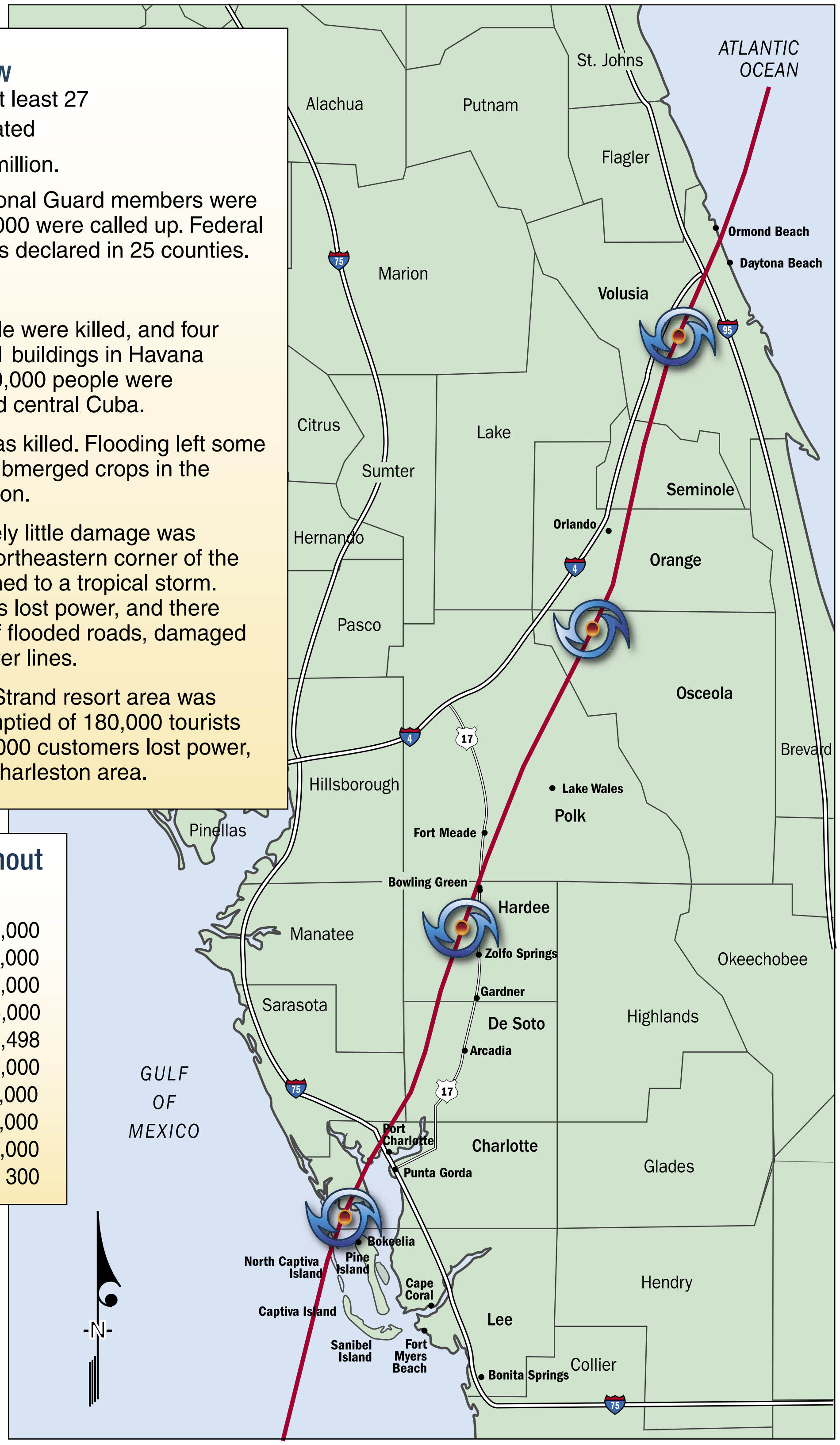


Figure 1-3. Map of Hurricane Charley's path of destruction

Lee County

Population: 440,888

Population 65 and older:..............................112,111

Manufactured (mobile) homes: 23,885

Customers without electricity: 145,000

Fort Myers population: 48,208

Captiva population: 379

Sanibel population: 6,064

1 death

County property appraiser estimated 250,000 building structures, homes, and churches were damaged. Extensive damage was reported on Captiva Island. Mayor of Sanibel Island said bridge to the island would be closed until Lee County officials could assess its engineering and structural integrity. About 20,000 residents of Fort Myers Beach, Captiva Island, and Sanibel Island were prevented from returning home.

Charlotte County

Population: 141,627

Population 65 and older: 49,167

Manufactured (mobile) homes: 6,440

Customers without electricity: 80,000

Charlotte Harbor population: 3,647

Punta Gorda population: 14,344

4 deaths

Sheriff's office and Emergency Operations Center were not operational. Two shelters were slightly damaged. Seven fire stations were heavily damaged. Thirty-one mobile home parks suffered major damage. Three hospitals sustained significant damage. Most schools were damaged, some severely. Punta Gorda and Port Charlotte were without water service.

De Soto County

Population: 32,209

Population 65 and older: 6,113

Manufactured (mobile) homes: 1,200

Customers without electricity: 15,000

Arcadia population: 6,604

1 death

Arcadia was without water service. Partial building collapse at Turner Agri-Civic Center, a hurricane shelter where 1,400 people had gathered.

Hardee County

Population: 26,938

Population 65 and older: 3,750

Manufactured (mobile) homes: 354

Customers without electricity: 2,173

Wauchula population: 4,368

Zolfo Springs population: 1,641

Polk County

Population: 483,924

Population 65 and older: 88,738

Manufactured (mobile) homes: 32,640

Customers without electricity: 96,324

Fort Meade population: 5,691

2 deaths

Osceola County

Population: 172,493

Population 65 and older: 19,709

Manufactured (mobile) homes: 4,854

Customers without electricity: 19,945

Four wells at water treatment plant shut down. Multiple fire stations were damaged. Mandatory curfew from 8 p.m. to 6 a.m.

Orange County

Population: 896,344

Population 65 and older: 89,959

Manufactured (mobile) homes: 14,027

Customers without electricity: 330,391

Orlando population: 185,951

1 death

Roofs were torn off three terminals and two giant glass panels blew in at Orlando International Airport, where more than 1,000 people spent the night, Major theme parks reopened the next day.

Seminole County

Population: 365,196

Population 65 and older: 38,853

Manufactured (mobile) homes: 2,908

Customers without electricity: 20,000

Volusia County

Population: 443,343

Population 65 and older: 97,811

Manufactured (mobile) homes: 20,495

Customers without electricity: 196,136

Daytona Beach population: 64,112

1 death

NOTE: The number of manufactured (mobile) homes in any county comes from the Federation of Mobile Home Owners of Florida and may actually be 10 percent higher to account for the number of owners who do not have to register.

Figure 1-3. Map of Hurricane Charley's path of destruction (continued)

1.2 Comparisons of Predictions and Post-Landfall Estimates: Wind

In order to place damage and windborne debris observations in context, reliable estimates of wind speeds are needed. Unfortunately, no surface level wind speed measurements were obtained that directly support the estimated maximum wind speeds of the hurricane at landfall.[1] For wind speeds to be useful in evaluating damages, it is important to report the wind speed along with the averaging time (sustained vs. gust), the height above ground, and the roughness of the area around the wind speed (expressed as Exposure Category A, B, C, or D, as defined in the Florida Building Code (FBC) and in the American Society of Civil Engineers' (ASCE's) *Minimum Design Loads for Buildings and Other Structures* (ASCE 7). Unless otherwise noted, wind speeds will be reported as 3-second peak gust, Exposure C, over land. (See sidebar.)

Exposure Category

A = Large city centers

B = Urban and suburban terrain

C = Open terrain and open water under hurricane conditions

D = Open water (non-hurricane conditions)

For more information, see Section 1606.18 of the FBC or Section C6 of ASCE 7.

Note: Exposure A was deleted in Section 6 and the associated commentary of the 2002 edition of ASCE 7.

1.2.1 Predictions

Hurricane Charley was upgraded from a Category 2 to a Category 4 storm based on a rapid intensification in winds measured by dropsonde from a U.S. Air Force Reserve/NOAA hurricane hunter aircraft less than 6 hours prior to landfall. The NHC report on Hurricane Charley (NHC, October 2004) lists the minimum control pressure at landfall at 941 millibars and the central pressure near Punta Gorda at 942 millibars in its best track estimates. The final advisories prior to landfall stated that the northeast quadrant of the storm, as is typically the case, contained higher winds and that the areas east of the track of the center of the hurricane could experience these high winds.

1.2.2 Post-Landfall Observations

Hurricane Charley was a very intense, but very narrow hurricane. By the time the hurricane had moved 20 miles inland from the barrier

[1] Doppler radar measurements for these areas may become available, but no indication has been made from the weather services in Florida to indicate that a high-wind measurement was captured with Doppler radar. However, even if such a measurement had been obtained, these readings only measure the component of wind velocity directed toward or away from the radar site. Furthermore, the surface along which the Doppler radar measurements are taken angles upward away from the radar unit so the values typically correspond to elevations well above the height of buildings and structures considered in this study.

islands, the swath of damage to trees and structures was only about 15 miles wide. The MAT is aware of approximately 9 reported tornadoes from this event (NHC, October 2004). The members of the MAT did not observe damage consistent with tornadoes during the course of the assessment. Wind damage was most severe to the east of the path of the center (eye) of the hurricane shown in Figure 1-3.

Because the highest expected wind speeds at landfall were not measured, model-based assessments of wind speeds are the only practical option for estimating actual surface level wind speeds in the areas where MAT investigations were conducted after Hurricane Charley. To date, the best known and most scientifically based estimates of wind speeds available in the public domain are those produced by the NOAA Atlantic Oceanographic and Meteorological Laboratory's Hurricane Research Division (HRD) using a program called H-wind (*Weather and Forecasting*, September 1996.) Past experience with H-wind-based analyses suggests that the model provides reasonably accurate estimates of the maximum wind speeds. The largest differences between measured and predicted values typically occur for lateral distributions of winds and the decay of winds as the storm progresses inland. Contours of sustained, 1-minute wind speeds from the H-wind analysis are shown in Figure 1-4. A second modeling approach that usually produces reasonable estimates of maximum wind speeds and lateral distributions of winds involves the use of wind field based models such as the one in FEMA's Hazards U.S. – Natural Hazard Loss Estimation Methodology (HAZUS-MH) and described in the *Journal of Structural Engineering* (ASCE, October 2000, pp. 1203-1221). The wind field analysis conducted by Applied Research Associates (ARA) using this model, with some adjustments, is shown in Figure 1-5. Despite their totally independent approaches to wind speed estimates, the maximum wind speeds for Hurricane Charley agree within approximately 3 mph between the H-wind and ARA analyses. There are, however, large differences between the locations of the highest winds. The following discussion provides estimates of wind speeds in the various areas visited by the MAT.

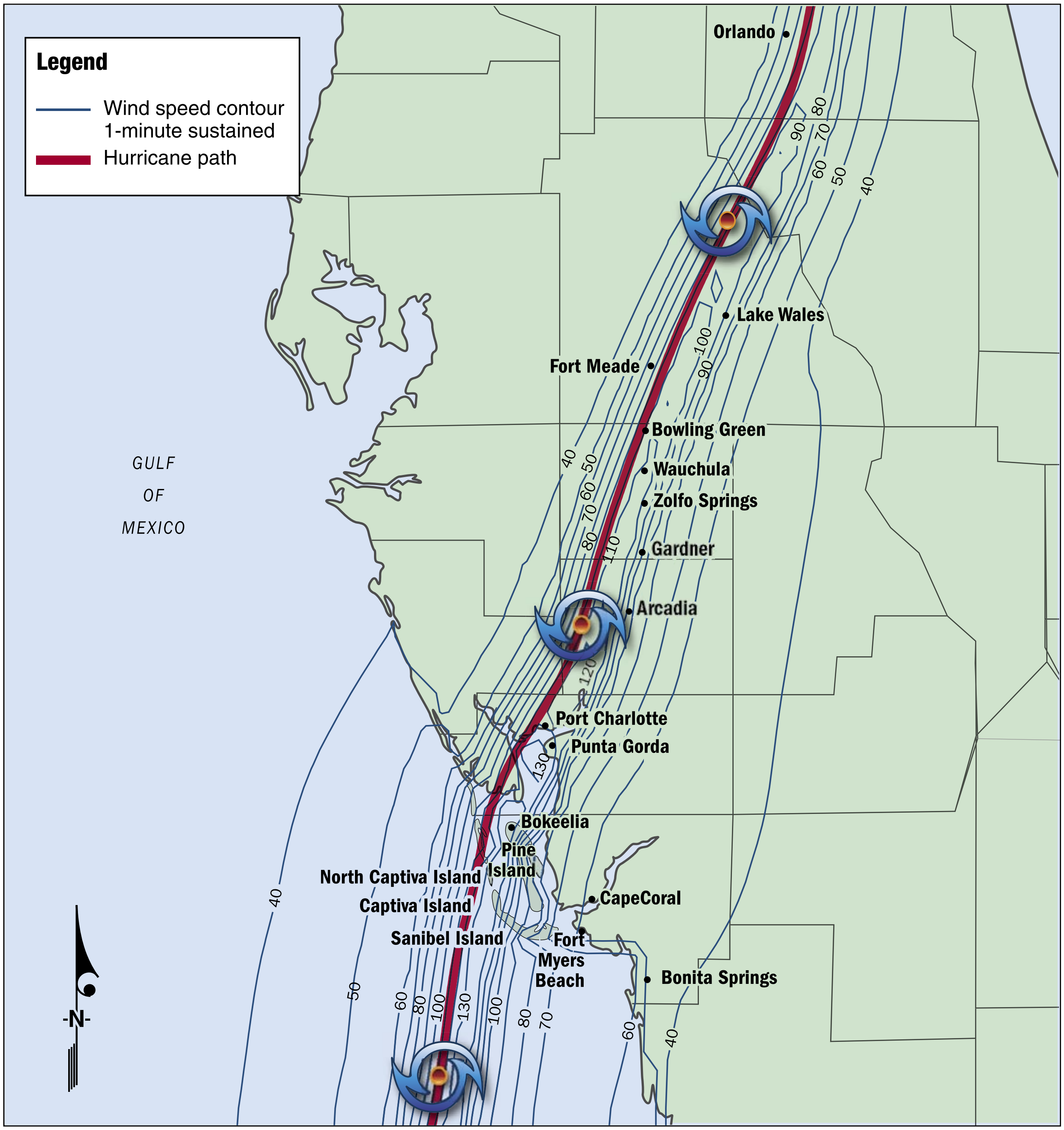


Figure 1-4 Results of the preliminary H-wind swath analysis for Hurricane Charley (NOAA/HRD)

1.2.3 Reported Data

In addition to the wind measurements presented in Section 1.1.1, only very limited reported surface wind data are currently available for Hurricane Charley. The two highest unofficial observations reported by the NHC (NHC, October 2004) are detailed below:

- Table 5 of the NHC report on Hurricane Charley lists a 172-mph gust speed reported from the Charlotte County Medical Center. The anemometer was located on the northwest elevator shaft that extends above the roof of the hospital and was blown off the building during the storm. No written record was available and no wind direction was reported. The medical center staff indicated that the 172-mph wind speed was maintained for some time and should be considered a sustained wind. The NHC, as noted above, reported it as a gust speed. It is possible that the high readings were associated with the failure of the anemometer support and may have reflected accelerated flow around the top of the building. The reported value may be plausible as a gust speed, given the estimated height of the instrument (40 to 50 feet above grade), but is very questionable as a sustained speed.
- Table 5 of the NHC report on Hurricane Charley lists a 160-mph gust speed at the Charlotte County Airport. This site is farther inland than the Charlotte County Medical Center, but at a similar location relative to the track of the storm and is a more open and exposed site. This gust speed is in reasonable agreement with but on the high side of the H-wind and ARA wind field analyses shown in Figures 1-4 and 1-5, respectively, for this distance inland.

1.2.4 Wind Field Estimates – Model-Based Results

Plots of wind speeds estimated using the H-wind and wind field based models are shown in Figures 1-4 and 1-5, respectively. The models suggest 3-second peak gust speeds of 150 to 160 mph or greater occurred at the coast of the barrier island where Charley made landfall. These numbers are a little lower than those suggested by the preliminary H-wind analysis where gust speeds ran 30 percent higher than the sustained wind speeds shown in Figure 1-4 and would be on the order of 160 to 170 mph 3-second peak gust. Center-line path plots of the track of the hurricane shown in Figures 1-4 and 1-5 are based on the data used at the time the models were run. These paths have not been altered to agree because they were prepared by others. The path represented in Figure 1-5 is based on the data provided in the October NHC report and is believed to be the most accurate.

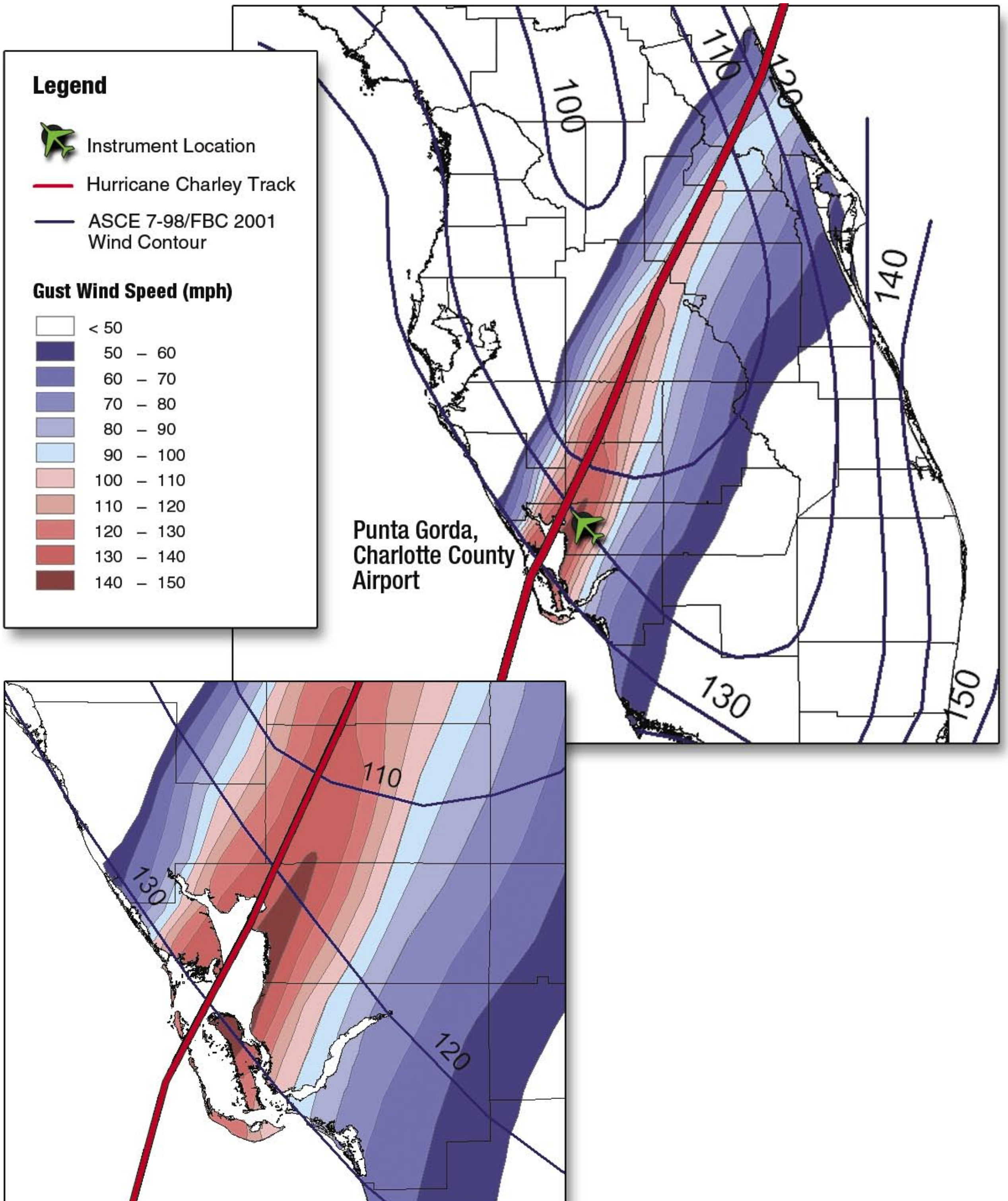


Figure 1-5. Results of the preliminary wind field analysis for Hurricane Charley based on HAZUS-MH wind methodology. The insets provide a close-up of the areas that experienced the highest winds with the design wind speed contour lines from the 2001 FBC overlaid across the wind field. (ARA)

Recognizing the limited information and modeling available at the time this report was prepared, it is possible to only roughly estimate the wind speeds in the various regions surveyed during the MAT. It may never be possible to provide precise estimates of sustained or gust speeds for particular locations. Based on available information, the following estimates are presented by the MAT:

- On Sanibel Island, 3-second peak gust wind speeds likely ranged from 90 mph at the south end of the island to 130 mph toward the northern tip of the island.
- The north end of Captiva Island was subjected to the edge of the eastern side of the eyewall and 3-second peak gust wind speeds were estimated to be between 145 and 155 mph. The built-up northern portion of North Captiva Island experienced the eye of the storm, with strong winds from two radically different directions: easterly winds when it was subjected to the northern eyewall and westerly winds when it was subjected to the southern eyewall. The highest gust wind speeds likely occurred in the region at or below where the cut occurred in North Captiva Island.
- Downtown Punta Gorda (Exposure B terrain – built-up or suburban areas) likely experienced 3-second peak gust wind speeds between 125 and 140 mph and the equivalent Exposure C terrain 3-second peak gust wind speeds would likely have been between 140 and 160 mph.
- Areas of Port Charlotte near Charlotte Harbor and extending northeastward through Deep Creek likely also experienced 3-second peak gust wind speeds between 125 and 140 mph in Exposure B terrain. Properties along the waterfront and in Exposure C terrain located between Charlotte Harbor and Deep Creek likely experienced 3-second peak gust wind speeds as high as 140 to 160 mph.
- In the areas around Arcadia, the 3-second peak gust wind speeds in the hardest hit Exposure B terrain were probably on the order of 110 to 120 mph and Exposure C terrain in the hardest hit areas likely experienced gust wind speeds of 125 to 140 mph.
- Three-second peak gust wind speeds in the hardest hit areas of the cities of Wauchula and Zolfo Springs probably ranged between 100 mph and 115 mph for Exposure B terrain and between 115 mph and 130 mph for Exposure C terrain.
- Three-second peak gust wind speeds in the hardest hit areas around Lake Wales probably ranged between 95 mph and 110 mph for Exposure B terrain and between 110 mph and 125 mph for Exposure C terrain.

- Three-second peak gust wind speeds in the hardest hit areas around Orlando probably ranged between 90 mph and 105 mph for Exposure B terrain and between 105 mph and 120 mph for Exposure C terrain.

Figure 1-4 shows results of the H-wind swath analysis for Hurricane Charley expanded out to show the storm track from Charlotte Harbor to Orlando. This analysis is based on data that were available in real time as the storm approached, struck, and crossed Florida (these data were compiled from NOAA and other agencies using aircraft, buoy, global positioning system (GPS) dropsondes, C-MAN, and surface level anemometer measurements). Generally, when sufficient additional data are retrieved after the storm's passage, a final reanalysis is conducted. Figure 1-4 represents a preliminary analysis of Hurricane Charley, but a final analysis has not yet been conducted. Figure 1-5 shows similar results for maximum gust speeds over open terrain from the ARA wind field analysis. Note that the H-wind values (1-minute sustained) need to be increased by approximately 30 percent before comparing them with the gust values in Figure 1-5.

1.3 Comparisons of Predictions and Post-Landfall Observations: Storm Surge

After every storm event, Federal, state, and research agencies study the forecasts and predictions of the storm event in order to compare them to the actual event. Even as Hurricane Charley was making landfall on the southwest coast of Florida, the NHC and NOAA were updating their predictions with real-time data from the field.

One of the prediction models used by the NHC is the Sea, Lake, and Overland Surges from Hurricanes (SLOSH) model. Storm surge (the abnormal rise of ocean water on land due mainly to strong onshore winds and a decrease in barometric pressure) is primarily forecast with the SLOSH computer model. SLOSH is run by the NHC to estimate storm surge heights resulting from historical, hypothetical, or predicted hurricanes by taking into account five factors: the wind speeds, the central pressure, the size, the forward speed, and the track direction of the hurricane.

The calculations are applied to a specific locale's shoreline, incorporating the unique bay and river configurations, water depths, bridges, roads, and other physical features. If the model is being used to estimate storm surge from a predicted hurricane (as opposed to a hypothetical one), forecast data must be put in the model every 6 hours over a 72-hour period and updated as new forecasts become available.

1.3.1 Predictions

One of the parameters used in SLOSH is the radius of maximum winds (R_{max}); although some report this the same as the radius of the hurricane's eyewall, this is not always the case. Although Charley was over open water, the R_{max} that was being entered into the model had been as high as 40 miles and as low as 12 miles. Because the last advisory was prepared prior to landfall, the NHC had kept the R_{max} value in the model at 12 miles. However, an aircraft penetration of the hurricane's eyewall just after that time found the winds had increased to Category 4 strength and the radius had decreased to approximately 5 nautical miles. As a result, SLOSH runs performed for the final advisories prior to landfall were calculated on R_{max} values from 40 to 12 miles as the eyewall shrank in size, but a final run of the SLOSH model with the actual 5- to 6-mile R_{max} was not done until after landfall.

Figure 1-6 graphically presents the predicted surges for the R_{max} value of 40 miles; surge heights for the barrier islands and the harbors and bays were predicted to be as high as 12 to 18 feet. The maximum storm surges estimated for this storm by the NHC in the hurricane advisories were for the 40-mile R_{max} illustrated in Figure 1-6. These maximum surges were predicted to occur southward along the coast to approximately Bonita Beach for this larger hurricane. These predicted surge elevations are only for this track and this basin; other areas would have different predicted maximum surges.

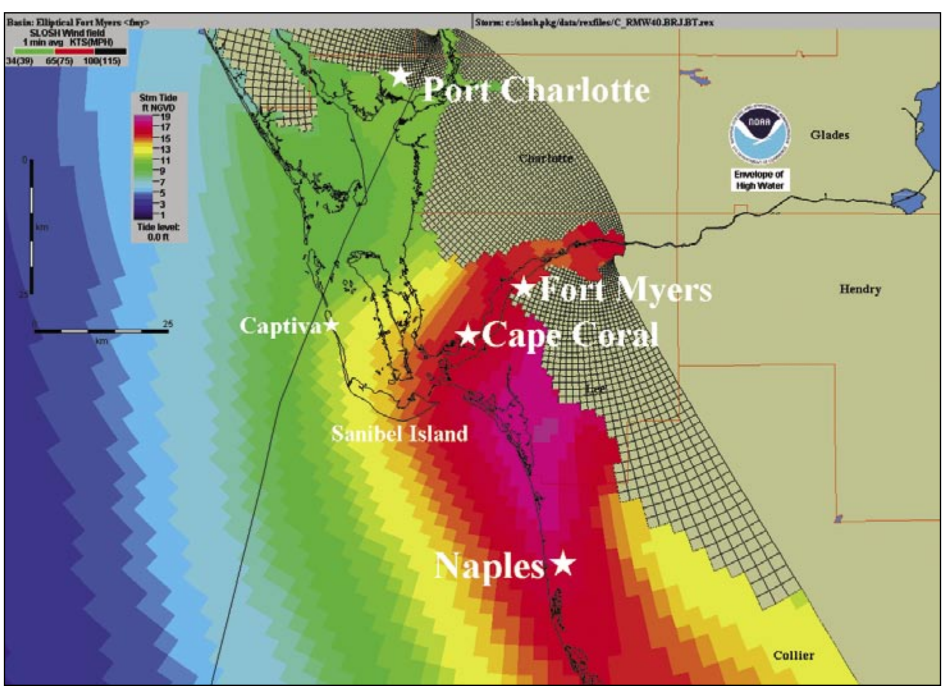


Figure 1-6.
Storm surges computed using the NWS SLOSH model for Hurricane Charley, using R_{max}= 40 miles

(NOAA/NHC)

1.3.2 Post-Landfall Observations

The results of the NHC SLOSH model run with Charley's size and intensity based on the NOAA flight information of an R_{max} = 6 miles (prepared shortly after landfall) are presented in Figure 1-7. As shown, the modeled storm surges reach only 6.7 feet, with values of 5 to 6 feet along the beachfronts of Captiva and Sanibel Islands, and the area from Fort Myers Beach to Bonita Beach.

Storm surge results as predicted by the SLOSH model using the latest data (refer to Figure 1-7) are within the same range as actual high water marks surveyed by FEMA field teams after the storm. This indicates that, although the parameters used in the models are constantly changing, the models are providing realistic values. A more detailed assessment of the Hurricane Charley storm surge will be produced by the NHC as more data are collected. Hurricanes are unpredictable and require constant monitoring to gather real-time data for better model input adjustments and improve surge forecasting.

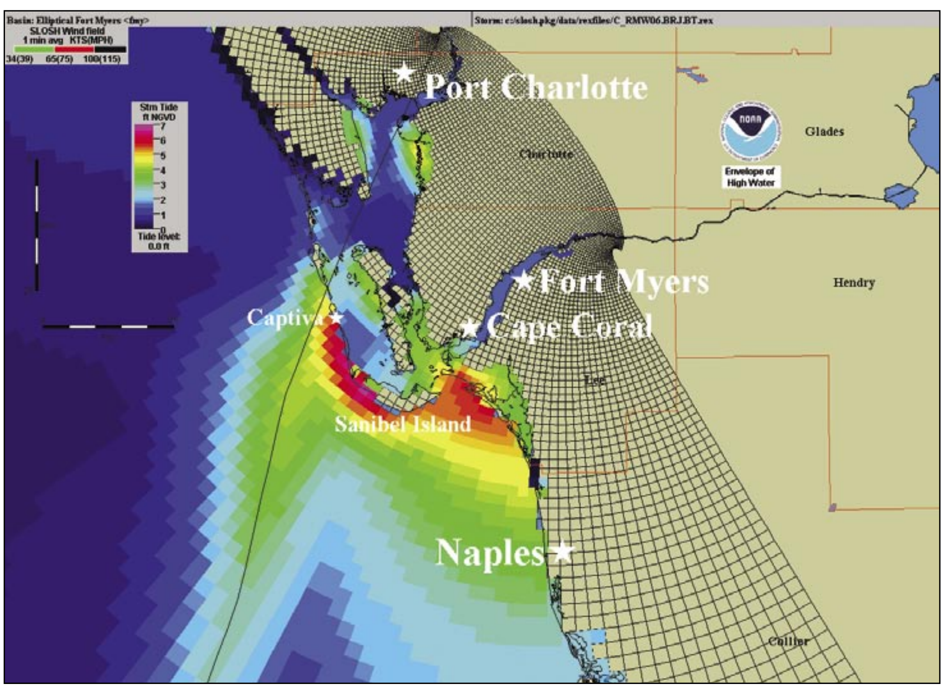


Figure 1-7.
Storm surges computed using the NWS SLOSH model for Hurricane Charley, using R_{max}= 6 miles. The track and intensity remain the same as those in Figure 1-6.

(NOAA/NHC)

1.4 Economic and Social Impacts of Hurricane Charley

Hurricanes can cause economic and social impacts, as well as psychological impacts, that have both short- and long-term effects. These impacts begin at a very personal level with damage to homes and places of employment that affect the lives and livelihoods of individuals and families. Other impacts begin at the community level with loss of function of lifelines and essential facilities such as utilities, police, fire and emergency services, hospitals, schools, and government functions. These impacts can forever alter the fabric of the affected neighborhoods and communities.

1.4.1 Loss Estimates

According to a field report from a National Science Foundation team, the final death toll in Florida was determined to be 27, with $15.4 billion in reported damages and an estimated $6.8 billion in insured losses (ISO, 2004). Table 1-3 presents the ISO and HAZUS-MH loss estimates based on the final storm tracks used by the modelers. It can be seen that the ISO and HAZUS-MH estimates for Hurricanes Charley and Jeanne are very similar, but there are significant differences in the estimates for Hurricanes Frances and Ivan. Initial estimates of industry-wide insured losses have been released by ISO for each of the four hurricanes. Care must be given when directly comparing the ISO estimates with the estimates produced by HAZUS-MH because the ISO estimates include losses for automobiles and boats, appurtenant structure losses, and additional living expenses, yet do not include deductibles or uninsured properties. In spite of these differences, insured loss estimates do provide a useful benchmark for the HAZUS-MH wind loss estimates.

Table 1-3. Summary of Initial ISO Insured Loss Estimates*

Hurricane	Landfall Date	ISO Press Release Date	Initial ISO Insured Loss Estimate ($B)	HAZUS-MH Estimate Based on Final Hurricane Tracks ($B)	States Included
Charley	8/13/04	8/25/04	6.8	7.1	Florida
Frances	9/5/04	9/23/04	4.1	1.8	Florida
Ivan	9/16/04	10/14/04	5.3	1.6	Florida, Alabama, Georgia
Jeanne	9/26/04	10/26/04	2.8	2.8	Florida
2004 Total	**--**	**--**	**18.9**	**13.3**	**--**

*This table was adopted from the internal FEMA report for HAZUS-MH Support for Hurricanes Charley, Frances, Ivan, and Jeanne. Additional information regarding the differences in the lost estimates for Frances and Ivan is presented in that report.

1.4.2 Economic Impacts

From an economic standpoint, jobs and housing are considered two stalwarts of a vibrant economy. Without either, a community cannot thrive. The economic vitality of a community is directly tied to its local businesses that supply goods or services, provide employment, and pay taxes.

Serious aftereffects of a major storm can include temporary or permanent loss of jobs. In addition to businesses being impacted directly after Hurricane Charley because of no power or being heavily damaged or destroyed, the Florida media reported severe impacts to Florida's multi-billion dollar tourism industry.

Florida's $9.1 billion dollar citrus industry was also severely impacted by Charley. The damage caused is the highest since Hurricane Donna in 1960. Approximately 35 percent of the state's citrus groves are located in the prime citrus-growing counties of De Soto, Polk, and Hardee, which saw their trees torn up and their barns and equipment destroyed. This damage has both short-term and long-term effects. The immediate loss is the crop on the trees that was to be harvested beginning in October. The long-term loss is the structural damage to the industry, primarily downed trees that could take years to replace and grow. In addition, consumers across the United States will be impacted by the higher costs of citrus products.

1.4.3 Social and Psychological Impacts

In addition to significant social and psychological impacts resulting from damage to one's home or business, loss of personal belongings, and possible personal trauma, other types of psychological impacts are often felt by communities after a significant hurricane event. These include the impacts of school closures and the price gouging by the service industry that can occur.

School closures. Social and psychological factors may result after a major storm because of school closures and other disruptions to daily life. Schools are mainstays of many communities, and even temporary loss of use can impose difficulties on students, parents, faculty, and the administration during the time a school is not usable. This is illustrated by the following excerpt from The Heinz Center (*Human Links to Coastal Disasters*, 2002):

- "From the standpoint of children and families, after an impact is a particularly bad time for schools to be closed. Damaged homes and neighborhoods are dangerous and depressing places. Children are often left with no safe place to play when yards, playgrounds and recreational programs are lost, no one to play with when playmates and friends are forced to dislocate and parents are too busy dealing with survival and rebuilding issues to have much time for them.
- The closing of a local school is highly disruptive to social networks and, if it becomes permanent, can rob a neighborhood of its identity and cohesion. One of the most dramatic effects that can occur to a severely impacted community is when a school is closed for a long time, maybe even permanently, due to regional depopulation after homes are destroyed.
- Getting schools reopened quickly has been found to be an important step toward rebuilding the community as a whole.
- An understudied area is the long-term effect of major disasters on the education and development of children.
- The shock of being uprooted and moved to a new school, even temporarily, can be very difficult for children. The effects can be particularly traumatic if they occur at a critical developmental time, such as the senior year with its preparation for college and graduation festivities."

Price gouging. Home and business owners can be taken advantage of by unscrupulous contractors. The State of Florida is very proactive in trying to protect its citizens. The Department of Agriculture and Consumer Services oversees a program where homeowners can report incidents of price gouging (http://www.doacs.state.fl.us). In the aftermath of a declared natural disaster, state law also elevates instances of price gouging and unlicensed activities to felony status. In addition, the Florida Home Builders Association (FHBA) has set up a Disaster Contractors Network web site (http://www.dcnonline.org/index.cfm) to provide homeowners with information about licensed contractors.

Economic, social, and psychological impacts can result from injuries received during the storm or in the aftermath while home and business owners, as well as contractors, are making repairs. The information contained in this MAT report will help in developing better building standards, which will reduce damages to housing and businesses, allowing people to return to their homes and go back to work sooner after a major event such as Hurricane Charley.

1.5 FEMA Mitigation Assessment Teams (MATS)

Most people know FEMA for its response to disasters and its assistance to the people impacted by storm events. Another important contribution of the agency involves the scientific and engineering studies that it performs before and after disasters to better understand natural and manmade events. These studies of disasters are conducted with the intent of reducing the number of lives lost to these events and to minimize the economic, social, and psychological impacts on the communities where these events occur.

Since Hurricanes Andrew (Florida) and Iniki (Hawaii) in 1992, FEMA has sent MATs to Presidentially Declared Disaster areas to assess damage caused by hurricanes and to provide recommendations to reduce future damage. After a hurricane, part of FEMA's response is to assess and evaluate the type and severity of damages caused by the event and the magnitude of the storm. Based on the preliminary estimates, FEMA will determine the potential need to deploy one or more MATs to observe and assess damage to buildings and structures from the wind, rains, and flooding. These teams are deployed when FEMA believes the findings and recommendations derived from field observations will provide design and construction guidance that will not only improve the disaster resistance of the built environment in the impacted state or region, but also will be of national significance to all hurricane-prone regions.

1.5.1 Methodology

In response to a request for technical support from the FEMA Disaster Field Office (DFO) in Orlando, FEMA's Mitigation Division deployed a MAT to Florida to assess damages caused by Hurricane Charley. Field investigations to assess building conditions in selected areas affected by the hurricane began on August 19 and concluded on August 24, 2004. The team assessed damage across the width of the storm track, shown in Figure 1-3, from its landfall near the communities on Sanibel and Captiva Islands to inland areas around Orlando. The MAT visited the following towns: Port Charlotte, Punta Gorda, Punta Gorda Isles, Sanibel Island, Captiva Island, North Captiva Island, Fort Myers Beach, Bokeelia/Pine Island, Cape Coral, Arcadia, Gardner, Zolfo Springs, Wauchula, Bowling Green, Fort Meade, Lake Wales, and Orlando.

Single- and multi-family buildings, manufactured housing, and commercial and industrial properties were assessed to determine areas of success or failure as a result of Hurricane Charley. In addition, critical and essential facilities, such as Emergency Operations Centers (EOCs), fire and police stations, hospitals, schools, and storm shelters were also observed to document damage as well as loss of function from this storm. Documentation of observations is presented in this report and in the included photographs and illustrations to relate successes and failures with expected performance in the wind field and surge areas produced by Charley. Conclusions and recommendations, based on the findings of the MAT, that will assist Florida and all hurricane-prone states are provided in Chapters 7 and 8, respectively.

1.5.2 Team Composition

The MAT included FEMA Headquarters and Regional Office engineers and experts from the design and construction industry. Team members from FEMA's database of national experts included structural engineers, architects, wind engineers, civil engineers, a coastal scientist, a technical writer, and building code experts. In addition, representatives from the National Association of Home Builders (NAHB), Institute of Building & Home Safety (IBHS), and National Fire Protection Association (NFPA) also participated on the team.

1.5.3 The Significance of Hurricane Charley

The State of Florida has over 1,300 miles of coastline, thousands of lakes, and hundreds of miles of rivers and is highly prone to hurricanes. Since the devastation caused by Hurricane Andrew, Florida has developed and adopted a state-wide building code, the 2001 Florida Building Code (FBC), which revised the design wind speed map to be used across the state for both residential and commercial construction and provided codified guidance for the protection of buildings from windborne debris. The 1999 edition of the Standard Building Code (SBC) was used as the foundation of the 2001 FBC, both of which based their wind-related requirements on the 1998 edition of ASCE 7, *Minimum Design Loads for Buildings and Other Structures*. The SBC is no longer published; instead, there are three national model codes available to adopting jurisdictions – the International Building Code (IBC), the International Residential Code (IRC), and the NFPA 5000, *Building Construction and Safety Code*. Their wind and debris requirements, in turn, are based upon the provisions specified in later editions of ASCE 7. In fact, since the development of the 2001 FBC, ASCE 7 has been revised twice – once in 2002 and again in 2005.

In addition, the U.S. Department of Housing and Urban Development (HUD) developed a set of high-wind standards for manufactured housing units that were adopted in 1994. The 1994 HUD standards for high-wind regions (wind Zones II and III) use a modified version of the wind load provisions of the 1988 ASCE 7 Standard. Wind Zone III homes would be required near the coast in the Punta Gorda area, but wind Zone II homes would be required roughly inland of Interstate 75. Although HUD sets the standards for design of the manufactured housing units, the states control the installation of the homes using either state rules or manufacturers' recommendations. It was clear that the newer manufactured homes in the Port Charlotte and Punta Gorda areas were being installed using the much closer anchor spacing of 5 feet 4 inches on center per the revised standards rather than the 8 feet on center spacing used on older homes.

Because Florida is so vulnerable to hurricanes, but also proactive in supporting better building codes, the MAT was tasked to develop an understanding of the performance of the building stock, both new (built to the 2001 FBC) and old (built to the SBC) in areas impacted by Hurricane Charley. Specifically, the MAT wanted to assess the performance of various types of buildings, including residential, commercial, and critical/essential facilities in order to understand how building code standards affected performance of the buildings for an event that can be classified as a "code event" near where the storm made landfall.

2

Codes, Standards, and Regulations

Codes, standards, and regulations are adopted and enforced to regulate the construction of buildings. In Florida, the Standard Building Code (SBC, published by Southern Building Code Congress International, Inc., [SBCCI] with local amendments) and the South Florida Building Code (SFBC) were used to regulate construction in Florida until early 2002.

By March 2002, the 2001 Edition of the Florida Building Code (FBC) had been adopted statewide. Currently, Florida is moving to adopt the International Building Code (IBC) and the International Residential Code (IRC) with amendments that retain the more stringent requirements of the 2001 FBC. This new code will be called the 2004 Edition of the Florida Building Code. In December 2004, the Florida Building Commission completed the 2004 Edition and will adopt the new code by administrative rule on July 1, 2005. Additional state and Federal standards govern the design and construction of other buildings and structures, such as manufactured housing, and these regulations are also discussed herein.

2.1 The Building Codes

The FBC is administered by the Florida Building Commission and governs the design and construction of residential and non-residential (commercial, industrial, critical/essential, etc.) buildings in Florida. The 2001 FBC (effective in March 2002) is the applicable building code for the State of Florida. Charlotte, Lee, and De Soto Counties experienced the heaviest damage during Hurricane Charley, with damaged buildings also observed in Hardee and Osceola Counties. Prior to the adoption of the 2001 FBC, these counties used the 1997 Edition of the SBC. It is important to note that the majority of the existing buildings and structures in these counties were built under the SBC.

Both the SBC and the 2001 FBC specify higher wind speeds for areas that are closer to the ocean or gulf, and lower wind speeds for the inland areas. The methodology required for calculating wind loads in the FBC are those prescribed in Chapter 6 of ASCE 7 (with exceptions). These exceptions include the SBCCI document SSTD-10, *Standard for Hurricane Resistant Construction*, as well as other wood and masonry association prescriptive design guides that may be used for residential construction when specific criteria in Section 1606.1.8 of the FBC are met. The acceptance of ASCE 7-98 as the methodology for calculating design wind pressures was an important step for the Florida Building Commission. Using ASCE 7 for determination of wind loads ensures that designers are using current methodology in wind load analysis to calculate wind loads. Design guides and standards, such as SBCCI's SSTD-10, *Standard for Hurricane Resistant Construction,* are currently being updated and will also be based on the methodologies of ASCE 7.

Furthermore, the 2001 (and recently completed 2004) FBC instituted improved design requirements for components and cladding (such as roof coverings), and for debris impact criteria that were not previously required by the SBC. The combination of the wind load determination process of ASCE 7, the new requirements for components and cladding, and the debris impact criteria for glazing systems provided immediate mitigation successes during Hurricane Charley. Most newer homes and commercial buildings designed and constructed to the 2001 FBC were observed to have performed well and sustained only minimal damage during this hurricane event. These results are in contrast to the variety of damages observed in the older building stock that often varied from roof covering and cladding damage, to roof structural failures, to partial structural collapse of the primary load-bearing system.

2.1.1 Comparing Design Wind Speeds

When comparing the SBC, the FBC, and ASCE 7 in hurricane-prone regions, there are three notable differences that have evolved in these codes and standards that will affect the performance of buildings. These differences are:

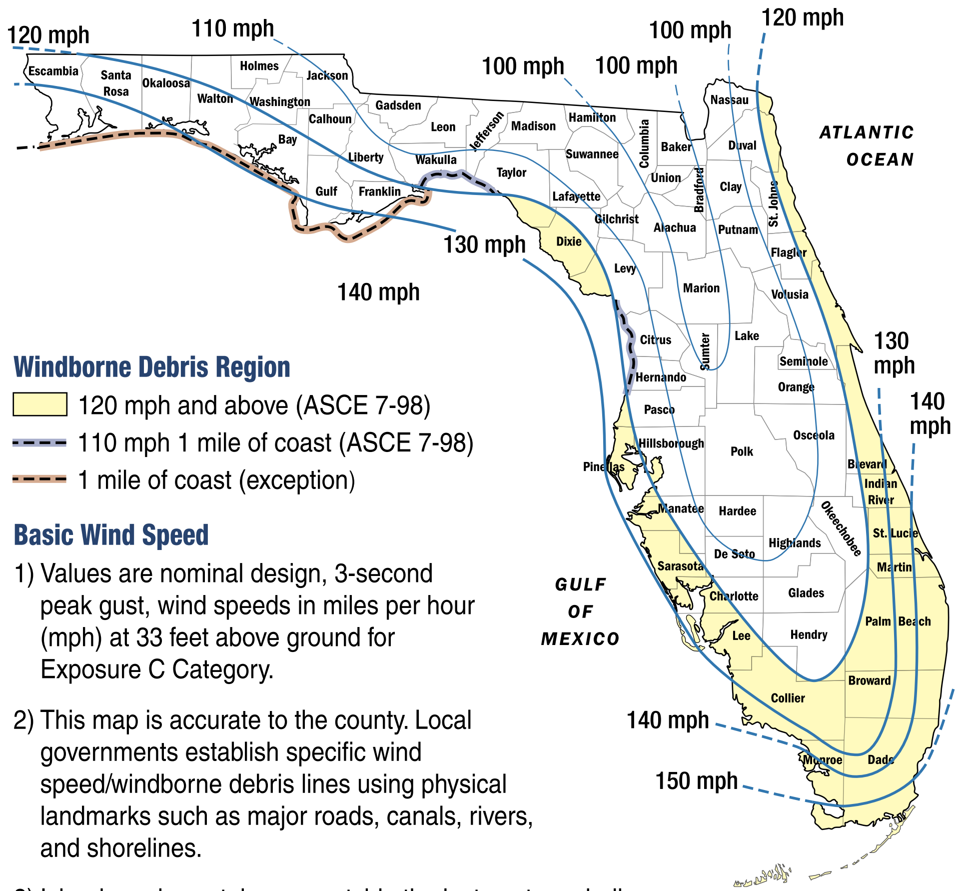
- The design wind speed (and the averaging time of the wind speed)
- How and where pressures are calculated on a building
- Requirements for debris impact protection

Looking at the design wind speed first, current codes and standards, such as the FBC and ASCE 7, standardized the wind speed averaging time as the 3-second peak gust. The wind speed map from the 2001 FBC is presented in Figure 2-1. This is different than the fastest-mile wind speed measure that was previously used by the SBC and ASCE 7. It is also different than the wind speed averaging time of 1-minute used in the Saffir-Simpson Hurricane Scale presented in Chapter 1.

As a result, comparing wind speeds from different codes or from NWS hurricane forecast advisories can be confusing and can lead to improper classifications of wind speeds and wind-related damage. When designing for high winds, it is important to ensure that the appropriate wind speed for the area has been selected and the proper methodology from the code has been identified. When this is not done, the building may be designed for an inappropriate design wind speed that does not represent the risk at the site (i.e., a design wind speed that is too low). Table 2-1 presents the design wind speeds (in 3-second peak gusts) for the counties heavily impacted by Hurricane Charley for three different codes.

Figure 2-1.
Wind speed and windborne debris region map

(2001 FBC)



Windborne Debris Region

- 120 mph and above (ASCE 7-98)
- 110 mph 1 mile of coast (ASCE 7-98)
- 1 mile of coast (exception)

Basic Wind Speed

1) Values are nominal design, 3-second peak gust, wind speeds in miles per hour (mph) at 33 feet above ground for Exposure C Category.

2) This map is accurate to the county. Local governments establish specific wind speed/windborne debris lines using physical landmarks such as major roads, canals, rivers, and shorelines.

3) Islands and coastal areas outside the last contour shall use the last wind-speed contour of the coastal area.

4) Mountainous terrain, gorges, ocean promontories, and special wind regions shall be examined for unusual wind conditions.

5) Wind speeds are 50 – 100-year peak gusts (ASCE 7-98).

Table 2-1. Basic Design 3-Second Peak Gust Wind Speeds (Ranges for Each County)

County	Standard Building Code 1979 Edition*	Standard Building Code 1997 Edition*	Florida Building Code 2001 Edition and ASCE 7-98
Charlotte	118-128 mph	118-122 mph	114-130 mph
Lee	118-128 mph	118-125 mph	117-130 mph
De Soto	118 mph	118 mph	108-120 mph

Where a range is given; the lower values correspond to the edge of the county farthest from the coast and the higher values correspond to the coastal value or the edge of the county closest to the coast.

The wind speeds shown in Table 2-1 are the nominal design, 3-second peak gust wind speeds at 33 feet above ground for Exposure C Category (open exposure). The SBC used fastest-mile wind speeds; the 2001 FBC uses a 3-second peak gust wind speed. To facilitate the comparison between the two codes, fastest-mile wind speeds provided in the older editions of the SBC Code were converted into 3-second peak gust wind speeds to compare with the FBC.

def-ə-

Exposure is the term used in the Florida Building Code and ASCE 7 to define the roughness of the ground surface around a particular building site. Selection of the correct Exposure Category is an important step with the wind load determination process that can alter design wind pressures by more than 15 percent across the building. See Section 1606.1.8 of the Florida Building Code or Chapter 6 of ASCE 7 for definitions of the Exposure Categories.

2.1.2 Comparing Calculated Wind Pressures (Old vs. New Code Methods)

A general comparison of the wind design requirements of these codes for a few select buildings was made to evaluate the effects of the change in the building code as it relates to the wind loads. A summary of the building codes comparison is presented herein.

In order to calculate the wind pressures acting on a particular structure or building components as a result of the design wind speed, various factors are specified in the different codes that play an important role in establishing the design wind pressures. These factors affect how the wind speed is adjusted for conditions at the site and how the wind is affected by the shape of the building. Some of the factors that affect the wind at the site are the importance factor (I) and Exposure Category (see text box above). The importance factor is used to increase the recurrence interval of the design wind; as a result, calculated wind pressures may increase or decrease if buildings are assigned an importance factor other than 1.0. Factors that consider the shape of the building are also used. These factors, often called pressure coefficients, are assigned to different surfaces of the building (e.g., windward or leeward side) and affect the wind pressures calculated for these surfaces. Typically, different coefficients are used on the different building surfaces and are dependent on the direction of the wind. These coefficients are then used when calculating wind pressures that put forces on the main structural system of a building (main wind force resisting system [MWFRS]) and on roof coverings, awnings, windows, and doors (components and cladding [C&C] systems).

Considering the information provided in these codes, a limited comparison of the design wind loads was performed for a typical single-family residence located in the center of Port Charlotte (Exposure B) and a critical/essential facility (e.g., a small one- and two-story fire and police station) also located in the center of Port Charlotte (Exposure B). Tables 2-2 and 2-3 are summaries of the comparisons, respectively.

These tables illustrate how the design wind speed and design wind pressure calculations have changed over the past 30 years as the wind/building interaction has become better understood.

The comparisons indicate that the buildings designed and constructed in accordance with the wind provisions of the 2001 FBC should sustain less damage than the buildings constructed in accordance with the SBC. The ability of the buildings to resist wind loads and resist damage is further improved in new buildings by the stricter components and cladding design requirements now specified in the 2001 FBC. Additional improvements will occur with the implementation of the 2004 FBC.

Table 2-2. Typical Single-Family Residence in Port Charlotte

Description	Standard Building Code 1979 Edition[1,2,3]	Standard Building Code 1997 Edition[1,2,3]	Florida Building Code 2001 Edition, also ASCE 7-98[1,2]	Percent Increase 1979 SBC to 2001 FBC	Percent Increase 1997 SBC to 2001 FBC
Basic wind design speed	105 mph	100 mph	125 mph		
Equivalent wind speed (3–second peak gust)	125 mph	120 mph	125 mph		
Wind design pressures on exterior walls					
As main frame					
edge	18 / –16 psf	22 / –19 psf	24 / –21 psf	33% / 31%	9% /10%
middle	18 / –16 psf	16 / –14 psf	17 / –15 psf	–5% / –6%	6% / 7%
net edge	30 psf	34 psf	34 psf	13%	0%
net middle	30 psf	22 psf	23 psf	–23%	5%
As C & C					
middle	25 / –25 psf	27 / –27 psf	28 / –31 psf	12% / 24%	4% / 15%
corner	25 / –25 psf	27 / –31 psf	28 / –38 psf	12% / 52%	4% / 23%
Wind design pressures on roof (4 in 12 slope)					
As main frame					
windward edge	–23 psf	–28 psf	–30 psf	30%	7%
leeward edge	–17 psf	–20 psf	–21 psf	24%	5%
windward middle	–23 psf	–20 psf	–21 psf	–9%	5%
leeward middle	–17 psf	–15 psf	–16 psf	–6%	7%
As C & C					
middle	–21 psf	16 / –24 psf	16 / –26 psf	-- / 24%	0% / 8%
corner	–21 psf	16 / –55 psf	16 / –54 psf	-- / 162%	0% / –2%

Table 2-3. Typical Critical/Essential Facility in Port Charlotte

Description	Standard Building Code 1979 Edition[1,2,3]	Standard Building Code 1997 Edition[1,2,3]	Florida Building Code 2001 Edition, also ASCE 7-98[1,2]	Percent Increase 1979 SBC to 2001 FBC	Percent Increase 1997 SBC to 2001 FBC
Basic wind design speed	105 mph	100 mph	125 mph		
Equivalent wind speed (3–second peak gust)	125 mph	120 mph	125 mph		
Wind design pressures on exterior walls					
As main frame					
edge	18 / –16 psf	21 / –16 psf	21 / –17 psf	17% / 6%	0% / 6%
middle	18 / –16 psf	15 / –13 psf	16 / –13 psf	–11% / –19%	7% / 0%
net edge	30 psf	28 psf	29 psf	–3%	4%
net middle	30 psf	19 psf	19 psf	–37%	0%
As C & C					
middle	25 / –25 psf	31 / –31 psf	32 / –35 psf	28% / 40%	3% / 13%
corner	25 / –25 psf	31 / –35 psf	32 / –43 psf	28% / 72%	3% / 23%
Wind design pressures on roof (4 in 12 slope)					
As main frame					
windward edge	–23 psf	–33 psf	–34 psf	48%	3%
leeward edge	–17 psf	–23 psf	–24 psf	41%	4%
windward middle	–23 psf	–19 psf	–19 psf	–17%	0%
leeward middle	–17 psf	–15 psf	–15 psf	–12%	0%
As C & C					
middle	–21 psf	12 / –31 psf	13 / –32 psf	-- / 52%	8% / 3%
corner	–21 psf	12 / –68 psf	13 / –82 psf	-- / 290%	8% / 21%

Notes for Tables 2-2 and 2-3:

1 The pressure calculations under each code for both main frame and components and cladding (C&C) were calculated using building design coefficients in wind zones that provide the maximum wind pressure for any area on that building surface.

2 Positive value pressures indicate pressures acting inward toward building surfaces. Negative value pressures indicate pressures acting outward from building surfaces.

3 Pressures calculated from the 1979 and 1997 SBC were calculated using their appropriate fastest-mile wind speed and design methods in the code that was in effect at the time. The 3-second peak gust wind speed is shown for comparative purposes only and was not used in the calculation of the design wind pressures.

mph = miles per hour

psf = pounds per square foot

net edge = the net pressure contributing to the shear force for the wall edge strips; equal to the sum of the external pressures from edge wall Zones 1E and 4E (see ASCE 7 Figure 6-4; internal pressures cancel).

net middle = the net pressure contributing to the shear force for the interior wall zone; equal to the sum of the external pressures from wall Zones 1 and 4 (see ASCE Figure 6-4; internal pressures cancel).

2.1.3 Comparing Debris Impact Criteria

The FBC instituted debris impact criteria requirements statewide and associated these requirements with design wind speeds across the state. Prior to the FBC, only the South Florida Building Code (with county provisions) identified debris impact criteria affecting the design of buildings for portions of Florida. Examples were the county provisions adopted by Miami-Dade and Broward Counties. The SBC, enforced in the portions of the state not using the South Florida Building Code, did not have debris impact protection requirements. Section 1606.1.5 of the 2001 FBC defines the windborne debris impact region as (refer also to Figure 2-1):

- Areas within 1 mile of the coastal mean high water line where the basic wind speed is 110 mph or greater.
- Areas where the basic wind speed is 120 mph or greater except from the eastern border of Franklin County to the Florida-Alabama line where the region includes areas only within 1 mile of the coast. Note: A detailed discussion of this exception and the coastal damage caused by Hurricane Ivan is presented in FEMA 489, *Hurricane Ivan in Florida and Alabama*.

For the above regions, the FBC provided clear guidance on design considerations in the windborne debris regions. Buildings in the windborne debris region were required to protect glazed openings (windows and doors) to ensure that the building envelope would remain "enclosed." To achieve the criteria of "enclosed building" shutters, laminated glass or solid doors were required to be installed. Protection measures were required to resist large or small debris (missiles), depending upon their height on the exterior of a building. An exemption was provided for residential construction in the Florida statutes permitting unprotected glazing if the building was designed and constructed to account for internal pressures (Section 2.2). If windows and doors are not protected, they may be damaged such that they allow wind into a building or structure. When this occurs, the building typically experiences higher wind loads. The code identifies a methodology to account for this by designing for the effect of the wind entering the building through the openings. This process designs for internal pressures within the building and typically results in structures that have the ability to resist higher wind loads, but the structural improvements do not improve the ability of the building to keep out the wind and water associated with the storm. Additional guidance on the windborne debris region and the debris impact criteria is provided in FBC Section 1606.1.4. Windborne debris criteria were added to the 1995 edition of ASCE. Those criteria have been modified in subsequent editions.

2.1.4 High-Wind Elements of the Code

The 2001 FBC has special and stringent requirements for "High Velocity Hurricane Zones" (HVHZs). Sections 1611-1616 in the FBC define wind and debris requirements of HVHZs. Only Miami-Dade and Broward Counties are included in the HVHZ areas.

The HVHZs affect the design and construction of buildings by requiring building elements other than just the structural system to be designed for the code specified wind speeds. In the HVHZs, the design of specific building components, attachments, and equipment must also be designed for the code specified wind speed. The difference in design pressure is often substantial and results in much stronger main structure and components design values for buildings. Many other requirements (e.g., mandatory inspections, Exposure Category, allowable stress increase, requirements for windborne debris, inspections during construction, product approval requirements, etc.) make HVHZ design and construction substantially stronger than in other areas. Buildings built according to HVHZ requirements have greater capacity to withstand hurricanes and provide additional safety for life and property protection.

As shown in Tables 2-2 and 2-3, the conversion from the 1997 SBC Code to the 2001 FBC has increased the design loads for buildings in the non-HVHZs. However, hurricane events in August and September 2004 have shown that, with respect to building mainframes, C&C, and rooftop equipment issues, many areas of Florida may benefit from incorporating some of the HVHZ requirements into the non-HVHZ areas. Observations related to specific examples of damage observed and the sections of the HVHZ criteria that would help resist the types of damage noted by the MAT are presented in Chapters 5, 7, and 8.

2.2 Florida Statutes Affecting Building Design

In addition to the FBC, there are legislative statutes in Florida that affect design and construction. These statutes are found in Ch. 553.71 and Ch. 2000-141 of the *Laws of Florida* and are presented herein to assist in understanding the design and construction process in Florida. Discussions regarding the use of these statutes as part of the design and construction process are presented in Chapters 7 and 8.

The following statutes address wind loads and windborne debris protection. The Florida Legislature mandated several items. The first mandate relates to the wind load provisions of ASCE 7-98:

"(3) For areas of the state not within the high velocity hurricane zone, the commission shall adopt, pursuant to s. 553.73, Florida Statutes, the wind protection requirements of the American Society of Civil Engineers, Standard 7, 1998 edition as implemented by the International Building Code, 2000 edition, and as modified by the commission in its February 15, 2000, adoption of the Florida Building Code for rule adoption by reference in Rule 9B-3.047, Florida Administrative Code." [Section 109(3), Ch. 2000-141, *Laws of Florida*]

Continuing with (3) above, the Florida statute identifies a modification to the windborne debris regions of ASCE 7-98 as follows:

"(3) …However, from the eastern border of Franklin County to the Florida-Alabama line, only land within 1 mile of the coast shall be subject to the windborne-debris requirements adopted by the commission. The exact location of wind speed lines shall be established by local ordinance, using recognized physical landmarks such as major roads, canals, rivers, and lake shores, wherever possible. Buildings constructed in the windborne debris region must be either designed for internal pressures that may result inside a building when a window or door is broken or a hole is created in its walls or roof by large debris, or be designed with protected openings. Except in the high velocity hurricane zone, local governments may not prohibit the option of designing buildings to resist internal pressures." [Section 109(3), Ch. 2000-141, *Laws of Florida*]

Lastly, the Florida statute modified the definition of Exposure C as follows:

"(10) 'Exposure category C' means, except in the high velocity hurricane zone, that area which lies within 1,500 feet of the coastal construction control line, or within 1,500 feet of the mean high tide line, whichever is less. On barrier islands, exposure category C shall be applicable in the coastal building zone set forth in s. 161.55(5)." [Ch. 553.71(10), F.S.]

2.3 HUD Manufactured Housing Design Standards

The design and construction of manufactured homes have been governed at the Federal level by HUD since the National Manufactured Housing and Construction Safety Standards Act was passed in 1974.

Beginning in 1976, the Manufactured Home Construction and Safety Standards, 24 Code of Federal Regulations (CFR) 3280, established the minimum requirements for the construction, design, and performance of a manufactured home. These standards are preemptive over any state or local standard for home construction, provided that the HUD standards cover that aspect of performance of the home. The HUD standards cover body and frame requirements; thermal protection; plumbing; electrical; heating, ventilation, and air conditioning (HVAC); fire safety; and other performance aspects of the home.

Currently, the HUD standards define a manufactured home as a dwelling unit, transportable in one or more sections, that, when erected on site, is of at least 320 square feet in size, with a permanent chassis to assure the initial and continued transportability of the home. In the traveling mode, a manufactured home is 8 feet or more in width or 40 feet or more in length.

In August 1992, when Hurricane Andrew hit southern Florida, over one third of all site-built homes were substantially damaged and almost all manufactured homes were destroyed. As a direct consequence, HUD developed improved wind-resistance requirements for the hurricane-prone coastal areas of the United States. Contained in Final Rule 59 FR 2456 (1994), these changes included defining three separate wind zones – Zone I, Zone II, and Zone III (Figure 2-2).

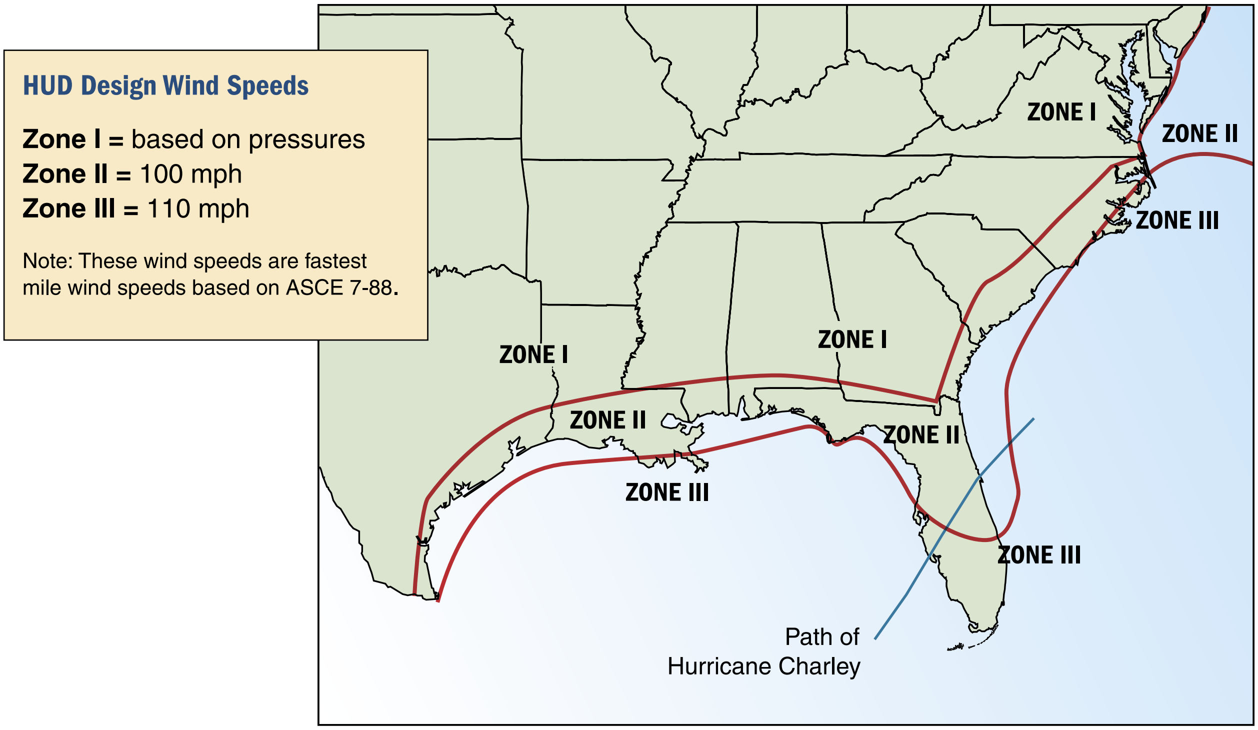


Figure 2-2. Basic wind zone map for the design of manufactured homes

For wind Zones II and III, this rule also designates higher wind loads. Specifically, the updated HUD standard requires that the manufactured home, each of its wind-resisting parts, and its C&C materials be designed by a professional engineer or architect to resist either the design wind loads for Exposure C specified in American National Standards Institute (ANSI)/ASCE 7-88, *Minimum Design Loads for Buildings and Other Structures,* for a 50-year recurrence interval; or a fastest-mile design wind speed of 100 mph, as specified for pressures in the Table of Design Wind Pressures (24 CFR 3280.305).

In addition, the new rule requires that each manufactured home have a support and anchoring or foundation system that, when properly designed and installed, will resist overturning and lateral movement (sliding) of the manufactured home, as imposed by the respective design loads.

Federal, state, and local governments and the manufactured home industry strive to institute construction practices and regulations to increase the safety of manufactured homes in natural hazards environments. The following list summarizes some of the recent regulations that have been passed or are in the process of being developed to improve the resistance of manufactured homes to natural hazards:

- Section 605 of the National Manufactured Housing Construction and Safety Standards Act of 1974 (42 U.S.C. 5401) requires the Secretary of HUD to establish and implement a national manufactured housing installation program by December 27, 2005. This installation program must include: (1) installation standards, (2) the training and licensing of manufactured home installers, and (3) the inspection of manufactured home installations. The HUD program will be implemented in any state that does not have its own program, which includes all three of the previous components, established by state law. Further, to be exempted, a state must have adopted standards that equal or exceed the protection provided by HUD's national manufactured housing installation program. More information on the development of this new program can be found at http://www.hudclips.org.
- The National Fire Protection Association currently maintains three documents on the subject of manufactured housing: (1) NFPA 501, *Standard on Manufactured Housing*, a consensus document on the design and construction of manufactured homes that provides a source for revisions to the Federal regulations (24 CFR 3280); (2) NFPA 501A, *Standard for Fire Safety Criteria for Manufactured Home Installations, Sites and Communities;* and (3) NFPA 225, *Model Manufactured Home Installation Standard*, a consensus document that governs the installation of manufactured homes. Both the 2005 editions of NFPA 501 and NFPA 225 have wind-related requirements based upon ASCE 7-02.
- The HUD program only requires that Zone III units be constructed to receive high-wind shutters to protect openings; there is no requirement to provide window protection in areas where other one-and two-family dwellings are constructed.

2.4 Florida Manufactured Housing Installation Standards

Although the HUD Manufactured Home Construction and Safety Standards, 24 CFR 3280, cover the design and construction of the home itself, it is the local jurisdiction that regulates the installation of the home. In the State of Florida, the Department of Highway Safety and Motor Vehicles has jurisdiction over the installation of manufactured housing. Per the Division of Motor Vehicles, Chapter 15C of the Rules and Regulations of the Florida Administrative Code addresses the requirements for installation, setup, and anchoring the foundation for manufactured homes.

The rules and regulations governing the Bureau of Mobile Home and Recreational Vehicle Construction are contained in Chapter 15C of the Rules and Regulations of the Florida Administrative Code. Some of the code's basic requirements include:

- Before being shipped from the manufacturing plant, all manufactured homes produced for sale in Florida are required to be inspected at the manufacturing plant and cannot be shipped until an appropriate Florida Code Seal has been affixed and validated by the inspector.
- Manufacturers are required to furnish complete printed setup, blocking, and anchoring instructions with each unit.
- The installer, dealer, or manufacturer is required to verify that the necessary permits have been obtained from the local building department.
- Setup of a new manufactured home must be in compliance with the installation instructions that are provided by the manufacturer.
- All work performed at the setup is required to be inspected by the local building official. The Certificate of Occupancy is issued by the local building department only after the department has ascertained that all work performed is in compliance with the applicable rules and regulations.
- All installers must be licensed by the Department of Highway Safety and Motor Vehicles. The installer is authorized to perform all setup operations for the home, including transporting, positioning, blocking, leveling, supporting, tying down, connecting utility systems, making minor adjustments, or assembling multiple or expandable units.
- All manufactured homes shall have support and anchoring at the locations specified in the manufacturer's installation manual for installation in Exposure "D." In the absence of the original manufacturer's installation instructions, the anchoring system shall be designed by a design professional, licensed in the State of Florida.
- Diagonal tie-downs for manufactured homes, in all wind zones, shall be spaced no farther apart than 5 feet 4 inches on center with anchors placed within 2 feet of each end (see also manufacturers' recommendations). In addition, all manufactured homes must

have longitudinal tie-downs or other approved longitudinal stabilizing systems designed to resist horizontal wind loads in the long direction of the home. These longitudinal tie-downs are in addition to the required anchoring systems.

- Additions, including new rooms, roof covers, and porches, are required to be free-standing and self-supporting, with only the flashing attached to the main unit, unless the added unit has been designed to be structurally attached to the existing unit. All additions must be constructed in compliance with state and locally adopted building codes.

It is important to note that, during the MAT assessments for Hurricane Charley, the most significant damage to post-1994 manufactured housing units was caused by failure of attached structures (including new rooms, roof covers, and porches). Typically, the attached structures were directly connected to the manufactured home (not free-standing) and were not capable of withstanding hurricane-force winds. Additional discussion on the performance of manufactured housing is provided in Chapters 3, 4, and 5.

2.5 Floodplain Regulations

The local counties impacted by Hurricane Charley have adopted the laws and regulations of the National Flood Insurance Program (NFIP). The NFIP has identified Special Flood Hazard Areas (SFHAs), which are depicted on the Flood Insurance Rate Maps (FIRMs). The FIRMs provide the base flood elevations (BFEs), which are used to establish minimum floor elevations for buildings in the 100-year flood hazard area. In coastal areas subject to wave action, BFEs include wave height effects. Wave heights greater than 3 feet are shown as Zone VE and require that the lowest horizontal structural member supporting the lowest floor be at or above the BFE.

Charlotte County (which includes Port Charlotte and Punta Gorda) and Lee County (which includes Fort Myers Beach, and Sanibel, Captiva, and North Captiva Islands) entered the NFIP in 1971 and 1984, respectively. The latest effective maps for these areas impacted by Hurricane Charley are dated May 2003.

3

Basic Assessment and Characterization of Damage

The MAT's observations of the type and extent of damage caused by Hurricane Charley's high winds and flooding are broadly presented in this chapter and discussed in detail in Chapters 4, 5, and 6. The majority of building damage observed was due to the effects of wind and windborne debris.

Damage to the structural systems of buildings, including full and partial collapses of buildings, was observed in both residential (site-built and manufactured housing) and commercial (non-residential) buildings. Buildings with severe structural damage were located in the area impacted by a narrow band of wind that tracked the eye of the hurricane from Charlotte Harbor up into De Soto County and were typically older structures; the buildings located along this narrow band experienced wind gusts estimated to be at or above the design wind speeds noted in the current Florida Building Code (2001 FBC). However, most of the observed damage was to the exterior portions of buildings, such as roof coverings, wall coverings, soffits, windows, and doors (elements that are commonly referred to as the building envelope). Additional observed damage was associated with wind-driven rain that entered and damaged building interiors through openings in the building's exterior caused by the failure of an element of the building envelope or attachment.

The MAT also observed damage to elements attached to the buildings, including rooftop equipment, carports, pool screen enclosures, etc. This type of damage was widespread across the impacted area and was observed in both residential and non-residential buildings. Failure of the attached structures and screen enclosures generated significant amounts of debris in areas not considered to be debris-prone regions (i.e., areas in the 2001 FBC where design wind speeds are 120 mph or greater). Damage to the building envelope and attachments also occurred across the area impacted by wind speeds estimated to be at or below the design wind speeds currently identified in the 2001 FBC. This type of damage can be extensive and is often under reported.

Wind speeds are measured and recorded as sustained and gust wind speeds. For consistency, this report defines **sustained wind speeds** as 1-minute average wind speeds and **gust wind speeds** as 3-second peak gust wind speeds.

Flood-induced damage to buildings was observed primarily along the barrier islands west of Charlotte Harbor and in a few instances along tributary rivers. Post-FIRM buildings received minor damage from floodwaters passing below elevated first floors. Pre-FIRM buildings experienced inundation and standing water in areas subjected to storm surge. The MAT observed this type of damage to buildings on the barrier islands of Fort Myers Beach, Sanibel and Captiva Islands, and North Captiva Island.

3.1 Wind Effects

The measured wind data, combined with wind field modeling, along with the observed damage in the field, suggest that Hurricane Charley made landfall as a strong Category 3 or borderline Category 4 hurricane in the Port Charlotte and Punta Gorda area. As the storm moved across Florida, winds decreased, but there was still a continuous narrow wind field containing winds at or above hurricane force (and with higher gusts) that continued across the state until the storm left the coast. Figure 3-1 illustrates the correlation of the estimated wind speed from Hurricane Charley (Figure 1-4) adjusted to 3-second peak gust values with the design wind speed requirements of the 2001 FBC (Figure 2-1) by overlaying the maps. The shaded area in Figure 3-1 represents the impacted areas that likely experienced a code-level event; the requirements of the 2001 FBC for the buildings in this area are shown. Although not all buildings were built to

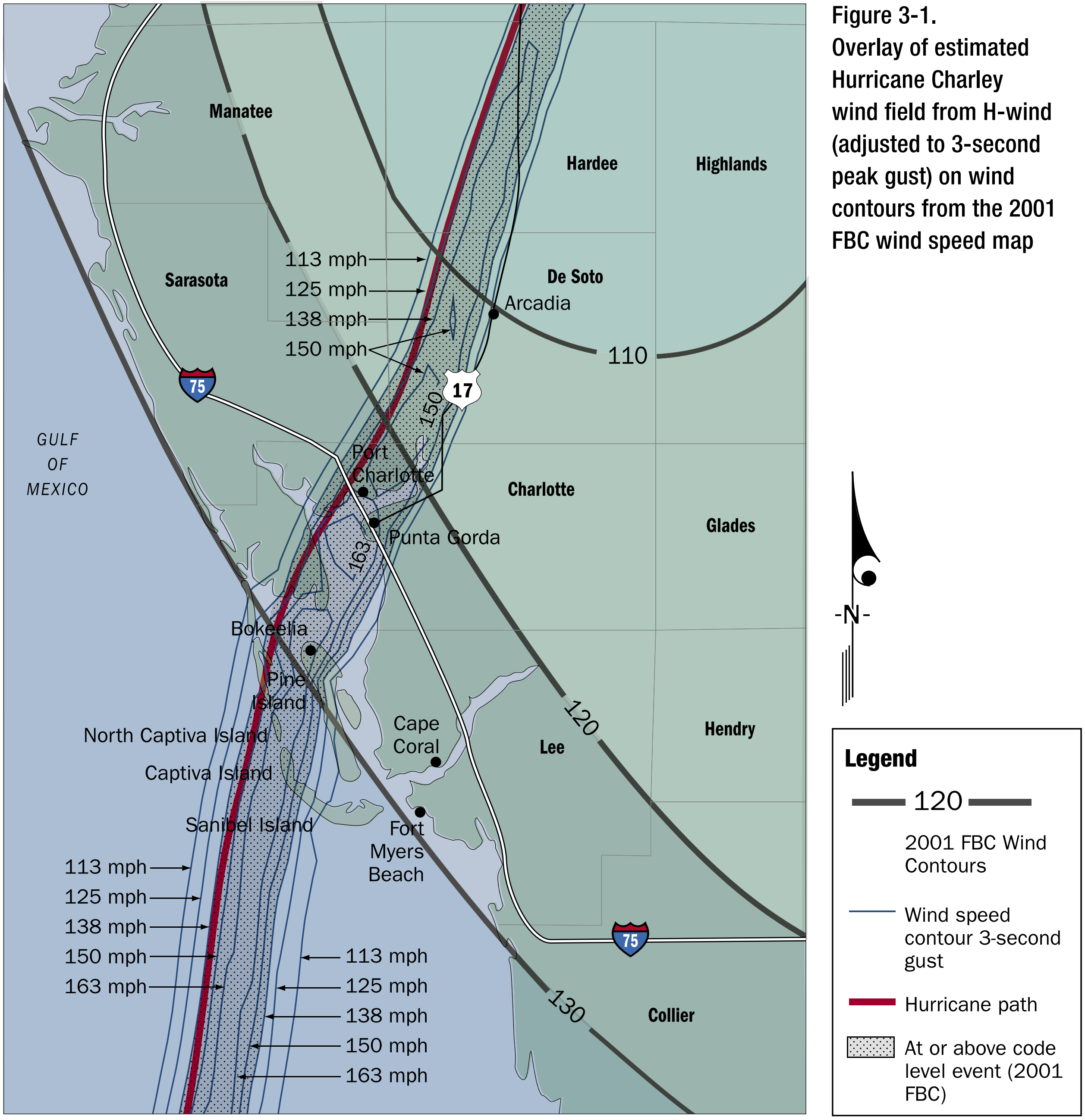


Figure 3-1.
Overlay of estimated Hurricane Charley wind field from H-wind (adjusted to 3-second peak gust) on wind contours from the 2001 FBC wind speed map

the 2001 FBC, Figure 3-1 will assist in relating damage from the wind event to the expected performance of both new and old buildings.

The most severe structural damage and the largest concentrations of building envelope damage were typically observed within 10 to 15 miles of the path of the eye of the storm. Structural damage to older buildings and manufactured homes was common. The most severe structural damage observed was loss of roof structure and some exterior wall failures and collapses. Failures of roof coverings and the detachment of rooftop equipment were observed throughout the areas visited, including, surprisingly, areas that did not experience hurricane-force winds. Soffit failures, which led to water damage, were also observed throughout the entire wind field of the storm. Tree blow-down, including the uprooting of large trees and the fracturing of pine trees, was observed throughout the entire wind swath, including areas experiencing only tropical storm-force winds.

3.1.1 Variability in Hurricane Winds

It is important to note that the actual wind field generated by a hurricane contains variability that is frequently associated with areas of significant convective activity, where stronger winds aloft are brought down toward the surface. Model-based assessments, such as the H-wind and HAZUS-MH models, do not capture that variability. Nevertheless, model-based assessments provide the best estimate of wind speeds in the path of a hurricane because wind instruments are typically spread some distance apart and, as a result, there are relatively little hard data indicating the magnitudes of these variables.

In situations where a large number of wind speed measurement instruments are present, the relative uniformity of measured wind speeds generally matches typical wind field models; this suggests that local variability may not be all that great. However, tree blow-downs and other tracers frequently suggest at least some level of local variation, particularly toward the edges of the storm and in areas where the strongest wind activity is contained within rain bands or convective cells. Thus, there are typically instances of severe damage to buildings outside of high-wind areas that are likely the result of either higher-than-estimated winds (due to variability) or the age and construction type of the buildings. These issues are addressed in this chapter and Chapters 4, 5, and 6.

In addition to actual wind speed measurements taken from permanent and mobile wind recording devices, there are often other opportunities to record wind speed and the effects on buildings and structures. FEMA, the National Institute of Standards and Technology (NIST), and other Federal, state, and industry organizations sponsor building monitoring programs in which residential buildings are supplied with instruments that record wind and air pressure. The intent is to capture full-scale wind/building interaction data to help study and improve the wind design criteria used in building codes. Although a number of instrumented houses were impacted during Hurricanes Frances, Ivan, and Jeanne, none were impacted by Hurricane Charley. As a result, characterizations of damage for this report were made with the best available data on the wind field (Chapter 1), wind pressure data computed after field investigations, and building data obtained during field investigations.

3.1.2 Building Structural Damage Due to Wind Effects

Across the impacted area, older buildings were typically affected more than new buildings. The poor performance of the older buildings was likely the result of a number of factors. The most significant factor is that older buildings were built to building codes less rigorous about building structural issues than the 2001 FBC. As a result, these buildings typically experienced more damage than buildings constructed since the adoption of the 2001 FBC. Another factor that contributed to the observed damage was that older buildings may have suffered from degradation of strength due to corrosion, termites, poor maintenance, or a variety of other factors. Also, design and construction methods and materials used at the time an older building was built may be now considered insufficient for a high-wind area. Finally, where flood damage occurred, the building may have been built at a time when the need for elevation to avoid flooding in that area was not well understood or, if it was understood, was not being enforced or required.

Some examples of the above factors include:

- Design wind loads used were too low, resulting in members and connections too weak for the winds encountered and roof and framing damage occurred as a result
- Fasteners for roof sheathing were too small or were spaced too far apart and led to loss of panels
- Small or missing strapping to anchor the roof structure to the walls led to roof framing damage
- Unreinforced masonry walls lacked a continuous load path and led to wall damage and failure
- Lack of a continuous load path at the connection between the walls to the foundations often resulted in wall and roof collapse
- Structural design that did not account for unprotected glazing, leading to structural failures due to increased internal pressures
- Unprotected glazing, leading to interior damage from wind and wind-driven rain

- Corrosion of ties or fasteners used to attach siding to the wall structure led to loss of wall cladding and water intrusion
- Corrosion of anchors or connectors that attach the building to the foundations or tie structural elements together led to structural collapse in some instances
- Improper elevation of habitable space and utilities relative to flood risks resulted in structural and contents damage
- Degradation of building elements and connections due to material deterioration, insect infestation, or lack of proper preventive maintenance resulted in premature building and envelope system failure

The MAT observed many cases where buildings constructed within the past few years survived the storm relatively unscathed (however, exceptions were noted), while older buildings next door or directly across the street sustained significant damage either due to roof covering loss or rain water intrusion through damaged roof coverings, damaged soffits, and/or broken windows and doors. A return visit to the area 2 months after Hurricane Charley struck Florida reinforced the stark contrast of successes and failures. During this visit, many families were observed living in the lightly damaged or undamaged homes and working from businesses that were lightly damaged or undamaged, while many of their neighbors' homes and businesses were still vacant.

The discussion below presents an overview and categorization of the structural damage observed. A more detailed discussion follows in Chapter 4.

3.1.2.1 Residential Buildings (One- and Two-Family Dwellings, Wood-Frame Multi-Family Buildings, and Manufactured Housing)

The effect of internal pressures from broken doors and windows on the windward side of buildings was an important factor in the structural damage to several homes and multi-family residences, although it was not the cause of all damage observed across the storm path. When a building is not designed for internal pressures or if a window or door is broken (breached) such that wind is allowed to enter the building, the building experiences an increase in loads it was probably not designed to handle.

Figure 3-2 shows a masonry home with a wood roof structure. Failure of the window in the front wall of the house likely led to pressurization of the house and contributed to the dramatic failure of the roof structure.

Figures 3-3 and 3-4 illustrate that installing shutters on a building to protect windows and doors can ensure the envelope is not breached and thus prevents the increase in internal pressure. The condominiums in these photos were located within a few hundred feet of each other at the north end of Captiva Island. The top unit in the building in Figure 3-3 was not protected with shutters, and most of the upper floor framing likely failed due to an increase in wind pressure when windows (and doors) were breached. Conversely, the same type of building constructed two buildings away had shutters to protect the building (Figure 3-4). The shutters protected windows and doors, keeping the building "enclosed," and ensured that the building performed without failure.

Figure 3-2.
Failure of roof structure from pressurization of a pre-2001 FBC house when the window failed on windward face (Punta Gorda)

Figure 3-3.
Loss of roof structure in a wood-frame building likely due to internal pressurization resulting from unprotected windows and doors (Captiva Island)

Figure 3-4.
Nearby undamaged wood-frame building similar to that shown in Figure 3-3 protected with shutters (Captiva Island)

In addition to structural framing damage due to internal pressures, some wood buildings experienced failures due to a lack of continuous load path. Figure 3-5 is an example of a wood-frame structure that experienced a partial wall failure due to a lack of continuous load path. These types of damages were typically limited to areas along the path of the eye and were not typical of damage in areas with estimated wind speeds less than 100 mph (3-second peak gust).

Figure 3-5.
Wall failure on older multi-family wood-frame building due to lack of continuous load path. Internal pressurization may have also contributed to this failure (Fort Myers Beach).

Most one- and two-family homes and multi-family dwellings observed as part of this study were constructed of either reinforced concrete or from concrete masonry units (CMUs). The primary roof structure on these concrete buildings was wood framing or trusses. For these CMU and wood-frame buildings, the most common damage observed was a roof sheathing failure due to inadequate connections to the underlying roof framing. This type of damage was typically observed on older buildings. Other structural failures to wood-frame buildings included a failure of the roof structures (trusses or rafters) at the connections to the top of walls and the collapse of gable end walls. Loss of roof sheathing (decking) was observed where large, improperly secured overhangs were present (Figure 3-6). Other damages to multi-family housing units commonly included damage to wall sheathing at gable ends; this damage occurred near the center of the hurricane's track.

Figure 3-6.
Damage to older multi-family building roof deck with inadequately supported and braced overhang (Captiva Island)

Structural failures to manufactured housing were also observed. Structural damages observed near the path of the eye could be classified as foundation damage, including shifting of the units on the foundations resulting in out of plumb foundations (piers) or complete collapse of the foundation. Figure 3-7 shows a pre-1976 manufactured housing unit completely displaced from its foundation piers. The homeowner of this unit indicated that his unit was retrofitted in the late 1990s during a park-wide mitigation project that installed additional tie-downs such that spacing would not exceed 4 feet. Improper installation of the additional tie-downs and saturated soil likely led to the failures observed. Other structural damages observed to manufactured housing were failures due to wind effects (not related to an attached structure or enclosure). Although these failures were not representative of the performance of all manufactured housing, the post-1994 unit in

Figure 3-7.
Pre-1976 manufactured home unit displaced from its foundation, damaging the structure itself (Pine Island)

Figure 3-8 experienced extensive structural damage from 3-second peak gust winds in excess of the range of 110 to 130 mph.

Figure 3-8. Post-1994 manufactured home with major roof and wall failure (east of Port Charlotte)

3.1.2.2 Commercial and Mixed-Use Buildings

Most buildings observed in this category were either load-bearing wall or frame. Buildings constructed from heavy steel and concrete frames were not observed to have experienced structural failures, although light metal-frame buildings experienced structural damage and failure. Buildings with load-bearing wall construction were typically constructed of either reinforced concrete or CMU wall systems supporting wood or steel frame roof structures. The CMU buildings had walls both with and without reinforcing. Concrete and CMU buildings were the primary type of commercial building observed throughout the damage path, although some wood-frame commercial buildings were also observed.

Concrete and CMU buildings. Damage to concrete and CMU buildings typically included a loss of roof sheathing that was inadequately attached to the roof deck supports or failure of roof framing elements at their connection to the walls. Figure 3-9 illustrates the partial collapse of a wood truss roof system due to loss of roof sheathing and lack of gable bracing. Figure 3-10 also shows wood-frame roof damage and loss of roof sheathing on a masonry structure in addition to damage to an inadequately reinforced masonry gable end wall. In Figure 3-11, the metal roof deck supported on steel joists failed. Field observations of the building shown in Figure 3-11 noted failed welds at the plate connectors used to secure the steel joists to the wall systems. The MAT observed that this type of roof damage to masonry buildings often led to partial or total collapse of walls that were left unsupported when roof systems failed. Unreinforced masonry (URM) construction, insufficient steel reinforcement, or improper grouting in the walls, particularly along the tops of walls and at gable ends, may have also contributed to the damages observed. These types of damages were observed primarily around the Port Charlotte and Punta Gorda areas of Charlotte County with isolated incidences observed along the path of the eye into De Soto, Hardee, and Polk Counties.

Figure 3-9. Example of wood truss roof failure due to sheathing loss and lack of bracing at gable end on a pre-2001 FBC unreinforced masonry building (north of Arcadia)

Figure 3-10.
Roof sheathing and partial failure of wood roof structure on a masonry building. Note damage to inadequately reinforced masonry parapet at gable end wall (Wauchula).

Figure 3-11.
Damage to a pre-2001 FBC masonry building with steel joist roof framing and metal deck (Port Charlotte)

Pre-engineered metal and light-metal frame buildings. Pre-engineered metal and light-metal frame buildings were also observed during the assessment. Most were rectangular buildings with gable ends. The walls of pre-engineered metal and light-metal frame buildings were constructed using steel columns. Lateral bracing was provided by CMU infill walls (with and without reinforcing), by purlins or tension rods, or by the exterior metal panels that clad the exterior of the building.

Structural damage to pre-engineered metal and light-metal frame buildings included the collapses of structural frames (partial and complete) as shown in Figures 3-12 and 3-13. Other damages to pre-engineered metal and light-metal frame buildings observed by the MAT included a partial or complete collapse of gable end walls. Common traits of the observed failures were partial or inadequate lateral bracing of the structural frame, loss of roof and wall panels, and failure of large rolling and sectional doors (e.g., service garage doors and loading dock doors). Panel loss and failure of doors may have contributed to the failures by allowing an increase in internal pressures. Another factor related to the failures of these buildings was the poor condition (i.e., corrosion) of structural members and connections on older buildings.

Figure 3-12.
Pre-engineered metal building with progressive failure and severe panel loss (Arcadia)

Figure 3-13.
Roof framing failure and gable end wall collapse due to insufficient supports of pre-engineered metal building. Note corroded base plate with failed bolts for gable end wall column (Wauchula).

3.1.3 Building Components and Cladding (C&C) Damage Due to Wind Effects

The building envelope is composed of the systems that clad the exterior of a building, including roof coverings, wall coverings, walls, windows, and doors. Designers refer to these systems, along with exterior building mechanical systems and attachments, as C&C. These building envelope systems or C&C were observed to be the areas of buildings that experienced the most damage from Hurricane Charley.

Over the past 20 to 30 years, research has demonstrated that localized pressures affecting the skin of the building can be much larger than originally anticipated. The use of electronic pressure sensors and data acquisition systems that allowed the rapid measurement of wind pressures on scale models in boundary layer wind tunnels have been responsible for much of the dramatic changes in code-based wind load provisions. Better understanding and improved modeling of the gust structure of extra-tropical winds also led to the development of new design coefficients that produce higher required C&C element loads along edges and in the corners of roofs and walls. As a result, the design guidance for C&C loads affecting the design of the building envelope and the design of attachments to buildings has resulted in a significant increase in the design loads for these building components. Questions persist concerning whether these simulations adequately model the gust characteristics of hurricane winds. Nevertheless, the wind load provisions used to design C&C and the attachment of these elements to buildings have changed, and the loads have increased significantly over the past 20 years. These provisions and design requirements were incorporated into later editions of the SBC and ASCE 7, and have always been in the 2001 FBC.

The discussion below presents an overview and categorization of the damage observed to the building envelope. A more detailed discussion follows in Chapter 5.

3.1.3.1 Residential Buildings (One- and Two-Family Dwellings)

The most widespread damage to one- and two-family housing units occurred at or above the roof line and included loss of asphalt shingles or tile roof coverings (Figures 3-14, 3-15, and 3-16). This type of damage was observed across the wind field on both the barrier islands and on the mainland (including inland areas). By contrast, one- and two-family homes with metal roof coverings suffered only minor, if any, damage (Figure 3-17). The metal roof systems most frequently noted to be damaged were those with concealed clips integrated into the seaming process; however, such fastening is not readily visible.

Figure 3-14. Asphalt shingle roof covering damage on a new one-story house. In some areas, the underlayment was also blown away (Deep Creek).

Figure 3-15. Typical asphalt shingle roof covering loss on elevated, two-story house (Captiva Island)

Figure 3-16.
Foam set tile roof covering failure (Punta Gorda)

Figure 3-17.
Typical pile-elevated residence with undamaged metal panel roof (coastal flood zone on Pine Island)

Other damages to one- and two-family housing units included loss of roof sheathing and the consequent partial or total collapse of gable end roof sections (Figures 3-18 and 3-19). The loss of roof sheathing was observed in the areas with the highest winds. This type of damage was not common.

Figure 3-18.
Example of roof decking loss on one-story house (Punta Gorda)

Other observed types of damage to residential buildings were to large roof overhangs, double-entry doors, garage doors, and soffits that were not properly reinforced to resist high-wind pressures. Homeowners repeatedly reported the failure of double-entry doors. These failures typically resulted in the blowout of sliding glass doors and the movement of furniture as wind and rain blew through the home. Figure 3-20 shows a double-entry door that failed; insets show the cracking of the door and the top of the door frame where the latches on the fixed door failed.

Figure 3-19
Partial gable end wall failure with loss of roof shingles (Deep Creek)

Figure 3-20. Double-entry door that failed under wind pressure. Upper inset shows close-up of crack in door frame at top latch. Lower inset shows crack in door emanating from bottom latch (Punta Gorda).

In addition, widespread loss of vinyl and aluminum soffit panels was also observed. These panels were either pulled out by negative wind pressures (suction) or pushed up by positive pressures (Figure 3-21). The damage was not limited to the loss of the windows or doors or loss of the exterior soffit cladding system. Damages to these building envelope components led to wind-driven rain entering the homes and wetting the building interior and the internal wall cavities, and saturating attic insulation and ceilings that sometimes collapsed (Figure 3-22).

Figure 3-21.
Typical elevated wood-frame house with extensive soffit damage (North Captiva Island)

Figure 3-22.
The drywall ceiling in the home shown in Figure 3-21 collapsed after becoming waterlogged and weakened by wind-driven rain that entered through the exterior soffit space. Plywood covers the opening of a window broken by windborne debris after the plastic shutters blew off (North Captiva Island).

3.1.3.2 Commercial and Mixed-Use Buildings (Including Multi-Family)

As with one- and two-family dwellings, the most common type of damage to multi-family housing units occurred at or above the roof line and included the loss of asphalt shingles and tiles, and metal roof coverings and roof decking. Roof covering, underlayment, and deck loss was mostly observed on older structures, but there were notable exceptions, which are discussed in Chapter 5. This type of damage was also observed in other areas affected by the highest winds, such as Captiva Island (Figure 3-23), but was observed less in areas farther inland. Other types of damage to multi-family housing units commonly included damage to wall sheathing at gable ends (Figure 3-24).

Figure 3-23. Roof covering loss. Note dark areas on roof are exposed underlayment (Captiva Island).

Figure 3-24. Vinyl siding wall covering on multi-family building with damage to gable end wall sheathing (Port Charlotte)

Damage to concrete and masonry buildings typically included a loss of roof sheathing that was inadequately attached to the roof or failure of roof framing elements (similar to the damage described in Section 3.1.2.2). In addition to these types of commercial buildings, steel and concrete frame buildings were observed. These robust framed buildings did not experience failure of framing systems or roof decks during Hurricane Charley, but still experienced damage. Wall cladding systems on commercial buildings were damaged across the path of the storm, with the heaviest damage observed along the path of the eye between Charlotte Harbor and De Soto County. Poor performance of wall cladding was observed where URM was used (Figure 3-25) and where exterior insulation and finish systems (EIFSs) were used (Figure 3-26).

Figure 3-25. Example of unreinforced masonry wall and parapet collapse due to breaching of roof (on opposite side of building) (Wauchula)

Figure 3-26.
Example of damage to EIFS wall panels (Punta Gorda)

Damage to windows, doors, and soffits was observed in commercial applications similar to the losses and damages observed in residential construction. Figure 3-27 is a medical office building in Punta Gorda that lost roof decking, suffered damage to EIFS wall coverings, and experienced significant glass breakage.

Figure 3-27.
Structural steel frame building showing loss of roof decking and damage to EIFS wall coverings (Punta Gorda)

In commercial applications, door losses were often more dramatic when the loss was not just to personnel doors, but to large rolling and sectional doors, leading to the pressurization of buildings. As a result, the failure of these doors due to wind loading, as shown in Figure 3-28, often caused significant damage to the buildings and the building envelope itself. This type of damage was observed frequently in essential and critical facilities; further discussion on this type of damage is provided in Chapters 5 and 6. Failure modes, including door panel failure, door track failure, and the door track-to-wall (door buck) attachment failure, are also discussed in Chapters 5 and 6.

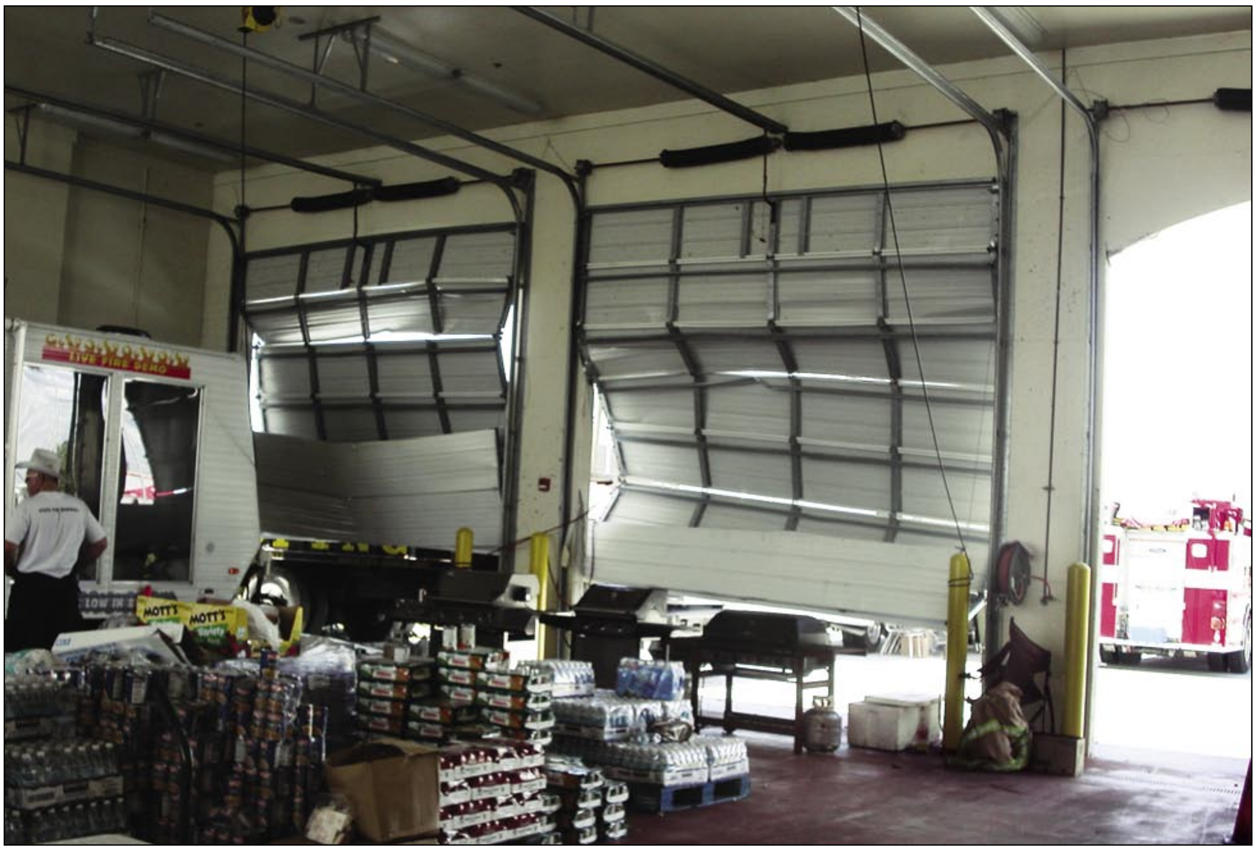


Figure 3-28. Damage to large rolling and sectional doors at Fire Station No. 1 (Punta Gorda)

Other types of damages to commercial buildings observed by the MAT included loss of large awnings and HVAC equipment due to the lack of proper connections (Figure 3-29). This type of damage was observed across the damage path of the storm.

Figure 3-29.
Dislocation of rooftop equipment (Pine Island)

3.1.4 Building Damage Due to Windborne Debris

In addition to damage caused by the wind itself, windborne debris (e.g., missiles) from failed building components and other sources caused damage to surrounding buildings. During a hurricane, the severity of the windborne debris problem and the resulting damage depends on:

- wind speeds
- debris source and elevation of the source
- proximity of the debris source
- weight and rigidity of the debris
- resistance of the debris to release into the wind field
- angle of debris impact

The MAT's observations clearly demonstrated that there were significantly larger numbers of debris missiles and greater windborne debris damage in the areas that experienced the highest wind speeds (e.g., 120 mph or higher, 3-second peak gust). In the Punta Gorda and Port Charlotte areas, where wind speeds were estimated to be between 125 and 130 mph 3-second peak gust, fully one-third of the homes that were not outfitted with shutters experienced at least one broken window (reported by damage assessment teams from the University of Florida and the IBHS) and only one of the houses surveyed that had shutters experienced a broken window. This suggests that, when an area experiences wind speeds at or above 120 mph 3-second peak gust, the damage of unprotected glazings can be significant and that using appropriate laminated glass or shutter systems will be an effective deterrent to such damage. In contrast, very few broken windows were observed in areas where the gust wind speeds were estimated to be less than about 100 mph 3-second peak gust. The 2001 FBC (and ASCE 7 since the 1995 edition) requirements for protection of glazed openings on buildings located in windborne debris regions are:

- where the basic design wind speed is greater than 120 mph 3-second peak gust, or
- within 1 mile of the coast where the design wind speed is greater than 110 mph 3-second peak gust.

Unfortunately, damage from windborne debris will remain an issue during hurricanes even if all glazings are protected. Significant amounts of debris were generated in the areas that experienced winds less than 100 mph when poorly constructed or non-engineered enclosures, pool screens, carports, and attached structures could not withstand the hurricane winds. Adequately protecting buildings from windborne debris, as required by code, is a sound building practice. Use of the 120-mph wind contour line to require glazing protection on buildings was supported by the extensive damage to glazing systems along the eye's path. However, as discussed in Section 5.2, glazing damage was documented in areas that experienced speeds well below 120 mph. An example of shutters performing as designed is shown in Figure 3-30.

Figure 3-30. Newer house with storm shutters (Sanibel Island)

Windborne debris released from the roofs of buildings traveled farther than that released from the ground and was a more serious threat. Heavier, rigid debris, such as roof tiles, flew long distances and typically caused more damage than debris that rolled along the ground. Significant damage was frequently observed in areas where clay and concrete tiles were used as roof coverings and in neighborhoods where the building began to fail and wood structural members were released as missiles. Although a number of buildings with mortar-set tiles lost significant numbers of tile (Figure 3-31), many landed a relatively short distance from the building. These shorter transport distances are attributed to the fact that many of the tiles were so poorly attached that they blew off under moderate wind speeds. Tiles and other building elements that were better anchored, but subsequently failed during periods of higher winds, were transported greater distances and frequently attained greater velocities. Figure 3-32 shows the impact of a roof tile that punctured a Miami-Dade County-approved shutter and broke the window. Although this shutter did not perform flawlessly, it did not allow the entry of enough air to cause excessive internal pressures; however, it did expose the building to the entry of wind-driven rain, but the building was not nearly as exposed as it would have been if the glass had been unprotected.

Figure 3-31. Extensive damage to mortar-set tile roof on this pre-2001 FBC home. Note broken windows to the right of the front door (Punta Gorda).

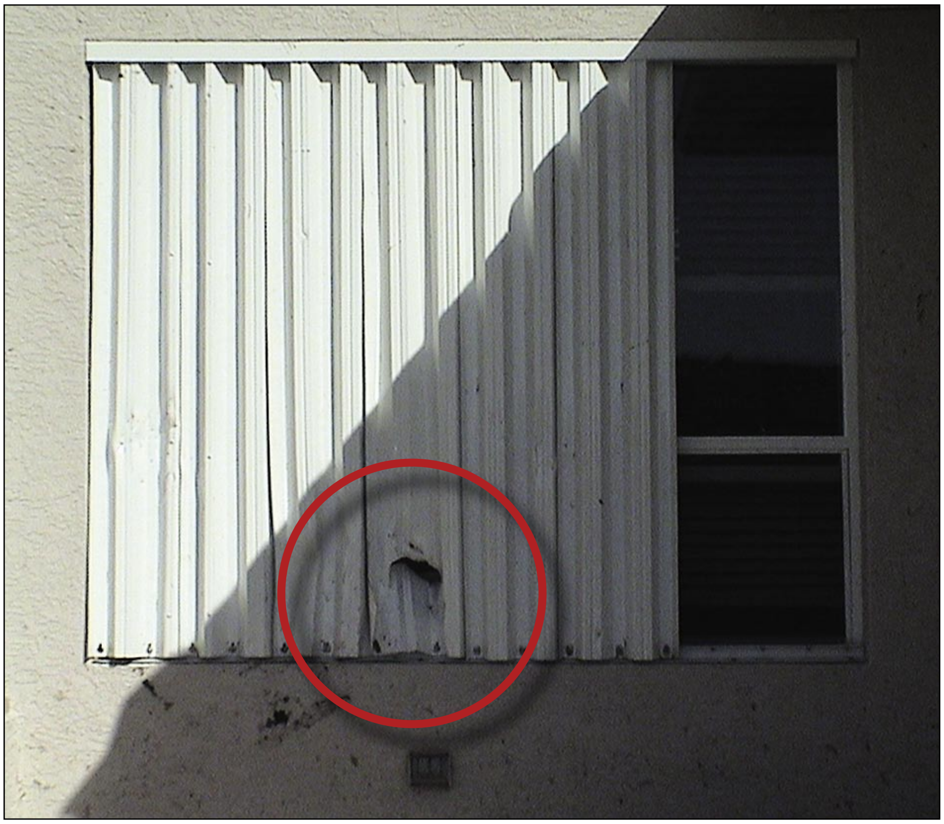


Figure 3-32.
A roof tile punctured this Miami-Dade County-approved shutter (Punta Gorda)

The importance of the height at which debris was released was also evident as far inland as the Orlando area. When a piece of debris is released into the wind field at a significant height, there is greater potential for that debris to remain aloft and be accelerated to wind speeds approaching the wind speeds of the event than for debris released or generated lower to the ground. An example of this was observed in the atrium of the hotel shown in Figure 3-33. At this hotel, the glass at the atrium was damaged by debris from the EIFS wall cladding.

Windborne debris observed by the MAT included roof coverings (tiles, shingles, metal panels, aggregate, etc.), structural and non-structural building elements, tree limbs, refuse containers, lawn furniture, and vehicles. Figures 3-34 through 3-38 show examples of windborne debris. Small debris, such as the roof shingle stuck in the side of the column in Figure 3-34, must have traveled at least a mile because this community only allowed tile roofs. As expected, larger items did not travel as far, although the section of roofing from a wood-frame building on Captiva Island traveled approximately 200 yards after being separated from the original structure.

Figure 3-33.
Damage to glass atrium of high-rise hotel. Note the loss of EIFS, which was the cause of the glass breakage (Orlando).

Figure 3-34.
Edge impact of an asphalt shingle on decorative column (Punta Gorda)

Figure 3-35.
Impact of tree branch through the stucco and metal lath wall system of a fire station. The branch was about 5 inches in diameter and protruded about 3½ feet out of the wall (Aqui Esta, east of Punta Gorda Isles).

Figure 3-36.
Tile damage to a metal-panel garage door (Punta Gorda)

Figure 3-37.
Impact of structural wood members in the gable end from a neighboring house (Pine Island)

Figure 3-38.
Large section of roof structure transported over 200 yards from its source (Captiva Island)

In manufactured home parks, there was a significant amount of aluminum and sheet metal debris from attached structures that failed and a significant amount of glazing damage even in inland parks, as discussed in Section 5.2; however, there were some windows surprisingly intact on the windward sides of the homes. It appears that the close proximity of the homes and the deformable nature of the debris may have helped to reduce the debris impact damage; it is likely that large sheets bumped into the next home before they had traveled very far or attained much velocity (Figure 3-39). In contrast, a manufactured home park observed with homes spaced considerable distances apart appeared to have greater windborne debris damage (Figure 3-40).

Figure 3-39. Typical metal roof panel and siding debris from failed accessory structures and manufactured homes that were stripped of siding resulting from accessory structures failure (Arcadia)

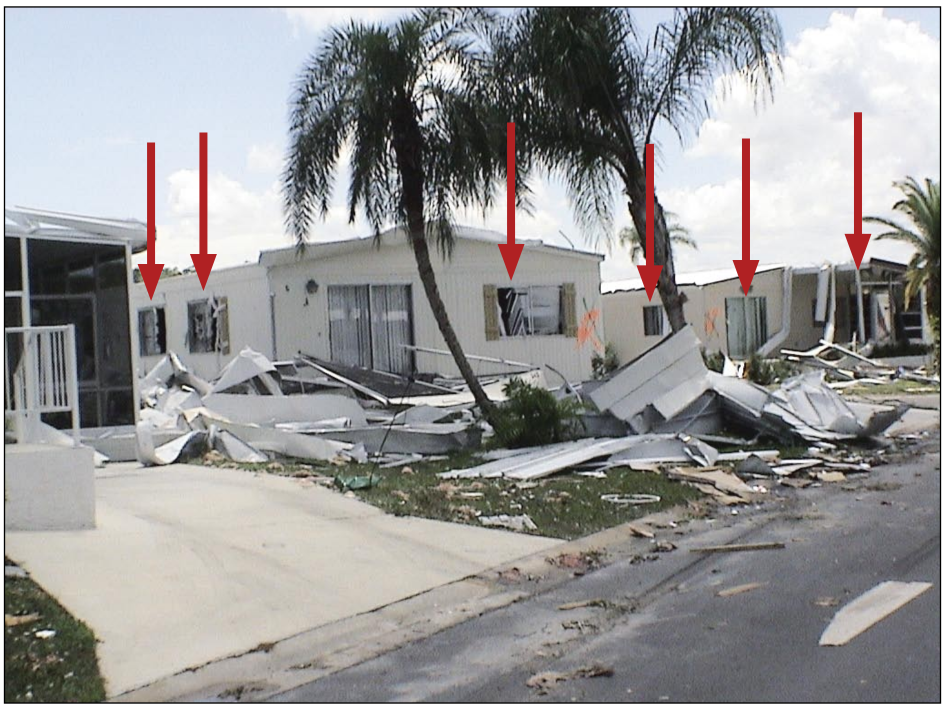


Figure 3-40. Typical metal roof panel and siding debris caused glazing damage to units (Port Charlotte)

It was clear, through investigations at a number of hospitals and other buildings with aggregate roof surfacing, that the aggregate could, and frequently did, cause damage to windows on the building itself. The damage to windows in the intensive care unit of the hospital in Arcadia (Figure 3-41) was a prime example of this effect.

Figure 3-41.
Aggregate from the built-up roofs broke windows at the intensive care unit of a hospital where 3-second peak gust wind speeds were estimated between 110 and 120 mph (Arcadia).

In addition to windborne debris, wind forces caused larger objects to fail and create falling debris. Buildings were damaged by several types of falling objects, including trees, communications towers, rooftop equipment, and chimneys. The uprooting or fracture of large pine and hardwood trees was observed throughout the areas surveyed. On the barrier islands, the extent of tree damage resulted in severe access problems by blocking roads and driveways and creating a severe fire danger. Inland, the tree damage was more isolated, but was frequently spectacular as trees came to rest on buildings or sliced through buildings. Manufactured homes typically suffered the greatest damage from tree fall. Figure 3-42 shows a large tree that fell on a three-story house, and Figure 3-43 illustrates damage from a pine tree that sliced through a manufactured home. Figure 3-44 shows a fallen communications tower at a fire station.

Figure 3-42. Damage to three-story home from tree impact (Wauchula))

Figure 3-43. Damage to manufactured home from tree impact (Pine Island)

Figure 3-44. Fallen communications tower (Aqui Esta, east of Punta Gorda Isles)

3.1.5 Attached and Accessory Structures

Most of the damages to accessory and attached structures were observed as failures of attached structures to manufactured homes and to failures of screened enclosures on both manufactured and site-built homes (typically around swimming pools). Damages to manufactured housing units most often occurred at overhangs, carports, and awnings that were improperly attached to the units and did not have an independent support structure as required by code (Figures 3-45 and 3-46). According to the 2001 FBC, accessory structures are allowed to be directly connected to the units if a registered engineer certifies that the accessory being attached can be supported by the unit. In the failures observed, there was no evidence that the areas to which the accessory was attached were different or reinforced to support attached structures; only standard manufactured housing construction systems were observed. In general, where accessory and attached structures did not contribute to damage to the manufactured home units, the housing stock that had been constructed to post-1994 standards performed much better than the older units.

Figure 3-45.
Example of typical damage to roof covering, roof sheathing, and exterior siding of a manufactured home as a result of the failure of an attached carport structure (Port Charlotte)

Figure 3-46.
Example of damage to manufactured home roof covering, roof deck, and siding due to failure of screen enclosure attached to home (Port Charlotte)

Screen enclosures around pools are common in Florida and incurred extensive damage as a result of Hurricane Charley. Damage typically occurred on the sides of buildings that received direct windward pressures. Figure 3-47 shows an example of a screened pool enclosure that failed from wind pressures. Note the damage caused to the window by the debris from the enclosure.

Figure 3-47.
Example of damage to pool screen enclosure. Note broken window in center of photo from debris (Punta Gorda Isles).

3.2 Flood Effects

Hurricane Charley did not produce large amounts of flood damage to the built environment. As documented in Section 1.3, due to the timing of the storm's landfall with respect to low tide, the compact size of the storm, and the change in course just prior to landfall, significant storm surge across Charlotte Harbor and up tributary rivers was not observed. The MAT performed assessments to identify flood-related damage in mapped flood zones (in both riverine and coastal areas) and mapped storm surge zones. Although the barrier islands west of Charlotte Harbor experienced erosion and North Captiva Island was breached by the storm, the MAT did not investigate or assess these issues.

3.2.1 Flood Damage Observations

Hurricane Charley produced flooding in isolated riverine and coastal areas, and the storm's heavy rainfall caused riverine flooding in low-lying inland areas. Coastal storm surge resulted in inundation along coastal areas of southwest Florida.

3.2.2 Coastal Surge Damage

The most significant coastal flooding occurred in Fort Myers Beach. Some overwash occurred on Captiva Island, but resulted in minimal flood damage. Coastal areas along Charlotte Harbor, including Port Charlotte and Punta Gorda, which were along the path of the storm, had tides only a few feet higher than normal and did not result in any flood damage.

Building damage as a result of coastal surge was concentrated in structures along the coast of Fort Myers Beach. Within the first several rows of houses near the coast and along Estero Boulevard, buildings constructed at or near grade experienced the most damage. Houses set back and on properly elevated piles suffered no damage from the coastal storm surge. Figures 3-48 through 3-55 show damage on Fort Myers Beach.

Figure 3-48.
Minor scour of parking lot from overwash of storm surge (Fort Myers Beach)

Figure 3-49.
Minor scour around pile (Fort Myers Beach)

Figure 3-50.
Oceanfront house constructed on piles sustained only minor damage as a result of storm surge
(Fort Myers Beach)

Figure 3-51.
Storm surge damage of 2 to 3 feet limited to lower floor of two-story house
(Fort Myers Beach)

Figure 3-52.
Typical house with first-floor living space at grade sustained 2 to 3 feet of storm surge damage (lack of wall damage suggests low velocity flows)
(Fort Myers Beach)

Figure 3-53. Newly constructed house elevated on piles sustained no storm surge damage (Fort Myers Beach)

Figure 3-54. Fire station elevated on fill prevented any storm surge damage (Fort Myers Beach)

Figure 3-55. Storm surge caused scouring of the road and damage to the infrastructure (i.e., water main) (Fort Myers Beach)

3.3 Critical and Essential Facilities

Critical and essential facilities were investigated by the MAT to assess the functional loss of services from these operations in response to Hurricane Charley. In addition to the buildings that would qualify under building code definitions as essential facilities, the following buildings were considered either critical or essential facilities due to their key roles in post storm recovery efforts and as day-to-day emergency response centers: fire and police stations, emergency medical facilities, non-emergency medical facilities, nursing homes, EOCs, storm shelters, schools, and other public buildings critical to the long-term recovery of a community following a major disaster. Most of the building types that serve as critical and essential facilities fit into these categories and are discussed further in Chapters 4 and 5. However, specific damages that significantly affected the ability of these facilities to function are summarized below and presented in detail in Chapter 6.

3.3.1 Fire and Police Stations and Hospitals

Most of the buildings being used for police and fire stations were older buildings that had not been enhanced or mitigated to resist wind and windborne debris to the level at which new essential facilities are required to be designed. Roof coverings, sectional doors, and roof structural systems were the most commonly damaged components of fire and police stations and hospitals. In one instance, the MAT observed cementitious wood-fiber decking that was not adequately secured to resist uplift had lifted off the supporting roof structure (Figure 3-56). On gable end and hip roofs, metal and asphalt shingle roof coverings were damaged; gable end wall collapses were also observed (Figure 3-57).

Other damages to fire and police stations included failure of large rolling and sectional doors and collapse of communications towers (previously shown in Figure 3-44). Other damages to hospitals included broken glazing from roofing aggregate and other windborne debris, and damage to awnings and other appurtenances.

Figure 3-56. Cementitious wood-fiber roof deck panels at this older fire station were not adequately secured to resist uplift (Port Charlotte).

Figure 3-57.
Gable end wall collapse and rolling and sectional door failure at fire station (Aqui Esta, east of Punta Gorda Isles). A close-up of the missile in the circle is shown in Figure 3-35.

3.3.2 Emergency Operations Centers, Storm Shelters, and Schools

The MAT observed EOCs, storm shelters, and school buildings that were impacted by Hurricane Charley. Although some of these facilities were specifically designed and retrofitted for their intended use as critical or essential facilities, many EOCs and shelters observed were older buildings not specifically designed or retrofitted for use as shelters. As was observed with the fire and police stations and hospitals, when older buildings were used for these operations, there was often little or no retrofitting or mitigating of the structure to resist high winds and debris impact.

Roof structures and coverings were the most commonly damaged elements of EOCs and storm shelters. On low-profile gable end roofs, roof damage or collapse occurred as a result of inadequate connections of roof sheathing, failure of roof framing elements, or collapse of gable end walls (Figure 3-58).

Figure 3-58.
End wall damage to long span, pre-engineered metal building designed for use as a storm shelter (Turner Agri-Civic Center, Arcadia – see Section 6.5.1.1)

Unreinforced masonry (URM) and reinforced masonry were the most commonly observed wall systems in school buildings. The amount of the steel reinforcement and grout within the reinforced masonry block walls varied based on the age and quality of construction. A few older school buildings were constructed using URM block or hollow clay tile walls. Roof framing systems for school buildings varied widely, depending on the age and condition of the structure. Many schools used low-sloped roof systems with either plywood sheathing supported by wood trusses or lightweight insulating concrete slabs on top of corrugated metal decking with steel joists. Other schools used gable end or hip roofs constructed of plywood or oriented-strand board (OSB) sheathing with wood or light-metal frame trusses. A variety of roof coverings were used; soffits were typically constructed of metal sheets or panels.

As with other critical facilities, roof coverings were the most commonly damaged components of schools (Figure 3-59). Other damage to schools included loss of soffits and large overhangs that were not adequately attached to the structure, leading to the collapse of URM parapets and walls in older schools (Figure 3-60). Glazing damage was common; windows were broken from aggregate surface roofs and other windborne debris. In the higher wind areas, typically, portable classroom units were damaged or destroyed.

Figure 3-59.
Example of roof covering damage at a school. This was a mechanically attached single-ply membrane over a previous aggregate surfaced built-up roof (Port Charlotte).

Figure 3-60.
Example of URM parapet wall collapse and broken windows at an older school (Punta Gorda)

4 Structural Systems Performance

Structural damage was observed from Captiva Island, inland along Highway 17 to north of Wauchula. Structural failure to residential buildings, site-built buildings (single- and multi-family housing), manufactured housing, and commercial buildings (wood frame, concrete and masonry, steel frame and pre-engineered metal) was observed. Throughout the path of the storm, a larger portion of the structural failures occurred to the older building stock; no structural failures were observed to new residential buildings constructed to the 2001 FBC.

Overall, the predominant damage to single-family, site-built buildings was not structural failure, but a failure of the building envelope, which will be discussed in Chapter 5. Considerable damage to accessory structures was observed that often caused additional damage to the primary buildings when they failed.

The following sections discuss structural performance of wood-frame buildings (Section 4.1), manufactured housing (Section 4.2), concrete and masonry buildings (Section 4.3), and structural steel-frame and pre-engineered metal buildings (Sections 4.4 and 4.5, respectively).

Building types include residential, commercial, and critical/essential facilities. Observations on the performance of accessory structures/attachments are presented in Section 4.6.

4.1 Wood-Frame Buildings

Most of the wood-frame buildings observed by the MAT were residential. The wood-frame buildings generally consisted of superstructures supported by the load-bearing exterior wood-frame walls. Building floors and roofs were supported by wood rafters and plywood decks. This type of construction is known as light wood construction and consists of nominal 2-inch framing members spaced closely together, normally concealed by interior finish materials such as gypsum board. Figure 4-1 shows a residential building designed to the 2001 FBC that performed well during this high-wind event.

Newer wood-frame houses, built in accordance with the 2001 FBC, generally performed well structurally. Most of the newer wood-frame houses observed by the MAT were along the Gulf Coast on Sanibel and North Captiva Islands; these buildings were typically two stories on wood pile foundations. The relatively new building stock located in areas of North Captiva Island was impacted by the northeast eyewall, which contained some of the strongest winds of the storm, with winds over 150 mph (3-second peak gust); the houses survived very well from a structural standpoint (Figure 4-2).

Figure 4-1.
No structural damage was observed to new buildings built to the 2001 FBC standards (North Captiva Island).

Figure 4-2.
Newer single-family wood-frame residences that demonstrated good structural performance (North Captiva Island)

A number of the older residential buildings on North Captiva Island experienced structural collapse as shown in Figure 4-3 and were not designed with the continuous load path concept in mind, which consists of following the loads from the point of load application to the foundation; this is essential for stability. Newer building codes and standards specify that design and construction be performed with the load path concept in mind, which is resulting in better structural performance of buildings.

Structural framing systems must be designed to transfer all gravity, uplift, and lateral wind loads to the foundation, as shown in Figure 4-4. In residential applications, the structural framing system is made up almost entirely by the exterior load bearing walls, the walls supporting the roof framing and diaphragm, and the foundation. The integrity of the overall building depends not only on the strength of these components, but also on the adequacy of the connections between them to properly transfer the forces. These critical connections occur where the roof systems are supported by the top plate of the wall, where there are openings and headers in the walls that collect forces, where the floors connect to each other, and where the base of the wall connects to the foundation system. In a single-story building with trusses or rafters as the roof framing system, the roof sheathing acts as a diaphragm and transfers lateral wind loads to the wall perpendicular to the exterior walls subjected to the lateral wind loads. These walls act as shear walls and transfer the loads to the foundation.

Figure 4-3.
An older building that was renovated for architectural improvements a few years ago collapsed due to limited load path connections (North Captiva Island).

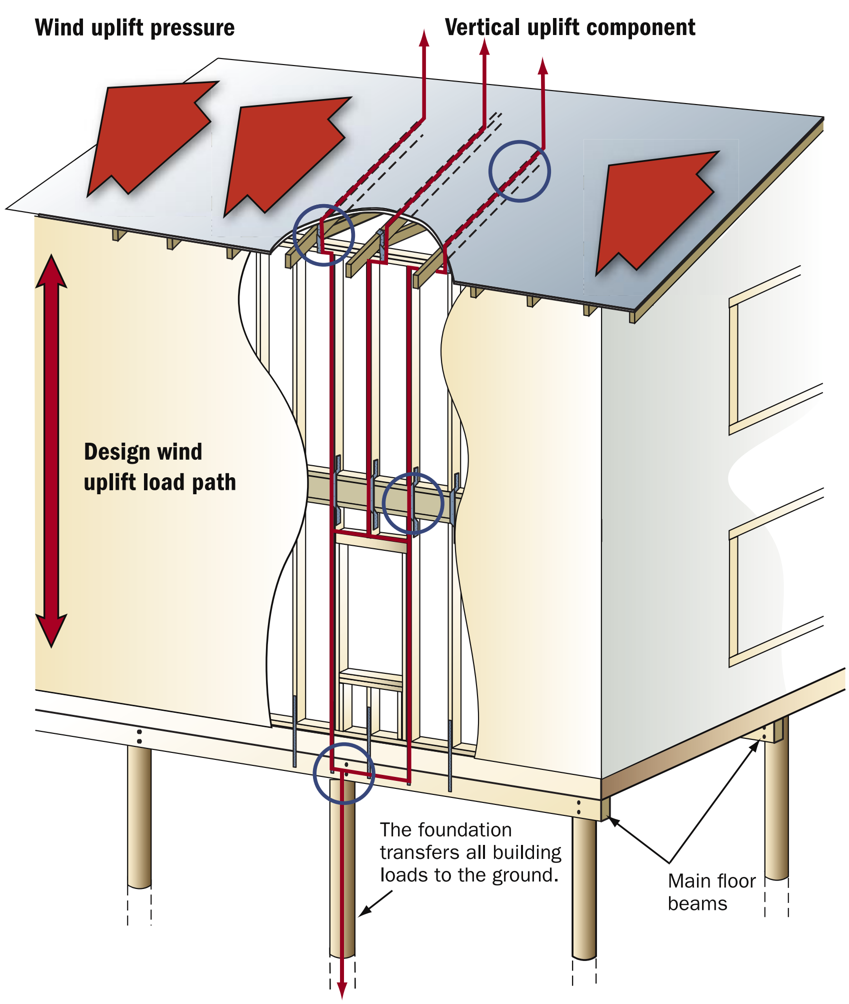


Figure 4-4.
Load path of a two-story building with a primary wood-framing system: walls, roof diaphragm, and floor diaphragm

A concept in building design for wind loading, termed “partially enclosed,” is intended to account for different configurations of a building that are not enclosed (i.e., a non-enclosed porch or a building with significant openings in the building envelope) that will allow the building and its connections to resist additional uplift loads. It also provides secondary benefits by reducing the likelihood of structural failure in the event of a window or door failure. This design practice increases wind loads on components and cladding (C&C) elements, as well as the main wind force resisting system (MWFRS), and accounts for additional wind pressure when a breach of a window or door occurs.

Once a building has been identified as "enclosed" or "partially enclosed," the designer must select a method or procedure to calculate wind loads. Two procedures are available for calculating MWFRS loads on buildings with heights less than 60 feet, and only one procedure is available for buildings taller than 60 feet. For buildings taller than 60 feet, the procedure is the simplified procedure for buildings with heights less than 60 feet. The second procedure for buildings with heights less than 60 feet has been allowed in the SBC since the 1980s, but was not introduced into the ASCE 7 standard until the 1990s. Consequently, there have been relatively minor changes in the MWFRS loads for buildings built in Florida over the past 20 years. A notable exception is the current ability to design in one of two ways:

- A building can be designed to be enclosed. In this case, windows and doors must be protected from windborne debris.
- A building can be designed to be partially enclosed. In this case, windows and doors are not assumed to protect the interior from wind forces or windborne debris. For this reason, the building must be designed to withstand internal pressures that would be created by the breach of these openings.

In the areas that experienced code level winds, the MAT observed a number of residences, presumably designed to be “partially enclosed,” with missing garage doors or broken windows (even when those windows were large) that survived without structural failure. The successful performance of these buildings seems to attest to the validity of the “partially enclosed” design practice. Figure 4-5 shows an example of a building not designed for internal pressure (not designed according to “partially enclosed” parameters) that resulted in major structural roof failure.

The importance of the internal pressures on the performance or failure of other components and structures can be determined by considering the relative magnitude of the internal pressure effect when compared with the external pressures on that same component or structure. Consequently, if the design of components, connections, and systems is closely matched to the design pressures and loads obtained from the building code, the effect of a change in the internal pressure is greatest on components and systems for which the code provides the lowest external design pressures. The lowest external design pressures are specified for the center portions of walls and roofs and the lowest net design loads for structural systems typically correspond to the roof structure as a whole. The increase in loads on windows and doors on the leeward or side walls or interior roof areas can be as high as 30 to 40 percent, while the increase in loads around the edges of the roof may be 10 percent or lower. It is much more likely that increased internal pressures due to breaching will lead to failure of properly designed and installed sliding glass windows, doors, wall panels, or interior roof sheathing than properly designed and installed roof edge connections or roof panels around roof edges. Because the overall loads on roof structures can be relatively low, especially for some roof slopes, the breach of a window or large door on the windward face can almost double the expected uplift load on the roof structure. This situation is particularly important for buildings with large open areas, such as a large room with a cathedral ceiling or a large meeting room. Chapter 5 provides examples of window and door failures in "partially enclosed" structures that did not result in structural failure, but did result in water intrusion.

Figure 4-5.
Failure of the roof over a cathedral ceiling from pressurization of the house when the window failed on the windward face (Pine Island)

Damage to roof sheathing, though not widespread, was observed (Figure 4-6). This damage was observed by the MAT on older homes most likely designed prior to improvements in the C&C design criteria discussed in Chapter 2.

Figure 4-6.
Roof decking failed due to uplift (Deep Creek)

Details in design and construction of wood structures tend to be very vulnerable to the forces associated with high winds even when they are followed carefully from design through construction. Proper structural framing requires a dedicated effort from the designer, to the building official, to the contractor, to ensure that all connections are installed in an approved manner.

In a multi-story building, the framing systems of the floors and the roof act as the diaphragm and transfer forces to the shear wall, which transfers the loads to the foundation. The taller the building, the stronger the shear walls must be to resist lateral wind loads. Overall, multi-family residential buildings performed well, although older buildings on Pine Island and Captiva Island did sustain considerable damage (Figures 4-7 and 4-8).

Figure 4-7. Multi-family residential building that performed well structurally, although it had severe roof covering and some sheathing failure at the overhangs, allowing water intrusion (Pine Island)

Figure 4-8. Wall failure on older (1980s vintage) multi-family wood-frame building due to lack of load path. Internal pressurization may have also contributed to this failure (Captiva Island).

4.2 Manufactured Housing

The pre-1976 HUD standard homes, which are now over 25 years old, performed poorly as expected. These homes were built in accordance with minimum requirements, and many of the homes were subjected to the narrow path of Hurricane Charley's highest winds and were damaged beyond repair. Figure 4-9 shows a pre-HUD home that was totally destroyed; however, surrounding pre-HUD homes appeared to have survived with little damage.

Figure 4-9. Pre-1976 HUD manufactured home sustained substantial damage (Bowling Green)

The pre-1994 HUD standard manufactured homes had the benefit of being built in accordance with the HUD standards, but they did not have the additional high-wind resistant features that are found in manufactured housing today. Damage to pre-1994 HUD standard homes varied tremendously even for units located near each other in the same park. The levels of damage to units ranged from beyond repair (shown previously in Figure 3-8) to almost intact with only the failure of carports and attachments or screen enclosures.

The post-1994 HUD standard home, built after the improved wind-resistant requirements were added to the HUD manufactured housing standards in 1994, performed better than its predecessors. In general, the main wind-force resisting systems in these homes remained intact. In many cases, when an attached accessory structure was torn off a home, it also tore off the metal paneling to which it was attached. Typically, this starts a continuing sequence of peeling of the skin, which could include both walls and the roof (Figure 4-10). The roof structural failures resulted in significant water intrusion, causing damage to these homes and their contents. Structural failures of accessory structures are discussed in Section 4.6.

Figure 4-10.
Post-1994 HUD manufactured home with significant roof damage (peeling of roof panels) resulting from collapse of attached accessory structure (Zolfo Springs).

4.3 Concrete and Masonry Buildings

Among the most predominant construction materials in the communities impacted by the hurricane are concrete and masonry units (CMUs), which are used for exterior walls. As shown in Figure 4-11, reinforced concrete masonry structures performed well.

Figure 4-11.
New concrete masonry residence built to 2001 FBC standards performed well structurally, although it did experience some asphalt shingle damage (Port Charlotte).

Concrete and masonry construction is commonly used for commercial buildings, such as shopping centers and office buildings. These buildings were supported on reinforced concrete foundations with spread or deep foundation systems. Reinforced concrete columns and beams support the superstructures. Exterior load-bearing walls were constructed utilizing CMUs. In general, the floor slabs in multi-story buildings consist of cast-in-place reinforced concrete slabs. At some locations, the floor decks were observed to be supported by open web steel joists with metal deck and concrete topping.

Concrete and reinforced masonry buildings provide a high degree of structural strength, rigidity, and security, and typically provide a long building life span. These buildings have sound structural wall systems due to inherent safety factors and redundancy built into the design and construction. Figure 4-12 illustrates an adequately designed reinforced masonry wall system.

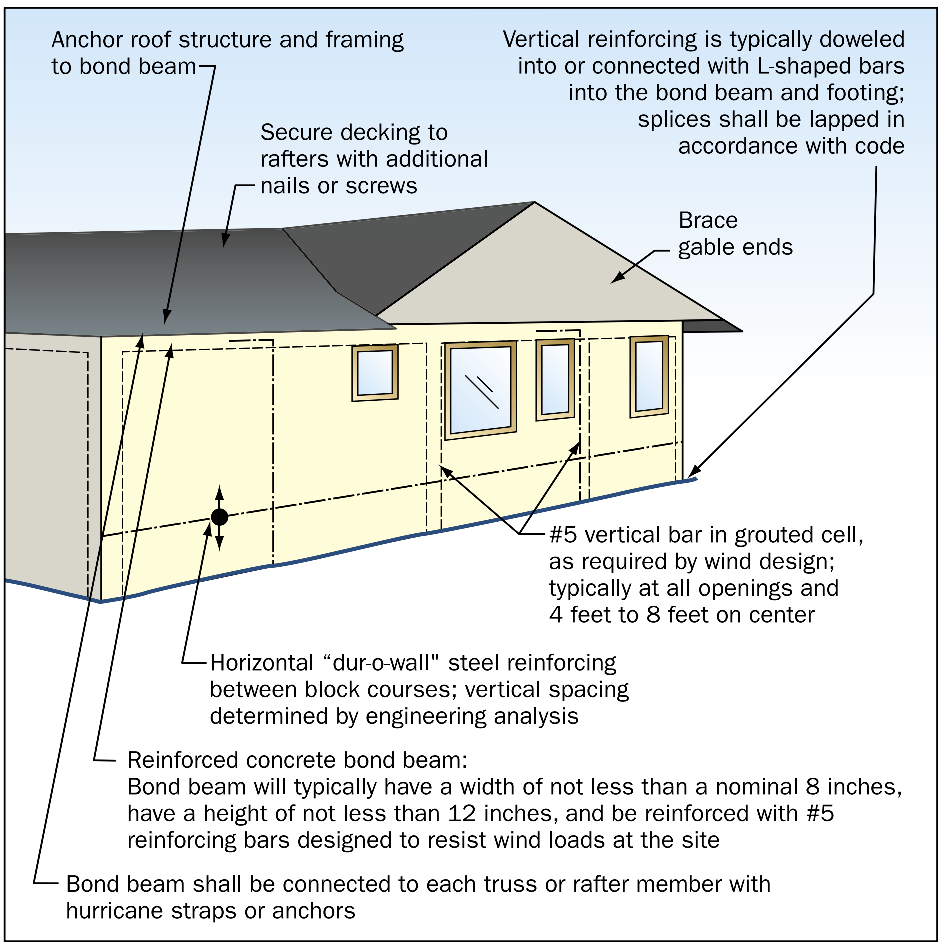


Figure 4-12. Adequately designed reinforced masonry wall system

In contrast to reinforced masonry, an unreinforced masonry building is very vulnerable to damage in a high-wind event, as shown in Figures 4-13 and 4-14 (and previously in Figure 3-9). The lack of reinforcing means that uplift is resisted only by the mortar; if the mortar is cracked, the engaging of the dead weight of the walls is reduced in resisting uplift loads. If the roof separates from the walls, the walls become cantilevered and can be blown over.

Figure 4-13. Unreinforced brick wall failure of a building built over 50 years ago (photo taken from the inside of a classroom, looking out) (Punta Gorda)

Figure 4-14. Partial failure of an unreinforced concrete masonry commercial structure (Port Charlotte)

The roof decking of commercial buildings is generally supported by open web steel joists with metal decking (sometimes with a lightweight concrete topping). Wood trusses are also used for the roof framing. In newer buildings, the roof structure is sometimes anchored to a reinforced bond beam using cast-in-place steel straps. In older unreinforced masonry buildings, the roof structure may be set on the walls with no positive anchorage to the walls or with only minimal anchorage provided using "J" hooks that effectively anchor the structure only to the top course of masonry.

Fire Station No. 12, a fairly new building in Port Charlotte, is a concrete structure with reinforced masonry walls and a concrete slab on grade foundation. The building was being used as a shelter for the fire station employees and their families during the hurricane. The roof framing system consisted of wood trusses supported by a tie-beam on the masonry wall. Wood roof trusses over the apparatus bays spanned approximately 68 feet. The anchorage of roof trusses to the load bearing wall apparently failed and blew away; however, all other structural components of the building stayed intact (Figure 4-15).

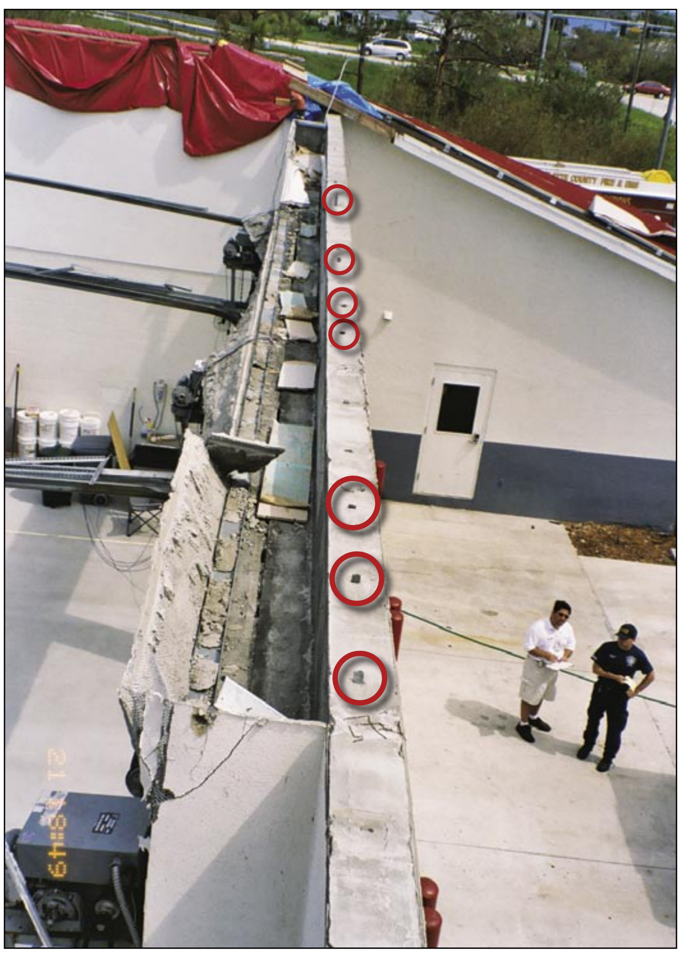


Figure 4-15.
Roof truss hurricane anchor straps failed at the tie-beam at Fire Station No. 12 (Port Charlotte)

In comparison, the roof framing system of Fire Station No. 11 in Port Charlotte consisted of open web steel joist with metal decking supported by reinforced masonry walls. The main structure of the multi-story concrete frame building stayed intact, and no structural damage was observed to the roof framing system.

4.4 Structural Steel-Frame Buildings

In structural steel-frame buildings, the main structures of the buildings are supported by structural steel columns bearing on reinforced concrete spread footings or piles. Structural steel beams and girders support the floors. Shear walls add rigidity to the frames. These buildings are typically constructed using hot-rolled steel sections.

The main structural members of the steel-frame buildings observed by the MAT appeared to have withstood the hurricane force better than the wood and pre-engineered metal structures, but not as well as the reinforced concrete structures. An office building and a shopping center constructed of a structural steel-framing system were observed in Wauchula. The exterior walls and window systems failed, the building envelope was penetrated, and the roof decking blew off the joist; however, no damage was observed to the main structural steel-framing members (Figure 4-16). No heavy steel-frame failures were observed.

Figure 4-16.
Older steel-frame structure performed well in spite of major damage to the roof decking and the exterior walls (Wauchula)

4.5 Pre-Engineered Metal Buildings

A pre-engineered metal building system is generally the most economical and is normally utilized for commercial purposes such as warehouses, storage facilities, hangars, and other similar uses. These buildings are easily recognized by their sheet metal siding, tapered rigid frames, and long spans with open spaces. Secondary members consisting of girts and purlins are installed to support the metal siding and roofing panels. Figure 4-17 shows the structural collapse of a pre-engineered building well inland in Arcadia; an adjacent reinforced concrete-frame hospital, however, was structurally undamaged.

Figure 4-17. Completely destroyed pre-engineered metal building (Arcadia)

Failure of the main structural members of pre-engineered buildings was observed at numerous locations. Many of the main support members were corroded, which may have led to the failure. In Wauchula, a large pre-engineered building partially collapsed because the main structural steel columns of the rigid frame had lost a significant amount of its cross-sectional area due to corrosion (Figure 4-18). These members did not have the capacity to support the hurricane loads and failed, causing failure of the superstructure. In general, other buildings surrounding this facility were not damaged to the extent of this storage facility.

Figure 4-18.
Collapsed older pre-engineered metal structure (Wauchula)

In the Port Charlotte area, some fire stations and other essential facilities were constructed of pre-engineered metal building systems. As previously observed after other storms, in some cases, the pre-engineered metal framed systems performed the worst of all the structural framing systems evaluated. Exterior walls consisting of sheet metal siding failed prematurely due to corrosion, resulting in failure of the main structural framing members and column collapse (Figures 4-19 and 4-20).

Figure 4-19.
Main column at Fire Station No. 8 collapsed due to corrosion and metal siding failed (Port Charlotte)

Figure 4-20. Significant amount of corrosion at Fire Station No. 8, which contributed to failure shown in Figure 4-19

4.6 Accessory Structures/Attachments

Significant damage to accessory structures was observed by the MAT throughout the path of Hurricane Charley. Most primary buildings had accessory structures (e.g., carports, garages, tool sheds, laundry and sitting rooms, and screened-in porches/pool enclosures) attached. Some of the accessory structures were free-standing.

Although accessory structures were present on both site-built residences and manufactured homes, almost all of the accessory structures observed by the MAT were associated with manufactured homes. According to the Administrative Code of Florida, all additions are required to be free-standing and self-supporting, with only the flashing attached to the home, unless the added item has been designed to be married to the existing home. Also, additions must be constructed in compliance with the 2001 FBC and locally adopted building codes.

Within the past few years, wind tunnel tests of screen enclosures, open canopy roofs, and roofs over partially enclosed spaces have already led to significant changes in code-based wind load provisions for these structures and additions. Changes in wind loads for screen enclosures that substantially increased the loads on screen walls were adopted in the 2001 FBC, but relatively few of these structures have been designed and built to these newer loads. Observations of newly constructed enclosures from damage assessments support the changes that have been instituted. The majority of the enclosures, attachments, and open canopy roofs were designed for substantially lower loads prior to the 2001 FBC. This likely was the reason for the widespread damage that was observed by the MAT.

In addition, the MAT observed significant damage to not only the accessory structures, but also to the homes in general as a result of the poor detailing and performance of the additions. Detailed examples of the types of damage observed are presented in Figures 4-21 through 4-23.

Figure 4-21. Damaged carport (Zolfo Springs)

Figure 4-22.
Damaged garage (Zolfo Springs)

Figure 4-23.
Damaged screened porch (Punta Gorda)

In a manufactured home park south of Wauchula where estimated 3-second peak gust winds were in the 100- to 115-mph range, most of the windward- side structures attached to the homes were severely damaged. When the attached structures were blown away from the manufactured home, they typically tore off some material from the main structure at the attachment location, including siding or roofing. This breach in the cladding allowed further damage to the siding or roofing, exposing the home to wind and wind-driven rain. Although none of the manufactured homes at this location sustained significant structural damage, many will require substantial repairs because of the damage at the attachment site of the accessory structure and resulting water damage.

A primary reason attached aluminum structures failed was inadequate tie-downs of the aluminum posts. The primary failure modes were that the screws attaching the post to the connector broke, the anchors pulled out of the concrete, or the heads of the bolts pulled through the connectors; additionally, sometimes bolts appeared to be corroded to a compromised extent, or the integral washers on some bolt heads had corroded to such an extent that the washers were rendered ineffective. In most instances, the specific cause of the failure of attached rooms could not be readily determined because the damage was so complete. In addition to having inadequate tie-downs, some of these attached rooms were likely elevated to meet the floor level of the manufactured home (approximately 3 feet) and the passage of air beneath may have added to the wind pressure and thereby increased the loads placed on the anchors. Typically, these rooms did not have shear walls capable of resisting wind pressures.

Figure 4-24 shows a freestanding stairway from a manufactured home that was not sufficiently anchored and had blown against the posts of the carport of an adjacent manufactured home, nearly causing the post to be torn from its anchor. If the post had been deflected much more, it is likely that the carport would have been so compromised it would have blown away, resulting in material being torn off the manufactured home and thereby subjecting it to water intrusion. The pile of debris visible in the distance through the carport is typical of damage caused by attachments in this manufactured home park.

The aluminum screen and pool enclosures that collapsed were observed to be on the windward side of residences of site-built and manufactured homes in areas that experienced wind gusts over 110 mph with open exposures to wind (see Figure 4-25). There were several instances of aluminum debris from the pool enclosures breaking windows of the house to which the enclosures were attached, resulting in interior water damage.

In several cases observed, the apparent cause of the primary failure was that the windward outside corner posts became detached from the slab. Typical construction of these structures included corner posts attached to adjacent 1-inch by 2-inch open back aluminum with only two #10 screws and mid-span posts similarly attached, but with the addition of substantial aluminum angle brackets secured to the slab with substantial anchor bolts. Figures 4-25 through 4-27 show the consequences of inadequately attached corner posts. In Figure 4-26, note that there was no direct tie-down of the corner post to the slab. The corner post was only tied down with lateral screws into one open back. Although the photographs show mid-span post anchoring failures, the MAT observations were that the mid-span posts failed subsequent to the corner posts. An additional mode of failure is likely to have occurred as a result of insufficient diagonal bracing.

Figure 4-24.
Stairway blown into a post of an aluminum carport accessory structure (Zolfo Springs)

Figure 4-25.
Typical consequence of corner post failure (Punta Gorda Isles)

Figure 4-26.
Consequence of corner post not directly tied down to the slab (Punta Gorda Isles)

Figure 4-27.
Breakfast nook window viewed through the pool cage (Punta Gorda Isles)

5

Building Envelope Performance

The ability of the structural system to perform without failure is critical to avoiding injury to occupants and minimizing damage to a building and its contents. It does not, however, ensure occupant or building protection. Good performance of the building envelope is also necessary.

The ability of the structural system to perform without failure is critical to avoiding injury to occupants and minimizing damage to a building and its contents. It does not, however, ensure occupant or building protection. Good performance of the building envelope is also necessary. The envelope includes exterior doors, non-load-bearing walls, wall coverings, soffits, roof coverings, windows, shutters, skylights, and exterior-mounted mechanical and electrical equipment. Historically, poor building envelope performance has been the leading cause of damage to buildings and their contents in weak to moderate intensity hurricanes, with damage to roof coverings and rooftop equipment being the predominant envelope problem. Building structural capacities have improved because of stronger building codes and better enforcement, resulting in less structural damage overall from intense hurricanes such as Hurricane Charley. Consequently, the performance of the building envelope is becoming increasingly important. The following sections describe envelope performance as observed for residential, commercial, and critical/essential facilities.

5.1 Doors

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 (as discussed in Chapter 4). Second, wind can drive water through the opening, causing damage to interior contents and finishes, and leading to development of mold. Essentials to effective high-wind door performance include product testing to ensure sufficient factored strength to resist design wind loads; suitable anchoring of the door frame to the building; proper flashing, sealants, tracks, and drainage to minimize water intrusion into wall cavities or into occupied space; and, for glazed openings, the use of laminated glass or shutters to protect openings against windborne missile damage as discussed in Section 5.2.

5.1.1 Personnel Door Damage

There were only a limited number of buildings where personnel door damage was observed. Observed damage included broken window panes (typically caused by missiles) and doors disengaged from their frames (likely caused by over-pressurization). Sliding glass door damage is shown in Figure 5-1, where several doors disengaged from their tracks; this damage was caused by over-pressurization. Water infiltrated the interior of a residence and caused damage because of a lack of weatherstripping between a pair of doors and their threshold. A ⅜-inch gap occurred between the door bottoms and the threshold, apparently allowing a substantial amount of wind-driven water to enter the residence. Double-entry doors were also observed to be damaged even when homeowners tried to support the doors by pushing heavy furniture against them. An example of double-entry door failures was shown previously in Figure 3-20.

Figure 5-1.
Sliding glass doors blown out of their tracks (Punta Gorda Isles)

A limited number of buildings with personnel door damage were observed in commercial and critical/essential facilities. Observed damages included broken window panes (caused by missiles as shown in Figure 5-2) and disengagement of doors from their frames (likely caused by over-pressurization). At one school being used as a shelter, a pair of exterior gym doors reportedly blew open. People pulled the doors shut and held on to the horizontal exit hardware bars for the duration of the hurricane. The right leaf had top and bottom vertical rods, and the left leaf had a horizontal bolt. Therefore, at the latch edge, the door on the right was attached to the frame at the top and bottom of the door. However, the door on the left was attached only at mid-height, where it bolted into the right door (Figure 5-3). If the left door had also been equipped with top and bottom vertical rods, it may not have blown open.

Figure 5-2.
Tempered glass in office building entry door and side windows broken by missiles (Punta Gorda)

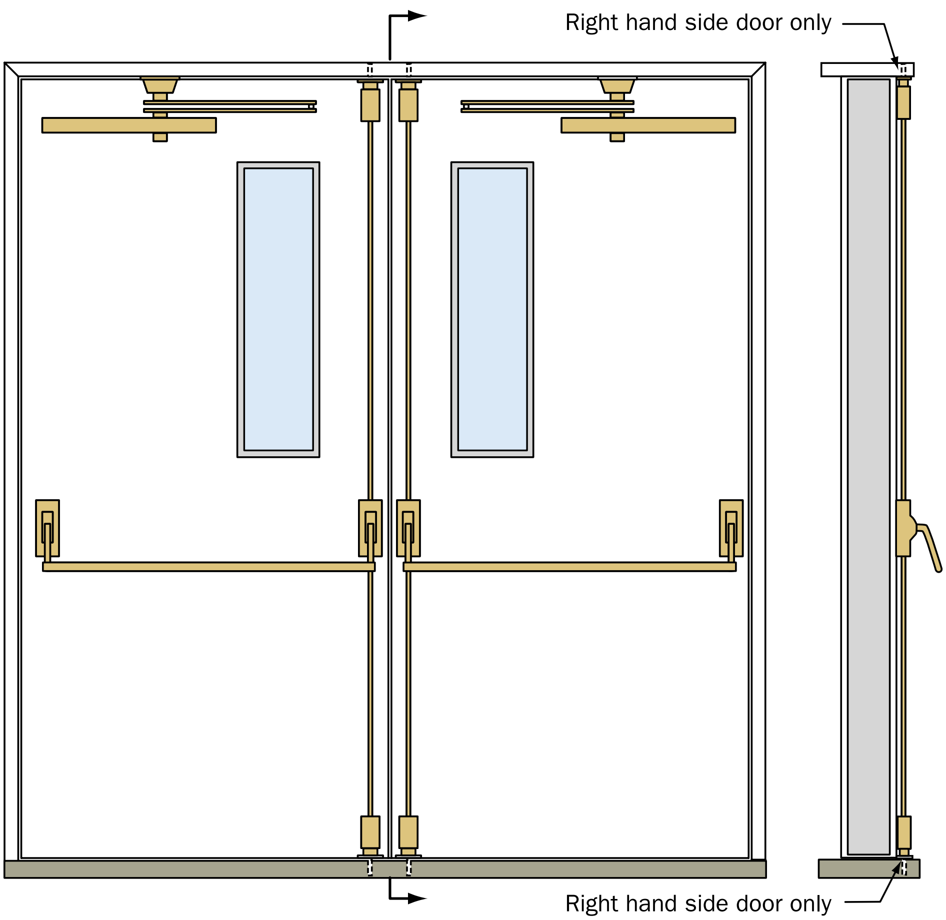


Figure 5-3.
Improper attachment of doors

5.1.2 Garage Door Damage

Damaged garage doors were observed throughout the Port Charlotte and Punta Gorda areas. In some instances, the doors buckled and were pulled outward (suction failures), as shown in Figure 5-4. In other instances, the doors were pushed inward (positive pressure failures), as shown in Figure 5-5. The home in the center of Figure 5-5 had a 5V-Crimp metal panel roof that performed well. Many of the other houses in this area (which typically had asphalt shingle or tile roofs) had roof covering damage. Many of the failures occurred because the doors had inadequate wind resistance. In these cases, the doors buckled inward or outward, and the rollers were often pulled out of the tracks. Other failures were caused by use of weak tracks or inadequate attachment of door tracks to the buildings. It was clear that most of the double car garage doors in older homes were not high-wind or debris-impact rated. In a number of the newer homes, the doors had improved bracing, but the metal gauge was much thinner than that used in Miami-Dade County approved impact-resistant garage doors. In addition, where door failures were observed, the tracks were not of the heavier gauge or braced according to high-wind recommendations. The garage doors approved by Miami-Dade County are constructed of thicker gauge material because they must meet different performance criteria for debris impact than is required by the 2001 FBC in other counties in Florida.

Figure 5-4.
Door lacked sufficient strength to resist the suction load (Deep Creek)

Figure 5-5.
Garage door at the home in the center buckled and the rollers pulled out from their tracks; garage door at the home on the right also failed (Deep Creek).

Some garage doors observed were designed with removable stiffener bars. One garage door with this type of design at a post-2001 FBC residence did not have the stiffener bar in place at the time of the hurricane, and it was damaged by wind pressure (Figure 5-6). There were instances where owners had left their homes for the summer season and had neglected to put into place the stiffener posts required to make their garage doors resist winds as they were designed.

5.1.3 Rolling and Sectional Door Damage

Damage to rolling and sectional doors (e.g., service garage doors and loading dock doors) was observed. Newer doors generally performed well. However, in one instance, a new door failed (the drawings were dated 1997), resulting in the failure of an interior partition wall, as shown in Figures 5-7 and 5-8. The failed door shown in Figure 5-7 was attached with 1¾-inch long by ⅜-inch diameter expansion bolts into concrete that spalled at the bolt locations, likely due to the placement of the bolts too close to the edge. There were no ties between the wall itself and the end wall (Figure 5-8). The drawings indicated continuous angles on each side of the wall, but they were not installed. Another sectional door around the corner and perpendicular to the door shown in Figure 5-7 failed after the door in Figure 5-7 failed. The buildup of internal pressure exerted a positive load on the other door, which was also loaded in suction on its outer surface. One of the expansion bolts along the right track sheared off, and the concrete spalled at the other bolts. The bolts were typically 2 feet on center, but some were closer.

Figure 5-6.
Garage door failed because the removable stiffener bar was not in place at the time of the hurricane (Punta Gorda Isles).

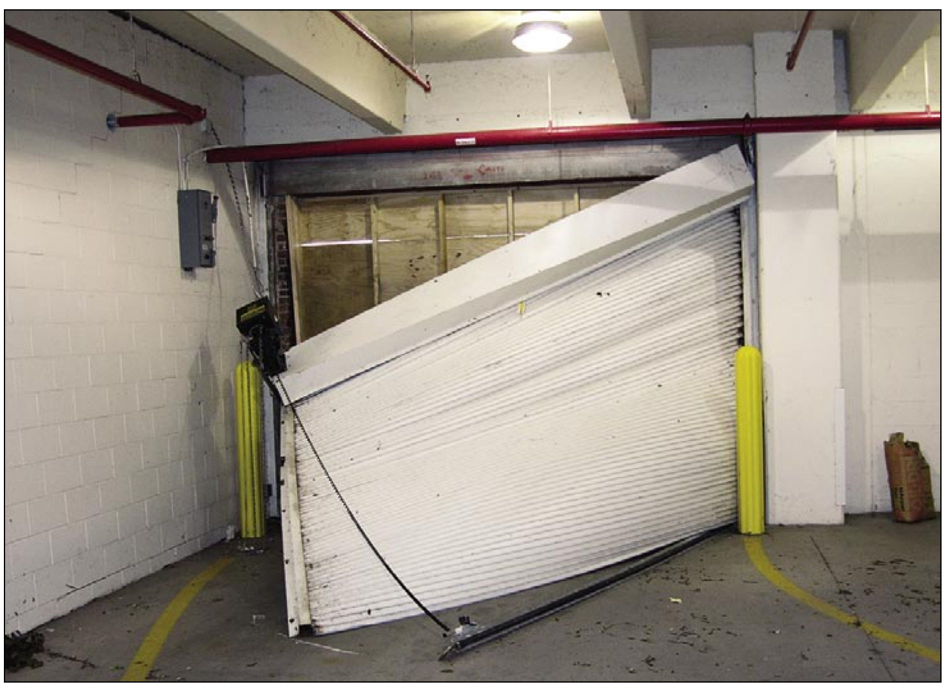


Figure 5-7.
New door that failed. Non-load bearing CMU wall at the left tilted (see Figure 5-8) (Punta Gorda).

The rolling and sectional doors at the older fire stations lacked sufficient wind resistance and typically failed by suction or positive pressure. Common modes of failure observed included doors disengaging from the tracks shown previously in (Figure 3-57), or tracks or track blocking pulling away from the walls, or breakage of glazed or metal panel doors. In several cases, the tracks bent or bowed enough to allow the wheels to disengage from the tracks. Damage to older doors was not surprising, illustrating the need to replace weak doors on these important buildings. However, when doors are replaced, it is important to replace all of the doors and the track hardware as illustrated by Figure 5-9. There were six sectional doors at the fire station shown in Figure 5-9. Five of the doors were damaged. On the leeward side, one door blew out, one buckled, and one had minor outward bowing. On the windward side, two of the doors blew inward as shown in Figure 5-9. The door that did not fail was a newer door. The tracks on the newer door were attached with ¼-inch screws at 18 inches on center. There were two stiffener ribs per 24-inch high door section. It is notable that one of the sidewalls was pushed out when the attachment of the wall angle to the slab failed, likely due to an increase in internal pressure. The wall angle was attached with nail-ins at 3 feet 3 inches on center. The concrete spalled at the fasteners. Because of the door damage, this station was taken off-line after the hurricane.

Figure 5-8.
After the door shown in Figure 5-7 failed, buildup of internal pressure tilted the wall (Punta Gorda).

Surprisingly, sectional doors on two newer fire stations also failed. At the Aqui Esta Fire Station (east of Punta Gorda Isles), five of the six doors were not damaged, but the sixth door pulled out of the track. This station was first occupied in 2000. At a fire station in Deep Creek (Figure 5-10), all three windward doors were blown in. The tracks were attached with ¼-inch lag screws at 24 inches on center. The leeward doors were not damaged, but the roof structure blew off the apparatus bay.

At several of the fire stations, the sectional doors blew inward on the apparatus (i.e., fire engines or ambulances). In some instances, the doors caused damage, such as a broken windshield, but there were no reports of door damage disabling a piece of apparatus.

Figure 5-9.
Windward side of a fire station; two doors blew inward, but the newer center door remained intact (Punta Gorda).

Figure 5-10.
At two of the windward doors, the doors were pushed out of the tracks; at the third door, one of the tracks was pushed from the wall (Deep Creek).

5.2 Windows, Shutters, and Skylights

Exterior windows are very susceptible to missile breakage during hurricanes unless they are protected against windborne debris (via use of laminated glass or shutters). Although the probability that any one window will be struck by windborne debris is typically small (except for manufactured housing in parks), when it does occur, the consequences can be significant. The probability of impact depends upon local wind characteristics and the amount of natural and manmade windborne debris in the vicinity. The greater the wind speed, the greater the amount of windborne debris that is likely to become airborne. Windows can also be broken by over-pressurization, but this damage is not as common as debris-induced damage.

The 2001 FBC defines windborne debris regions (see Figure 2-1) as those specified in ASCE 7-02, except in the Florida Panhandle, where the 2001 FBC has different requirements than ASCE 7. This difference in windborne debris regions is discussed in Section 2.2. In windborne debris regions, the 2001 FBC requires glazing to be impact-resistant or protected by shutters (glazing above 60 feet from grade is exempt). The Port Charlotte and Punta Gorda areas are in the windborne debris region, but inland areas along Hurricane Charley's track (such as Arcadia) are not.

One of the notable successes observed was the greatly increased use of shutters on both residential and commercial buildings, in both the windborne debris region as well as inland areas. Although some windows were shuttered during Hurricane Andrew in 1992 (FEMA FIA-22, *Building Performance: Hurricane Andrew in Florida*, 1992), it was apparent that many residents of Florida now have a greater appreciation of the benefits of protected glazing. The increased glazing protection is likely due to code requirements, development and increased availability of protection products, and the public's awareness of the vulnerability of unprotected glazing.

5.2.1 Residential Buildings

In a manufactured housing park in Zolfo Springs, an area not in the defined windborne debris region, windborne debris broke windows in several homes. The winds (estimated at 100 to 115 mph in Exposure B) generated a large amount of windborne debris. The majority of the windborne debris was from accessory structures and attachments as discussed in Section 4.6. In a manufactured housing park east of Port Charlotte, windows were broken in most of the homes and, in some cases, nearly all of the windows on the windward wall were broken (Figure 5-11). This park was in a windborne debris region, but the windows were not protected. Figure 5-12 illustrates broken windows in a new home that was still under construction. Because this house was still under construction, the contractor may have intended to install shutters in order to meet the windborne debris requirement; however, this was not done before the hurricane arrived. Window breakage was also caused by the failure of attached structures and pool cages. Figures 4-25 and 4-27 illustrated this type of damage.

Figure 5-11.
Most of the windows on this side of a manufactured home were broken by windborne debris (east of Port Charlotte).

Figure 5-12.
Three of four panes broken by windborne debris; other windows in this house also broke (Deep Creek).

Many windows in the windborne debris region were equipped with shutters, although most were not. Shutters were made of wood sheathing, metal panels, or plastic panels of various designs. A common shutter design used metal panels that were held by top and bottom tracks permanently mounted to the wall. Figure 5-13 shows a house with roll-up shutters at the windows and metal panel shutters at the garage (garage door shuttering was rare).

Figure 5-13.
This house, which appeared undamaged from windborne debris, had roll-up shutters at the windows and metal panel shutters at the garage (Deep Creek).

Figure 5-14 shows a common metal awning shutter. These types of shutters provide very limited protection and should not be considered impact-resistant; they have not been tested to 2001 FBC requirements. A plastic roll-up shutter was observed that had been broken by windborne debris. It is doubtful that this shutter met the impact-resistance requirements specified in the 2001 FBC. In one case, windborne debris (a roof tile) was observed to have penetrated a Miami-Dade approved shutter (shown previously in Figure 3-32).

Figure 5-14.
Metal awning shutter penetrated by a missile (Zolfo Springs)

Some of the shutters did not have the strength to withstand the forces of the wind or the impacts of windborne debris. Others may have had sufficient strength, but were improperly installed. Figure 5-15 shows a house that used plastic shutters that blew off.

Figure 5-15.
All of the windows on this house were covered by plastic shutters, many of which were blown off during the hurricane, resulting in several broken windows (North Captiva Island).

The MAT observed some laminated glass windows, but none of them had been impacted by windborne debris, or if they had been impacted, they did not break. Some broken tempered glass windows were observed. Although tempered glass is more resistant to windborne debris than common glazing, when tempered glass breaks, it shatters into small pieces and falls out of the frame. Wind-driven rain could then be driven into the residence and substantially increase the internal pressure. When laminated glass breaks, the glass remains bonded to the plastic film between the panes, and the glazing remains in the frame. Although the glass will need to be replaced, the costly interior water and wind damage is avoided. On North Captiva Island, a house with laminated glass was observed where one sliding glass door panel was broken by impact from porch furniture, but the laminate held without a penetration. However, the impact of debris knocked the glass doors out of their tracks and opened the home to wind and water.

Some power-operated roll-down shutter systems were also observed. In at least one case, the shutter system did not include a manual system for retracting the shutter. As a result, it was impossible for the owner to open the shutters and air out the home after the storm. To minimize the possibility of developing mold, power-operated shutters should have alternate means of operation to allow opening after a storm.

5.2.2 Commercial and Critical/Essential Facilities

Window damage was observed on commercial buildings and critical/essential facilities throughout the impact area. Figure 5-16 shows a broken window in a mid-rise hotel in the Orlando airport area. Two windows on the same floor were likely broken by the missing plastic lens covers on the hotel sign. Figure 3-33 also showed glass breakage near the Orlando airport. In the Wauchula central business district, windborne debris broke glass in several adjacent buildings (Figure 5-17). The estimated wind speed in this area was 100 to 115 mph. In Punta Gorda, tempered glass in a door and several windows were broken by windborne debris (as shown earlier in Figure 5-2) and a nearby three-story office building had very extensive glass breakage on all sides of the building (Figure 5-18). At least some of the breakage in both buildings was caused by aggregate from a nearby built-up roof (BUR) (Figure 5-19). Other types of windborne debris also impacted the three-story building (one missile penetrated the stucco and underlying metal lath). All of the glazing, including glass spandrel panels, was broken on the long side of the building shown in Figure 5-18.

Figure 5-16.
Window most likely broken by missing plastic lens covers on hotel sign (see top of building) (Orlando airport area)

Figure 5-17.
Broken glass in windows and doors in this building. Buildings across the street also had several broken windows caused by windborne debris (Wauchula).

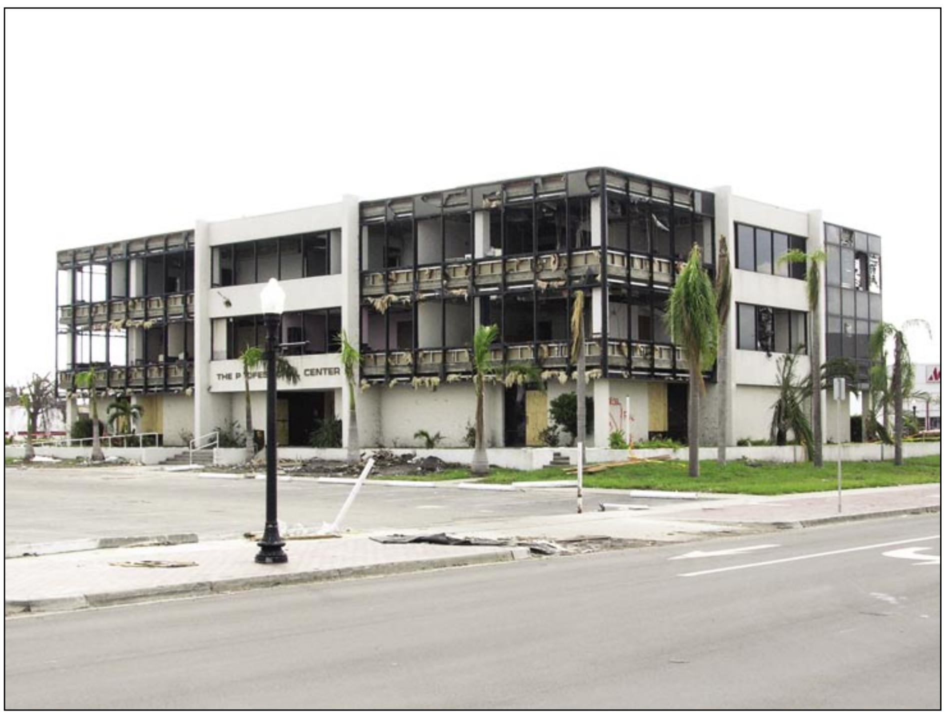


Figure 5-18.
All of the glazing, including glass spandrel panels, was broken on the long side of the building (Punta Gorda).

Figure 5-19.
Windows broken by aggregate from a nearby BUR. Besides impact at the crack intersection, aggregate chipped the glass in three other locations (Punta Gorda).

At a Charlotte County government building in Punta Gorda, a few of the windows were broken by windborne debris. Figure 5-20 shows missing spandrel panels; in other locations, the glass was broken. The windows extended from the floor to the ceiling, so tempered glass was used for personnel protection. Had laminated glass been used instead, any damaged glass would likely have stayed in its frame and would have provided wind and water protection. Glass broken by windborne debris was also observed at a hospital in Arcadia (Figures 3-41 and 6-8) and some of the fire stations in Port Charlotte and Punta Gorda.

Figure 5-20.
Plywood panels installed where aluminum spandrel panels were blown out of the curtain wall (Punta Gorda)

Skylights were not particularly common in the area, but a couple of failures were noted. In one case, the skylight in the bathroom of a manufactured home was broken by flying debris, allowing water to flood the bathroom. In another case, the failure of a skylight and difficulties in getting it replaced resulted in building officials prohibiting the owners from inhabiting their house for 2 months following the storm.

Skylights were observed at a fire station on Pine Island in the service garage area; one of these skylights blew out. It was an old plastic skylight that integrated with an R-panel roof covering. This skylight likely failed due to inadequate resistance to wind pressures rather than by missile damage.

5.3 Roof Systems

Historically, damage to roof coverings and rooftop equipment is the leading cause of building performance problems during hurricanes. Rains accompanying a hurricane can cause water to enter buildings through damaged roofs, resulting in major damage to the contents and interior (Figures 5-21 and 5-22). Unless quick action is taken to dry a building, mold bloom can quickly occur in the hot, humid Florida climate. Drying of buildings was hampered after Hurricane Charley by the lack of electrical power to run fans and dehumidifiers. These damages frequently are more costly than the roof damages themselves. Water leakage can also disrupt the functioning of critical and essential facilities and weaken ceilings and cause them to collapse. Although ceiling collapse is unlikely to result in death, it can cause injury to occupants and further frighten them as they ride out the hurricane.

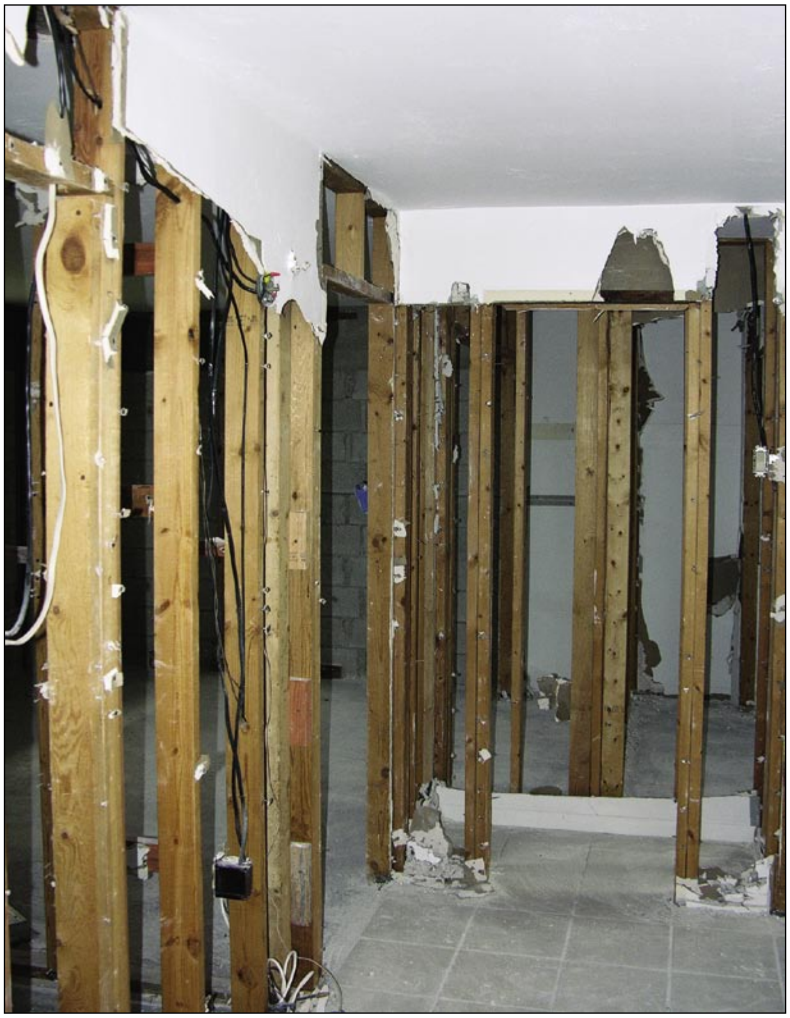


Figure 5-21.
After the attic vent failed, water entered this residence. Wet carpeting and a substantial amount of wet gypsum board had to be removed (Punta Gorda Isles).

Figure 5-22.
The attic vent to the right (temporarily covered with felt) on this foam-set tile roof lifted during the hurricane and allowed water to enter the residence shown in Figure 5-21. The failed vent is like the one on the left (Punta Gorda Isles).

Essentials to good high-wind roof system performance include selection of a suitable system; product testing to ensure sufficient factored strength to resist design wind loads; enhanced design of details; quality application; and timely maintenance and repair. In addition, for critical and essential facilities in hurricane-prone regions, it is important to design a roof system that is likely to avoid water infiltration if the roof is hit by windborne debris (guidance is given in FEMA 424, *Design Guide for Improving School Safety in Earthquakes, Floods, and High Winds*).

For steep-sloped roofs, a secondary water penetration barrier that minimizes the water infiltration through the sheathing, if the roof cover fails, offers important backup protection for shingle, tile, and metal panel installations. Figure 5-23 illustrates the installation of self-adhering modified bitumen tape at sheathing joints. The tape is installed at the joints to allow water to shed off the sheathing if the primary roof covering (e.g., shingles) and underlayment are blown off.

In lieu of attaching metal panels directly to structural members, installation of a roof deck between the panels and structure is preferred in hurricane-prone regions. The deck provides increased protection from windborne debris in the event of roof panel blow-off, as well as an opportunity for a secondary membrane.

Figure 5-23. Installation of self-adhering modified bitumen tape at sheathing joints, as part of an enhanced underlayment system on a Fortified…for safer living™ house under construction (IBHS)

5.3.1 Asphalt Shingles

Although damage was observed on several new roofs (Figures 3-14, 4-11, and 5-24), in general it appeared that asphalt shingles installed within the past few years performed better than shingles installed prior to the mid-1990s. The enhanced performance is likely due to product improvements (e.g., availability of greater bond-strength of the self-seal adhesive and availability of greater adhesive surface area) and less degradation of physical properties due to limited weathering time. It is doubtful that any of the observed roofs had been designed in accordance with UL Standard 2390, which was published in 2003. This standard pertains to two main items: 1) it provides a lab test method that manufacturers use to establish pressure coefficients for specific types of shingles; and 2) it provides a calculation procedure for a designer to determine the design wind load on the shingles, which is based on the coefficient from the testing, ASCE 7 criteria such as basic wind speed, and factors developed specifically for shingles. FEMA *Hurricane Recovery Advisories No. 1 and No. 2* (Appendix D) provide recommended practices for asphalt shingles on roofs in hurricane-prone regions. FEMA *Hurricane Recovery Advisories No. 1* and *No. 2* were based on guidance given in the fact sheets for FEMA's *Home Builder's Guide to Coastal Construction* (to be published).

Many shingle roofs in the Port Charlotte and Punta Gorda area were undamaged, while others lost a few hip and/or ridge shingles or a few tabs. Other roofs, including roofs far inland, lost many shingles, as shown in Figures 5-24 and 5-25. The shingles shown in Figure 5-24 were attached with 6 nails per shingle, but the nails were attached about 1½ inches above the nail line. In addition, the shingles were poorly bonded. Though continuous, the self-seal strip was narrow (approximately ½ inch). When shingles were pulled apart during the investigation, many granules from the underlying shingle were pulled up, thus indicating that the granules were not well embedded. The starter course was incorrectly applied, and the nails at the hip shingles were incorrectly located. Note the area where the deck is exposed. Water can flow between the deck and underlayment and leak into the building at the sheathing joints.

Figure 5-24.
Asphalt shingle roof installed on a new residence about 2 months before the hurricane hit; shingles were blown off several areas (Deep Creek).

Hip or ridge shingles were often blown off while the remainder of the shingles were undamaged. The fasteners on all of the hip and ridge shingles that were observed were located in or above the self-seal adhesive, rather than below the adhesive as recommended by the industry. However, the hip and ridge shingles were blown off because of lack of bonding of the adhesive. Sometimes a limited amount of bonding occurred as shown in Figure 5-26, but frequently none of the adhesive had bonded. Lack of bonding of hip and ridge shingles is common. Figure 5-2 shows nails that were improperly installed through the adhesive strip; they should have been driven below it. Use of asphalt cement to bond hip, ridge, and rake shingles (as recommended in FEMA 55, *Coastal Construction Manual*) was observed on only one roof.

Figure 5-25.
Residence with a significant number of asphalt shingles lost. The metal window shutters shown were not designed for windborne debris (Fort Meade).

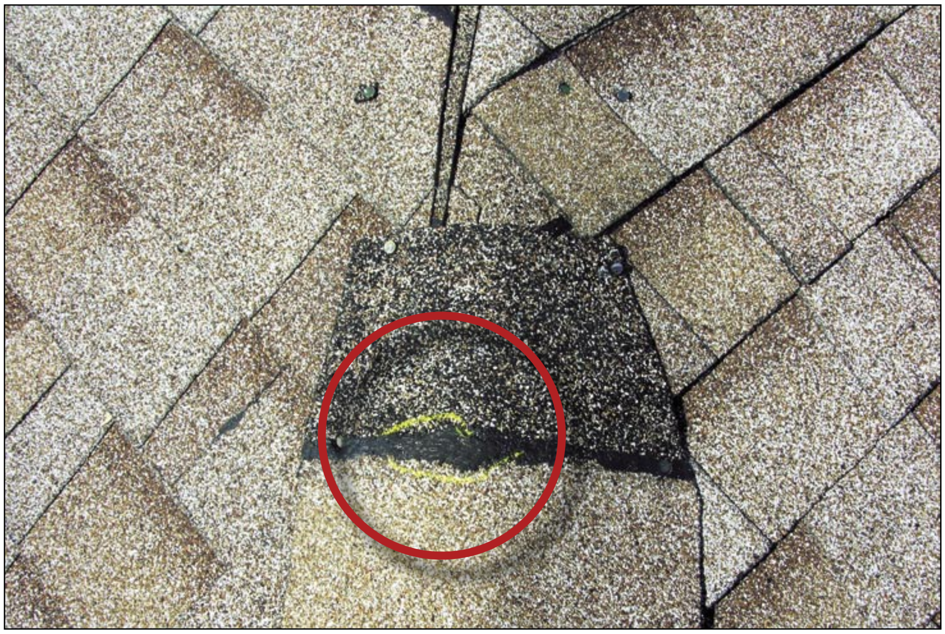


Figure 5-26.
Only the portion of the self-seal adhesive that is indicated in yellow had bonded (within the red circle). No bonding occurred on the right side of the hip line (Deep Creek).

Only one of the observed starter courses complied with industry recommendations. A common practice was to turn the starter shingle 180 degrees, rather than cut off the tabs. By turning the starter 180 degrees, the tabs of the first course of shingles were not bonded to the starter course, thereby making them susceptible to lifting. Use of asphalt cement to bond the first course (as recommended in FEMA 55, *Coastal Construction Manual*) was not observed.

On a few roofs with architectural shingles, instances of blow-off of laminated tabs were observed (Figure 5-27). This type of failure was due to an inadequate amount and/or strength of adhesive used in the manufacturing of the shingles.

Figure 5-27.
Two laminated tabs blown off (Deep Creek)

In many instances where shingles were blown off, the underlayment was not damaged and, therefore, provided some degree of protection from water infiltration. In other instances, the underlayment was also blown off. Rain was then able to enter the building at the sheathing joints. FEMA *Hurricane Recovery Advisory No. 1* (Appendix D) provides recommended practices for underlayments on roofs in hurricane-prone regions, including the use of self-adhering modified bitumen tape at the sheathing joints as shown in Figure 5-23.

On many residences that had been re-covered (i.e., new shingles had been installed on top of old shingles), large numbers of the re-cover shingles were blown away and the underlying older shingles remained in place. Some of these blow-offs may have been due to use of nails that were too short, although on the building shown in Figure 5-28, the nails had adequate sheathing penetration, but the newer shingles were poorly bonded (likely due to substrate irregularities). When re-covering versus tearing off the old shingles down to the sheathing, more substrate irregularity occurs, which can interfere with bonding of the self-seal adhesive of the new shingles. Most of the re-cover blow-offs were likely due to bonding problems associated with substrate irregularities.

Figure 5-28. Re-covered apartment building (the newer shingles are grey and the older shingles are brown) (Deep Creek).

The shingles on the roof of the elementary school shown in Figure 5-29 were installed over underlayment over two layers of gypsum board atop a steel deck. The shingles were attached with a split-shank self-locking nail. At the rakes, the shingles were set in asphalt roof cement over the metal edge flashing (somewhat similar to the detail shown in FEMA *Hurricane Recovery Advisory No. 2* (Appendix D)). The 4½-inch vertical flange of the edge flashing was not cleated. At this rake and another rake, the edge flashing lifted. Because the shingles were well bonded to the flashing, they progressively failed. The shingle end nails at the rake were well inward of the industry's recommended 1-inch placement. One of the end nails was 4 inches in from the edge of the shingle. Adhering the shingles to the edge flashing was a good practice, but the end nails should have been much closer to the edge, and the edge flashing should have had a much shorter vertical flange or the flange should have been face-fastened or cleated. Several of the laminated tabs at this school were blown off (similar to Figure 5-27). This type of failure was due to an inadequate amount and/or strength of adhesive used in the manufacturing of the shingles.

A portion of the shingles at the fire station in Cape Coral (constructed in 1991) also blew off. Water leaked into the room housing the Emergency Management Services (EMS) computer equipment, resulting in minor damage. Minor damage also occurred at a post office on Pine Island that was constructed in 1993. Performance was quite good except for the loss of a few hip shingles and laminated tabs (similar to Figure 5-27). At a fire station in Punta Gorda, many of the three-tab shingles were blown off, and many of the staples were incorrectly oriented. This was one of the few roofs observed that had been attached with staples.

Figure 5-29.
Edge flashing that caused a progressive failure of the shingles (Deep Creek)

Several instances of ridge vent blow-off were observed. The performance of ridge vents with respect to prevention of wind-driven rain infiltration during the hurricane was not evaluated.

The use of a larger number of nails (six instead of four) to attach shingles may have also played a role in the improved resistance of some of the newer roofs, but this was not verified through detailed inspections of the installations because it would have required access to the attics. The fasteners on all of the damaged shingles that were observed were located too high above the nailing line (i.e., the line printed on the shingle by the manufacturer). Fasteners were typically located 1 to 2 inches above the nailing line. End fasteners were often 2 to 3 inches from the end, rather than the industry-recommended 1 inch. Nails rather than staples were used to attach most of the shingle roofs that were investigated.

5.3.2 Tiles

Clay and concrete tiles were observed, with concrete being the most common. A variety of tile profiles (e.g., S-tile and flat) were also observed, but no significant wind performance differences were attributed to profile. Mortar-set, mechanically attached, and foam-set (adhesive-set) attachment methods for tile roofs were observed during the assessment. Tile damage was observed along the path of the hurricane from the Port Charlotte/Punta Gorda area to Orlando. For the areas east of Port Charlotte and Punta Gorda, damage was typically limited to blow-off of hip and ridge tiles and blow-off of tiles along eaves. In the areas of Port Charlotte and Punta Gorda that received very high winds, there were larger areas of blown-off tiles. Tile underlayments were generally not blown off, with few exceptions (Figure 5-30). Therefore, many buildings with significant tile damage likely experienced little, if any, water infiltration from the roof.

Figure 5-30.
A large area of underlayment at this mortar-set flat tile roof blew away. The loss of tile underlayment was atypical (Punta Gorda).

5.3.2.1 Mortar-Set Tile Roofs

The size of the blow-off area of tile roofs attached using mortar-set systems was typically much greater than for tile roofs attached using foam-set and mechanically attached systems. Figure 3-31 showed a mortar-set roof with a large area of blown-off tiles.

On the roof shown in Figure 5-31, some of the tiles debonded from the mortar patties; other tiles debonded from the underlayment; and, in other instances, the underlayment tore off with the mortar. Mixed failure modes also occurred on the roof shown in Figure 5-32. Mixed failure modes also occurred in Hurricane Andrew (FEMA FIA-22, 1992). The mortar patties at the roofs shown in Figures 5-31 and 5-32 were incorrectly located, and most of them were too small.

On the roof shown in Figure 5-32, most of the mortar-set hip and ridge tiles blew off. Some of the mortar-set flat tiles were also blown off, and other field tiles were broken by windborne debris (likely other tiles from this roof). Figure 5-33 shows three tiles from the roof shown in Figure 5-32. The mortar paddy on the left debonded from the underlayment. For the other two tiles, the underlayment tore away. The paddies were incorrectly located near the head of the tiles, which offers reduced uplift resistance.

Figure 5-31.
Mixed failure modes occurred on this mortar-set tile roof (Port Charlotte).

Figure 5-32.
Most of the mortar-set hip and ridge tiles blew off this house (Port Charlotte).

Figure 5-33.
Tile debris from the roof shown in Figure 5-32 (Port Charlotte)

5.3.2.2 Mechanically Attached Tile Roofs

Both direct-to-deck and batten-attached systems were investigated. Figure 5-34 shows a batten-attached system where the roof is attached with nails. According to 2001 FBC (Table 1507.4.7), the attachment method observed on the roof shown in Figure 5-34 is suitable for buildings with a mean roof height up to 40 feet in areas with a design wind speed of 100 mph.[1] The building (which has a mean roof height of less than 15 feet) is located in an area that is now mapped with a wind speed of approximately 110 mph; therefore, the installed attachment at this older residence was inadequate to meet the current code. The estimated speed at this Exposure B location was in the range of 110 to 120 mph. If the speed was in the lower portion of this range, the tiles did not perform as predicted by 2001 FBC (i.e., the tiles should have been good for 100 mph at a roof height up to 40 feet).

[1] In this chapter, basic wind speeds cited from the 2001 FBC are 3-second peak gust wind speeds, Exposure B, unless otherwise noted.

Figure 5-34.
Each tile on this building was attached to battens with a single 3$^1/_8$-inch long smooth shank nail (Arcadia)

The building shown in Figures 5-35 and 5-36 is located in an area with a basic wind speed of approximately 120 mph. The 2001 FBC, therefore, requires compliance with the calculation method given in Section 1606.3.3. Load and resistance data can be found in the March 1, 2003, Addendum to the 3rd edition of the *Concrete and Clay Tile Installation Manual* (published by the Florida Roofing, Sheet Metal and Air Conditioning Contractors Association [FRSA] and Roof Tile Institute [RTI]). The roof in Figures 5-35 and 5-36 was attached with one 2½-inch long screw per tile directly to the deck. According to Table 12 of the Addendum, the attachment of this roof is suitable for buildings with a mean roof height up to 40 feet in areas with a basic wind speed of 150 mph. The estimated speed at this Exposure B location was in the range of 125 to 140 mph; therefore, the tiles did not perform as predicted by the *Concrete and Clay Tile Installation Manual*.

At a residence near the one shown in Figure 5-35, missiles (likely tiles from its roof) broke a few field tiles. The field tiles were attached with one screw per tile directly to the deck.

Figure 5-35.
Windborne debris (likely tiles from this roof) broke several of the field tiles (Deep Creek).

Figure 5-36.
Loss of mortar-set hip tiles and several of the field tiles. Some of the screws remained in the deck, while others had been pulled out (Deep Creek).

Figure 5-37 shows several areas where batten-attached tiles on a fire station were damaged. The tile debris on the lower roof is from the upper roof. The tiles were installed when the building was re-roofed in the mid- to late-1980s. According to the 2001 FBC (Table 1507.4.7), the attachment method observed on this roof is suitable for buildings with a mean roof height up to 40 feet in areas with a basic wind speed of 100 mph. The building (which has a mean roof height of less than 30 feet) is located in an area that is now mapped with a basic wind speed somewhat less than 110 mph; therefore, the installed attachment at this pre-2001 FBC building does not meet the current code. The estimated speed at this Exposure B location was in the range of 95 to 110 mph. The tiles did not perform as predicted by the code (i.e., the tiles should have been good for 100 mph at a roof height up to 40 feet).

Figure 5-37.
Fire station with at least three battens blown off. Some tiles remained attached (Fort Meade).

5.3.2.3 Foam-Set Tile Roofs

The foam-set attachment method was developed after Hurricane Andrew in response to the widespread poor performance of mortar-set systems. Hurricane Charley was the first hurricane to deliver at or near-design wind speeds to this new attachment method. One- and two-part specially formulated polyurethane foam tile adhesives are available. Depending upon design uplift pressures and tile profiles, a variety of proprietary paddy schemes are available, including single paddy placement (with either small, medium, or large paddies) and two paddy placements. Although large areas of blow-off were unusual with this attachment method, they were observed on some residences.

A large number of damaged foam-set systems were observed as shown in Figures 5-38 through 5-45. Significant installation problems were observed with the size and/or location of the foam paddies. The side of the residence shown in Figure 5-38 was the side the damaging winds came from. Assuming the intent was to provide a small paddy placement, according to the foam manufacturer's literature, this attachment would have been suitable for a basic wind speed of 135 mph in Exposure B (assuming proper application). According to the 2001 FBC, the basic wind speed where this residence is located is approximately 125 mph; therefore, this small paddy placement meets code. The estimated Exposure B wind speed at this site was in the range of 125 to 140 mph. If the foam paddies had been properly sized and located according to the manufacturer's literature, the tiles should not have blown off.

In Figure 5-39, to meet the small paddy placement criteria, the paddy should have been 3 inch by 3 inch minimum, with approximately 8 to 9 square inches of foam contact with the tile near the head. As shown in the photo, clearly there was very insufficient contact area. The paddies were rectangular rather than square; perhaps a medium paddy placement was intended. To meet the medium paddy placement criteria, the paddy should have been 2 inch by 7 inch minimum, with approximately 12 to 14 square inches of foam contact area. The small round paddies shown in Figure 5-39 were placed after the down-slope tiles were set. Foam from these paddies occurred between the tile end laps. These round paddies are not shown in the foam manufacturer's installation instructions. Although failed tiles typically debonded from the paddies, in at least one location, the paddy debonded from the cap sheet underlayment.

Figure 5-38.
In addition to the damage shown in this photo, this one-story roof lost virtually all of the hip and ridge tiles (see Figures 5-22, 5-39, and 5-40) (Punta Gorda Isles).

Figure 5-40 is a close-up of the eave area of the roof shown in Figure 5-38. The manufacturer's installation instructions do not require screws, but they do require foam paddies.

Figure 5-39.
Note the very small contact area of foam at the tile heads (left side of the tiles) and very small contact area at the tails. The long narrow paddies were intended to be underneath the pan portion of the tile (Punta Gorda Isles).

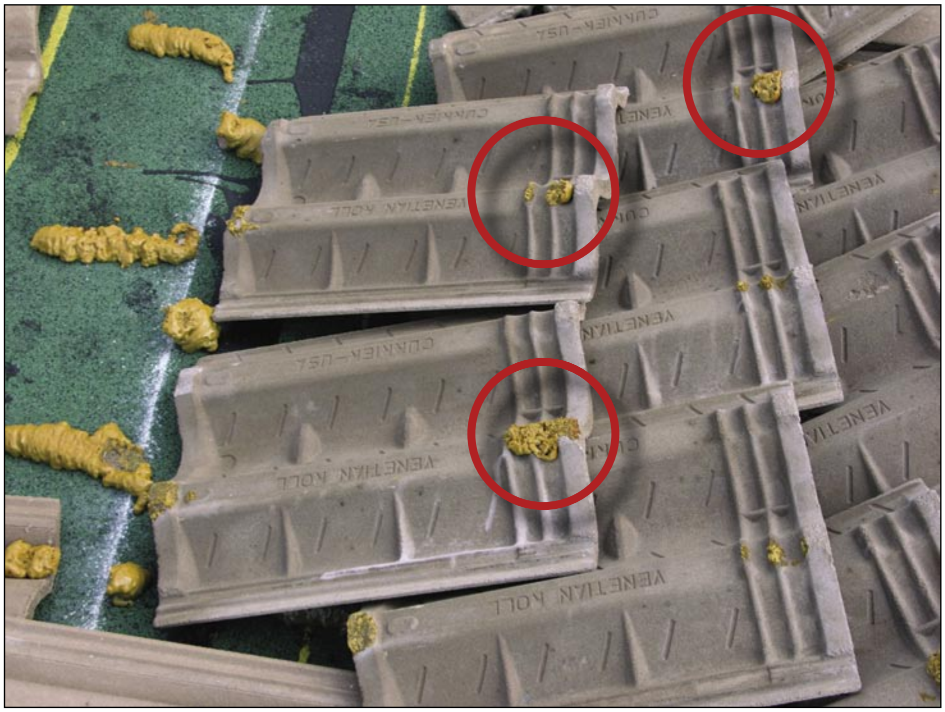


Figure 5-40.
View of the eave. The first row of tiles was attached with two screws per tile; foam was not used to adhere this row (Punta Gorda Isles).

The residence shown in Figures 5-41 and 5-42 was located in an area identified in the code with a basic wind speed of approximately 125 mph. Assuming the intent was to provide a small paddy placement, according to the foam manufacturer's literature, this attachment would have been suitable for a basic wind speed of 135 mph in Exposure B (assuming proper application). The estimated speed at this Exposure B location was in the range of 125 to 140 mph. Therefore, had the foam paddies been properly sized, located, and installed according to the manufacturer's literature, the tiles should not have blown off.

To meet the small paddy placement criteria, the paddy should have been 3 inch by 3 inch minimum, with approximately 8 to 9 square inches of foam contact with the tile near the head. The paddies were typically about the correct size, but they did not achieve the required contact area (see inset in Figure 5-42). The paddies were also typically located too close to the upslope end of the tile. In Figure 5-42, the first row of tiles at the eave was attached with one nail and a foam paddy. Most of the nails remained in the deck. The foam manufacturer's instructions do not require nails at the eave. (The dark spots on the tile are rain drops.) An attic vent also rolled back and allowed water to enter the building.

Figure 5-41.
In addition to field tile blow-off, most of the hip tiles and several ridge tiles were also blown off this house (Punta Gorda Isles).

Figure 5-42.
The paddy on the tile at the lower left debonded from the asphalt bleed-out near a cap sheet lap. Only the center portion of the paddies made contact with the tiles, as shown in the inset (Punta Gorda Isles).

Several foam-set tiles were blown off a one-story bank (Figures 5-43 through 5-45), primarily due to insufficient contact area of the paddies. To meet the small paddy placement criteria, the paddies should have provided approximately 8 to 9 square inches of foam contact with the tile near the head. The paddies were observed to be about the correct size, but they did not achieve the required contact area. The paddies were also typically located too close to the upslope end of the tile. Though not required, a very small paddy was placed at the tile overlaps (red arrow in Figure 5-43). The tiles typically debonded from the paddies, but the two paddies shown at the bottom of Figure 5-43 debonded from the cap sheet. Many mortar-set hip and ridge tiles were also blown off. The bank was located in an area identified in the code with a basic wind speed of approximately 125 mph. Assuming the intent was to provide a small paddy placement, according to the foam manufacturer's literature, this attachment would have been suitable for a basic wind speed of 135 mph (assuming proper application). The estimated speed at this location was in the range of 125 to 140 mph. Therefore, had the foam paddies been properly sized and located, according to the manufacturer's literature, the tiles should not have blown off.

Figure 5-43.
This photo clearly shows insufficient contact area of foam-set paddies on the bank's roof (Punta Gorda Isles).

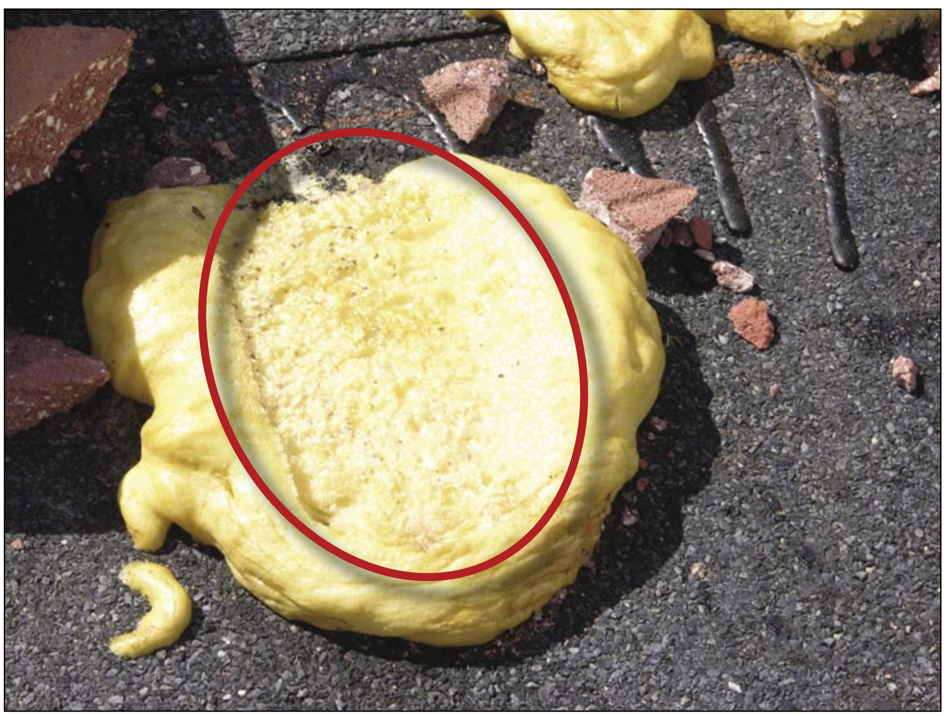


Figure 5-44.
In this photo, the portion of the paddy that made contact with the tile is clearly visible (Punta Gorda Isles).

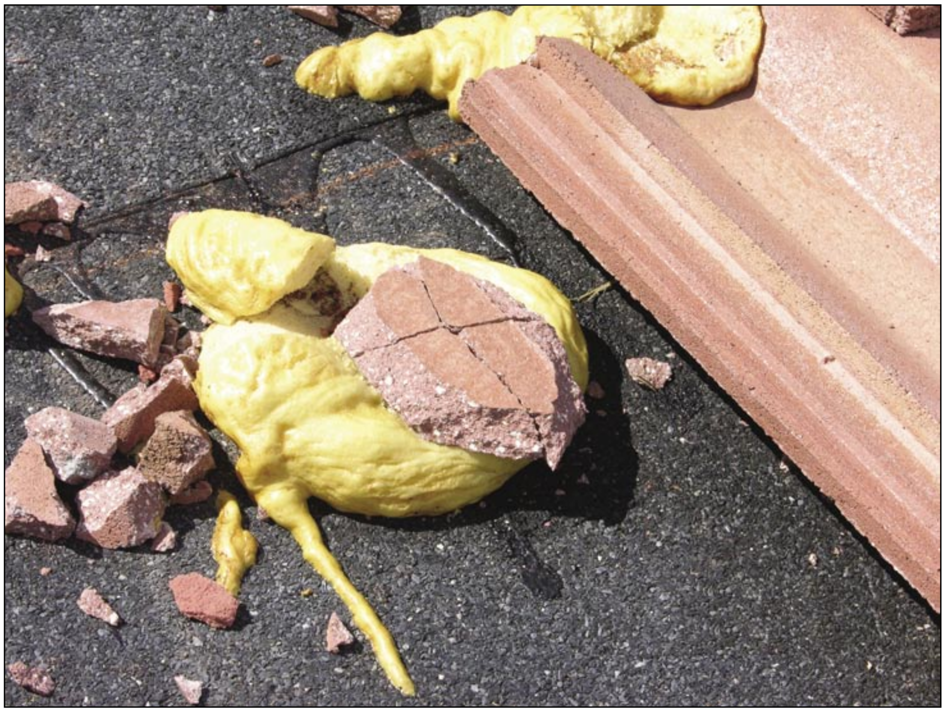


Figure 5-45.
Tile remained bonded to the paddy, but, except where bonded, the tile blew away. A large portion of the paddies shown in Figure 5-43 and this figure failed to make tile contact, which was a typical observation (Punta Gorda Isles).

5.3.2.4 Hip and Ridge Tiles

Blow-off of hip and ridge tiles as shown in the previous figures was very common, even in areas with only moderate wind speeds. Most of the hip and ridge tiles that were investigated were attached with mortar, although a few were attached with mortar and a single nail. The installation of a nail near the head of the hip and ridge tiles did not greatly improve blow-off resistance. Because the hip and ridge tiles project several inches above the adjacent field tiles and form a transition between different roof surfaces, the raised hip/ridge line of tiles may be subjected to higher wind loads than expected on the field tiles due to turbulence. This research issue is worthy of future investigation. The vulnerability of hip and ridge tile blow-off was documented following Hurricane Andrew (FEMA FIA-22, 1992). It was reported that the current design guidelines were inadequate (T.L. Smith, 1994).

5.3.2.5 Sprayed Polyurethane Foam

A few tile roofs that had been covered with sprayed polyurethane foam (SPF) were investigated by the MAT. Figure 5-46 shows one of these roofs. A missile had impacted the foam and gouged it in several locations, but no tile debris was blown off. The SPF appeared to provide some protection for the tiles. However, SPF applications may not improve the uplift resistance. Figure 5-47 shows a roof that lost SPF covered tiles. In this instance, the SPF bonded tiles together and, as a result, large sections of tiles were lifted off the roof. Although the larger fragments should not fly as far as smaller fragments, because they are more massive, they could be more damaging (depending upon their velocity) if they were to become windborne.

Figure 5-46.
This residence had a tile roof that had been covered with SPF. A missile gouged the foam, but no tile debris was blown off (Punta Gorda Isles).

Figure 5-47.
The other side of the roof shown in Figure 5-46 with a portion of the underlayment and several tiles blown off (Punta Gorda Isles)

5.3.2.6 Tile Missiles

There were many reports of tiles or tile fragments hitting occupied buildings and flying through windows (shown previously in Figures 3-31 and 3-32). The owner of one residence reported that six of their windows were broken by tiles from a neighbor's house (Figure 5-48). The homeowner's metal roof was not damaged, but wind-driven rain forced through the broken windows caused extensive interior wind and water damage.

Figure 5-48.
Tiles that flew through windows of an occupied residence (Deep Creek)

In addition to becoming windborne debris and further damaging the roof on which they were installed, many tile roofs were damaged by other types of windborne debris. One of the advantages of foam-set, according to one of the manufacturer's literature, is that foam-set installation is supposed to result in "high resistance to damage from missile impact," meaning that the "tile may break but remains adhered to the roof." Although this may be true for the portion of the tile that is adhered, the MAT observed that broken portions that are not adhered are vulnerable to being blown away as shown in Figure 5-49.

It is important to note that other types of roofing systems are also capable of generating windborne debris (Figure 3-34); however, missiles are most problematic with tiles. FEMA *Hurricane Recovery Advisory No. 3* (Appendix D) provides recommended practices for tiles on roofs in hurricane-prone regions. This Advisory was based on observations from Hurricanes Charley, Frances, and Ivan.

Figure 5-49.
A view of the roof on the back side of the residence shown in Figure 5-41. Tiles (including a hip tile) from the front garage roof landed in this area and broke several field tiles (Deep Creek).

5.3.3 Metal Panel Roofs

Although small in number compared to houses with asphalt shingle and tile roofs, several residences in the Port Charlotte, Punta Gorda, Pine Island, and Sanibel and North Captiva Island areas had metal roof coverings. Many of these coverings were 5V-Crimp metal panels. This type of panel uses exposed fasteners (Figure 5-50). The majority of the 5V-Crimp metal panel roofs observed were not damaged, or only experienced hip or ridge flashing damage. However, significant panel loss was observed at a few residences. At a fire station on Pine Island, the 5-V Crimp metal panels blew off the main building and the plywood panels blew off with the panels. Furring strips (1x) occurred between the plywood and the trusses. The furring strips, which had been stapled to the trusses, were lifted off with the plywood and likely were the cause of the panel loss. There was significant water infiltration; however, a temporary roof had been installed after the hurricane, and the station was occupied at the time of the investigation.

Success or failure of the 5-V Crimp metal roof coverings was likely primarily dependent upon fastener spacing and type, although panel gauge may have had some influence (panels are available in 24 to 29 gauge). Screws provided greater pull-out resistance than ring-shank nails and were more resistant to dynamic loading. One of the failed roofs that were investigated was attached with ring-shank nails.

Another key element of good performance is the spacing of fasteners along the eave and at hip and ridge flashings. Only a single fastener occurred at the eave between the rib fasteners shown in Figure 5-50; considering the basic wind speed of 125 mph 3-second peak gust in this location, use of two fasteners between the ribs would have been prudent. Note that the hip flashing is bowed; two fasteners between the ribs would have also been prudent at the flashings. Close spacing at the flashings and eave is important to keep the flashings and panel ends from billowing during high winds. Although the roof in Figure 5-50 did not fail, the flashing and eave fasteners were too far apart.

Figure 5-50.
The number of fasteners was not increased at the corner, perimeter, hip, or ridge areas (close-up of the residence shown in Figure 5-5). Also note that several of the soffit panels were blown away (Deep Creek).

Most of the 5V-Crimp panels that blew off failed as a result of the panel fasteners pulling out of the sheathing. However, plywood substrate blow-off and wood nailer failures were also observed (Figure 5-51). The upper asphalt shingle roof shown in Figure 5-51 had been recovered with 5V-Crimp panels attached to nailers. The nailers were inadequately attached to the sheathing. Note that the hip flashing on the lower roof blew off.

Figure 5-51.
These panels blew off the upper roof and landed on the lower roof of this house (Bokeelia, north end of Pine Island).

All of the 5V-Crimp roofs that were observed were unpainted galvanized or aluminum-zinc alloy ("Galvalume") panels. Aluminum-zinc alloy panels are very resistant to corrosion. No significant corrosion problems were observed. An advantage of 5V-Crimp (and other types of exposed fastener) panels (versus panels with concealed clips) is that, after installation, it is easy to verify that the correct number of fasteners were installed.

A variety of architectural metal panels were also observed. As with the 5V-Crimp panels, some of the roofs were undamaged, others had lost hip or ridge flashings, and others lost a large number of panels. Performance of architectural panels is a function of the strength of the panels and their interlock with the clips, clip spacing and attachment, and strength of the flashing attachments. Some of the failed hip and ridge flashings were attached with cleats rather than exposed fasteners. Cleat attachment is not as reliable as exposed fasteners.

When metal panels or hip/ridge flashings blow off, they can become high-energy windborne debris that can damage buildings and other property and cause injury. These types of windborne debris can travel a considerable distance.

A variety of exposed fastener and architectural and structural metal panels were observed on commercial and critical/essential facilities. Figures 5-52 through 5-54 show a medical office building that lost approximately 75 percent of the superstructure supporting the architectural metal panel roof that encircled the perimeter of the building. This building experienced significant water damage. Although much of the aggregate roof covering remained in the center portion of the roof, temporary roof covering (Figure 5-53) was installed to minimize water intrusion after the metal panel structure blew away.

Figure 5-52. Medical office building (Port Charlotte).

Figure 5-53. The wood and metal framed superstructure blew away and exposed the lightweight insulating concrete roof deck (Port Charlotte).

Figure 5-54.
View of the canopy ridge at the building shown in Figure 5-52. The ridge flashing fasteners were placed too far apart. A significant amount of water leakage can occur when ridge flashings are blown away (Port Charlotte).

Figure 5-55 shows a roof on a school in Arcadia that performed fairly well; the building was located inland in an area that experienced approximately 110 to 120 mph wind speeds. Temporary repairs to the roof covering had been made prior to this photo taken by the MAT.

Figures 5-56 and 5-57 show an architectural panel roof on a fire station in the Deep Creek area that performed poorly, with metal panels that were blown off. At this station, the 2-inch high ribs had a 16-inch spacing. The panels had a single-lock fold. There were two screws per clip. Typically the clips remained attached to the deck, but some did not. Clip spacing varied widely across the roof and from panel to panel with spacings ranging from 2 feet 4 inches to 3 feet 3 inches. The eave clips shown in Figure 5-57 should have been located near the edge. It would have been prudent to install double clips along the eave.

At the headwall flashing, the flashing was pop-riveted to the panels at 16 inches on center. Along one side of the hip, the flashing was attached at 2 feet 2 inches; on the other side of hip line, they were at 1 foot 10 inches. The hip and headwall flashing fastener spacing was excessive; for the building code design requirements in Charlotte County, a fastener spacing of 4 to 6 inches on center is typically used, depending on the design wind speed at one site. Some panels on another roof area were damaged by windborne debris (OSB panels), and water entered the building at the penetration location.

Figure 5-55.
This standing seam metal roof had a 16-inch rib spacing. There was some rake flashing damage, and a few rake panels were also damaged (Arcadia).

Figure 5-56.
Several of the architectural panels and hip flashings blew off this fire station (Deep Creek).

Figure 5-57.
This photo provides a view of the eave of the building shown in Figure 5-56. The clip at the left was 13 inches from the edge of the deck. The other clip was 17 inches from the edge (Deep Creek).

Several structural standing-seam trapezoidal panel system failures were observed, including the panels on the Turner Agri-Civic Center in Arcadia, which partially collapsed (see Section 6.5.1.1. and Figures 6-17 and 6-18). It was reported that the roof covering was lifting prior to the collapse. The panels were installed over fiberglass batts over a vapor retarder atop the light-gauge purlins.

Figure 5-58 shows an exposed fastener R-panel roof on two old pre-engineered metal buildings that had been re-covered with SPF. A large wall section blew out of one of the buildings, and the edge flashing was torn away, but the metal roof panels remained in place. At an adjacent building with a similar roof, the metal panels on a canopy were blown away, but the failure did not propagate into the roof panels on the main building. The SPF covering likely prevented progressive failure at both of these buildings due to the stiffness that it imparted to the panels.

Figure 5-59 shows a mansard with metal shingles simulating tiles. The metal shingles performed well. However, metal shingles can also experience significant damage as discussed in FEMA 489, *Hurricane Ivan in Florida and Alabama.* Note that the rooftop mechanical equipment in Figure 5-59 remained attached to the support stands. Also note the lightning protection system on the parapet in the foreground. One of the conductor connectors detached from the roof and the conductor pulled out of some of the connectors.

Figure 5-58.
The metal wall panels and metal edge flashing on this building blew away, but the exposed fastener R-panels with an SPF covering did not progressively fail (Wauchula).

Figure 5-59. Metal shingles (simulating tile) that performed well (Port Charlotte)

5.3.4 Low-Slope Membrane Systems

The MAT observed several types of low-slope roof systems. These systems included BURs, modified bitumen, and single-ply, which are described below.

5.3.4.1 Built-Up Roof (BUR) and Modified Bitumen

A BUR failure was observed at one of the terminals at the Orlando International Airport. Portions of its BUR blew off, resulting in water infiltration. To dry out the interior and to avoid mold growth, the airport used large air dryers to remove the moisture.

At a hospital in Arcadia, several windows at the intensive care area were broken by windborne debris (Figure 6-8). Most, if not all, of the windborne debris was aggregate from the hospital's roofs. Three of the eight intensive care rooms were taken out of service due to the glass breakage and windows were broken in other patient rooms. Gutters and walkway pads were also blown off (Figure 5-60). The gutters and pads possessed sufficient mass to be very damaging missiles and may have caused some of the glass breakage observed.

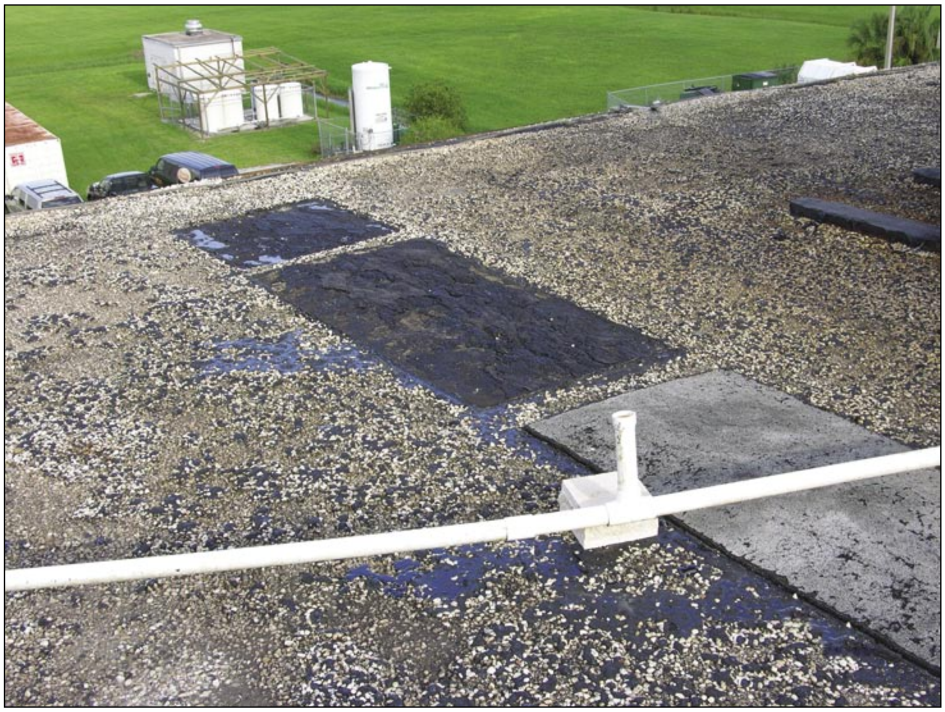


Figure 5-60.
This view of the back side of the upper roof of a hospital (see Figure 6-8) shows that the missing gutter and asphalt plank walkway pad were blown away (Arcadia).

Aggregate commonly used on BUR systems was blown off many buildings. One example is shown in Figure 5-61 where the school was being used as a shelter. There was no other apparent damage to the roofs at the school, including the mechanically attached single-ply membrane on a courtyard building. The boarded-up broken windows at the residence across from the school in Figure 5-61 were likely broken by aggregate from this roof. Roofing aggregate was found at the far side of the street in front of the house. The inner leg of the coping in Figure 5-61 was attached with screws spaced at 3 feet 5 inches, 2 feet 11 inches, and 3 feet 1 inch; the coping was not damaged. Aggregate also blew off a new portion of a hospital in Port Charlotte, but no missile damage was observed. At another roof area of the hospital, a portion of the mineral surface cap sheet roof was blown off. The metal edge flashing had improperly been installed underneath the membrane; therefore, the flashing was unable to clamp the roof edge. Wind lifted the gutter and metal edge flashing and peeled the roof membrane. Figure 5-62 shows an area of the hospital roof that nearly failed. With the flashing in a lifted position, the membrane was very susceptible to peeling. Apparently the winds subsided before this occurred.

Figure 5-61.
Although this roof had an 11-inch high parapet, aggregate was blown off (Port Charlotte).

Figure 5-62.
The edge flashing at this mineral surface cap sheet roof lifted (Port Charlotte).

An edge flashing failure also occurred at a middle school in Cape Coral, first occupied in 1998 (Figure 5-63). This metal edge flashing had also been improperly installed underneath the membrane. The flashing should have been installed over the modified bitumen cap sheet and then stripped in to clamp the edge of the membrane. Wind lifted the gutter and metal edge flashing and peeled the modified bitumen membrane. The gutter was not designed for uplift resistance. A portion of a middle school in Port Charlotte also had a mineral surface BUR cap sheet roof, and the metal edge flashing had also been improperly installed underneath the membrane. However, none of the edge flashings lifted. Except for some missile damage, the BUR on this roof performed very well.

Figure 5-63.
The edge flashing had a 2-inch vertical flange that extended into the gutter. The flashing was not cleated (Cape Coral).

A high school in Arcadia had an aggregate surface BUR over lightweight insulating concrete (LWIC) over steel form deck that had been installed in the mid-1970s. Two areas over the cafeteria blew off, as did a portion over the gym. Repairs had been made by the time the MAT inspected, so it was not possible to definitively determine the cause of the failures. The failures at the cafeteria occurred several feet from the parapet. These failures may have been due to base sheet rupture around the fasteners (which may have been due to spacing problems, fastener corrosion, or deterioration of the base sheet), or deformation or cracking of the LWIC. At the gym roof, the blow-off area extended to the parapet, but it was unclear if the blow-off originated at the parapet. This roof may have failed for the reasons given at the cafeteria, or this failure may have been related to the coping or base flashing attachment. The 13½-inch-wide coping was attached only at each coping joint with three nails in the horizontal flange and one in the vertical flange. There was significant water infiltration in the cafeteria and gym.

5.3.4.2 Single-Ply

One aggregate ballasted system was observed in the Orlando airport area. Some aggregate was blown off the roof, but this may have been due to gutter blow-off. A detailed investigation was not performed. In addition to the BURs discussed above, one of the hospitals in Port Charlotte had single-ply membranes at two different areas. There was no apparent damage to the mechanically attached ethylene propylene diene monomer (EPDM) membrane roofs on the lower levels. However, there was extensive damage to the mechanically attached polyvinyl chloride (PVC) membrane (with 6-foot 3-inch row spacing) on the fourth floor roof (the highest roof), as shown in Figure 5-64. Emergency repairs had been made, so it was not possible to definitively determine the cause of the failure. Mechanical equipment was missing and portions of the lightning protection system (LPS) had become detached. It is possible that a piece of equipment or LPS conductor cut the membrane, and a progressive failure occurred. Extensive water damage was observed on the fourth floor and some on the third floor. The fourth floor was evacuated after the roof membrane blew off.

Figure 5-64.
View of a portion of the fourth floor roof of a hospital after installation of an emergency roof (the black area). The deck was concrete (Port Charlotte).

In addition to the BUR discussed above, the middle school in Port Charlotte also had single-ply membranes on two roof areas. Wind likely lifted the gutter and metal edge flashing and peeled the membrane on the gym (Figure 6-21). At a lower roof, the mechanically attached PVC alloy membrane with 4-foot 3-inch row spacing was installed over polyisocyanurate insulation over an old BUR over LWIC over a steel form deck (shown previously in Figure 3-59). The failure of this roof was also likely initiated by gutter failure. However, it may have been initiated by progressive tearing after missile impact (there were numerous missile tears), or by pull-out of membrane fasteners. Several membrane fasteners near the edge of the roof had been pulled out, which is not surprising. Metal form decks are typically thinner and therefore offer less pull-out resistance than standard steel decks.

At a county building in Punta Gorda, the mechanically attached PVC alloy membrane was punctured in several areas. Because the roof was much taller than surrounding buildings, the punctures were likely caused by rooftop equipment that was blown away and by the LPS components that became detached. The membrane peeled back at a corner area, but since emergency repairs had been made at the time the MAT visited, it was not possible to definitively determine the cause of the failure. The membrane fastener rows were at 4 feet 6 inches on center in the field of the roof. At the perimeter, the rows were 1 foot 11 inches on center. The perimeter width was 11 feet 8 inches. The corners appeared to be attached in the same manner as the perimeter.

5.3.5 Gutters and Downspouts

Gutters and/or downspouts were blown off many buildings. In most cases, loss of gutters caused little or no damage to the steep-slope roof coverings to which they were attached; however, the gutters and downspouts that were blown off became windborne debris. As discussed in Section 5.3.4, loss of gutters often resulted in lifting and progressive failure of low-slope membrane systems.

5.4 Wall Coverings, Non-Load Bearing Walls, and Soffits

Hurricane Charley caused wall covering, non-load bearing walls, and a significant amount of soffit damage throughout the hurricane path. The following factors are essential to resist high winds: product testing to ensure sufficient factored strength to resist design wind loads; suitable anchoring of the wall coverings, non-load bearing walls, and soffits to the building; use of moisture barriers (e.g., asphalt saturated felt or housewrap) where appropriate; and proper flashing, sealants, and drainage to minimize water intrusion into wall cavities or into occupied space.

5.4.1 Wall Coverings

Wall covering damage was observed by the MAT primarily on houses with vinyl siding. There were several instances of vinyl siding failure as shown in Figures 5-65 and 5-66 (and previously in Figure 3-24). Wall covering failure was more commonly observed in manufactured home parks than elsewhere in the hurricane's path. When vinyl siding was blown off, the underlayment (either asphalt-saturated felt or housewrap) was also typically blown away. With loss of the siding and underlayment, wind-driven rain was then able to enter the wall cavity, causing water damage and initiating mold growth. Vinyl sidings that became windborne debris were capable of breaking unprotected windows.

Vinyl siding that was blown off typically tore around the fastener points. Vinyl siding manufactured for high-wind areas is available. With high-wind siding, the nailing flange is folded over, so there is a double thickness of vinyl at the fastener points. None of the failures that were observed used high-wind siding.

In some cases, the MAT believes that the blow-off was triggered by unlatching of the bottom portion of the panel (Figure 5-65). Once the panel unlatches from the retainer slot just below the nailing flange, the panel is free to rotate outward where it can be caught by the wind and blow off. The magnitude of the unlatching issue, compared to the strength of the nailing flange and fastener spacing, is unknown. When unlatched, panels are very susceptible to blow-off.

Figure 5-65.
The vinyl siding panel with the red arrow is unlatched. The panel above and several others are also unlatched (Zolfo Springs).

Vinyl siding is quite susceptible to windborne debris damage as shown by Figure 5-66. Because the vinyl siding cannot resist debris impact, resistance to debris impact is provided by the wall sheathing (if any) between the siding and the wall studs. On some of the residences, plastic foam sheathing was used instead of wood sheathing between the vinyl and the studs. The walls of these buildings offered very little resistance to windborne debris penetration, as they were composed only of vinyl siding, underlayment, foam sheathing, fiberglass batt insulation in the wall cavity, and gypsum board on the interior side of the studs. Residents who rode out the hurricane in their homes were quite susceptible to injury from windborne debris penetrating the light exterior walls.

Underlayment had not been installed at all on some residences and at the Bokeelia Post Office on Pine Island (constructed in 1993). Not installing underlayment is a poor practice because vinyl siding (like many other types of wall coverings) does not prevent water from getting behind the siding. Underlayment should always be installed to intercept the leakage and drain it out of the wall. The 2001 FBC does not currently require underlayment underneath vinyl siding. Further discussion and analysis of vinyl siding is presented in FEMA 489, *Hurricane Ivan in Florida and Alabama*.

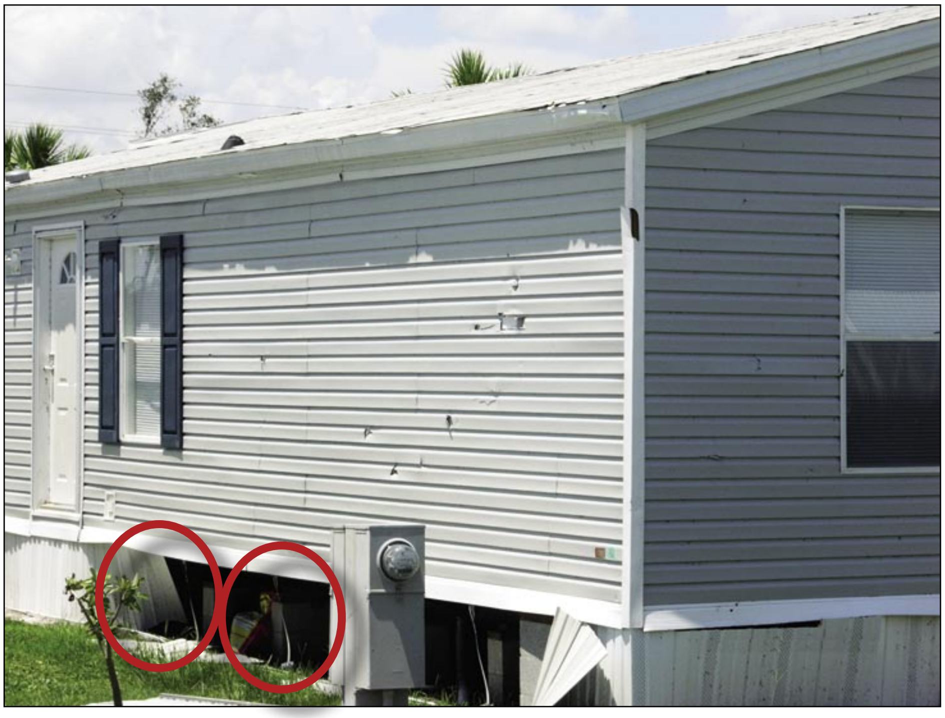


Figure 5-66.
The vinyl siding on this manufactured house was ruptured in several locations by windborne debris (most of which were likely building envelope components from other nearby manufactured houses). Note the missing skirt and loose foundation anchor straps (Zolfo Springs).

A variety of wall coverings other than vinyl siding were observed. They also typically performed well, but there were exceptions. There were several instances of metal wall panel failures; these typically occurred on older pre-engineered metal buildings. The key to achieving good performance of metal panels is selecting an appropriate panel system and installing an adequate number and type of fasteners. Figure 5-67 shows good attention to attachment of metal fascia panels on a school. Stitching the termination of panels with closely spaced fasteners as shown in Figure 5-67 prevents the end of the panel from billowing and becoming detached from the concealed clips.

Figure 5-67.
Standing seam metal panels with a 16-inch rib spacing were used at the fascia and secured with closely spaced exposed fasteners (Arcadia).

5.4.2 Non-Load Bearing Walls

Exterior non-load bearing walls generally performed well, but there were notable exceptions. Figure 3-25 showed a collapsed unreinforced masonry wall. Figures 3-33 and 5-68 show extensive EIFS failure on a hotel near the Orlando airport. Other EIFS damage was shown in Figure 3-26. Further discussion and analysis of EIFS failures is given in FEMA 489, *Hurricane Ivan in Florida and Alabama*, where this type of damage was prevalent.

5.4.3 Soffits

Many buildings lost some or all portions of their soffits (shown previously in Figure 3-21). The damaged soffits were typically vinyl or aluminum. Some of the soffits failed by suction (i.e., downward pressure), while others failed by positive pressure (i.e., they were pushed upward). In many instances where soffits were lost on residences, water was driven into the attics and ultimately into living spaces. The wind also displaced attic insulation and blew it out of attics (much of the insulation was blow-in insulation, rather than insulation batts). Figure 5-69 shows ceiling damage adjacent to soffit loss at a residence on North Captiva Island.

Figure 5-68.
This hotel experienced significant EIFS failure on several sides (Orlando). EIFS debris broke several windows (Figure 3-33).

Figure 5-69.
An exterior eave with soffit failure, which resulted in water intrusion (North Captiva Island)

Figure 5-70 shows a damaged soffit at a bank drive-through canopy. Figure 5-71 shows damaged soffits at the Aqui Esta Fire Station. Most of the gutters and downspouts at the fire station blew away, but the 5V-Crimp metal roof had only minor damage at a hip flashing lap. The soffit panels were connected to the building only at their ends. A substantial quantity of wind-driven rain blew into the attic space and caused ceiling boards to collapse. Because of the water infiltration, this station was taken off-line after the storm.

Figure 5-70. Loss of soffit at a bank drive-through. Note the coping damage (Port Charlotte).

Figure 5-71. Essentially all of the perforated aluminum soffit on this fire station was blown away (Aqui Esta, east of Punta Gorda Isles).

5.5 Exterior Mechanical and Electrical Equipment Damage

The MAT observed many damages to mechanical and electrical devices mounted on the exterior of buildings. The devices attached to residential, commercial, and critical/essential facilities are typically different from each other; for this reason, the following section presents information according to building type.

The following factors are essential to good high-wind performance of exterior mechanical and electrical equipment: determining design wind loads on equipment and designing suitable attachments to resist the loads; special anchoring of fan cowlings and access panels; and special design of LPS anchorage. Guidance for these design factors is provided in FEMA 424, *Design Guide for Improving School Safety in Earthquakes, Floods, and High Winds.*

5.5.1 Damage to Exterior Equipment Attached to Residential Buildings

Typically, the types of exterior equipment attached to residential buildings included air-conditioning condenser units and TV satellite dishes; however, this report focuses on condensers.

Condenser units were generally not anchored to their support pad, which resulted in their being displaced off the support pad by wind (Figure 5-72). In some instances, the condensers broke free from the electrical and copper tube connections and were blown away entirely.

In several cases, the condensers were fastened and remained anchored throughout the hurricane (Figure 5-73). Typically, where anchors were used, the clips were often very thin and the screws quite small. Although the condensers did not move during this hurricane, additional precautions to prevent wind damage should be taken. In some cases, corrosion of fasteners was observed; this can result in failure in a future hurricane event. In high-wind areas, clips and screws with high strength and corrosion resistance should be used.

Figure 5-72.
This condenser was not anchored to the concrete pad. The electrical and copper tube connections kept it from blowing farther away (Deep Creek).

Figure 5-73.
Condenser on the elevated platform attached with four angle brackets. The other condenser, located adjacent to it on the ground, should also have been on an elevated platform to account for storm surge (Pine Island).

5.5.2 Damage to Exterior Equipment Attached to Commercial and Critical/Essential Facilities

Commercial and critical/essential facilities typically have a wide variety of mechanical and electrical equipment attached to their rooftops and elsewhere. Equipment lost included fan units and HVAC units, electrical and communications equipment, and LPS systems. There are several effects due to loss of this equipment: in many instances, the displaced equipment left large openings through the roof and/or punctured the roof membrane; equipment loss often affected the operational functions of the facilities; and blown-off equipment became high-energy windborne debris in some cases. The equipment observed on hospitals, fire stations, and schools was not anchored more effectively than the equipment on common commercial buildings.

5.5.2.1 Condensers

Condenser problems like those discussed in Section 5.5.1 were also observed at commercial and critical/essential facilities (Figures 5-74 and 5-75). A complete lack of anchor systems or inadequate or deteriorating fasteners resulted in the loss of many compressors. Installation methods observed were not standardized. In Figure 5-75, although the condenser did not move off its rail, it would have been prudent to use two side-by-side screws, with more edge distance between the screw and strap end.

Figure 5-74. Condenser unit displaced from the elevated platform (Port Charlotte)

Figure 5-75.
Rooftop condenser anchored to a support rail, but with only one small screw (which was corroded) used to connect the strap (Port Charlotte).

5.5.2.2 Fan Units and HVAC Units

Figure 5-76 shows the loss of fan cowlings on a roof. Two of the three cowlings had blown off. At one curb, which was 2 feet 4 inches square, the fan unit was attached to the curb with two small screws at two sides and three small screws on the other two sides (total of 10 screws). Attachment was not checked at other fans. No fans were blown off this building. This success was likely the result of using multiple screws to secure the fasteners (unlike many other buildings, where often only two screws per fan were used).

Figure 5-76.
Cowlings blown off two exhaust fans in the foreground. Note also the loose LPS conductors and missing walkway pad (Punta Gorda).

Loss of HVAC units was also observed as shown in Figure 5-77. A number of these large units were blown off their supports. Additional damage to equipment included loss of access panels on package units, debris impact damage to relief air hoods, and damaged rooftop ductwork. Figure 5-78 shows a unit that was marginally anchored.

Figure 5-77.
A large HVAC unit blew off this curb. Note the loose LPS conductors (this side of the curb). This school had significant damage to several pieces of rooftop equipment (Port Charlotte).

Figure 5-78.
A thick angle bracket was used to anchor this unit. Although two screws attached the angle to the support beam, only one screw was used at the unit (Port Charlotte).

5.5.2.3 Electrical and Communications Equipment

Rooftop electrical and communications equipment were also observed to be inadequately anchored. Problems included blow-off of satellite dishes (Figures 5-79 and 5-80), antenna collapse (shown previously in Figure 3-44), and displacement of LPS (Figures 5-59 and 5-81 through 5-85). Four buildings with LPS were investigated, and the systems on all four buildings were damaged. Three of the buildings had two or more roof levels and damage occurred at several of the different levels. Consequences of the damage included loss of communications, damage to the roof covering, and loss of lightning protection, the latter of which is significant, considering the frequency of lightning storms in Florida.

Figure 5-79.
This satellite dish at a hospital was held down only with CMU. Note the loose LPS conductors and displaced air terminal at the corner (Arcadia).

LPS failures were typically the result of poorly anchored systems. Connectors often fail by opening up and releasing the conductor cable or they debond from the roof (Figure 5-82). In other cases, the air terminal base plates debond from the roof (Figure 5-83). In Figure 5-84, a prong-type conductor splice connector (approved for roof heights up to 75 feet) failed. Bolted-type connectors are prudent in hurricane-prone regions because they are less likely to pull apart and cause damage to the roof (Figure 5-85).

Figure 5-80.
A satellite dish previously sat in this location. It was held down only with CMU and blew off the five-story building (Punta Gorda).

Figure 5-81.
The LPS conductor on this hospital blew away, but the air terminal was still attached. A lightning strike to this air terminal would not be safely dissipated (Port Charlotte).

Figure 5-82.
The LPS conductor pulled away from the conductor connector at the top of the photo. The conductor was also attached to the membrane with poorly welded strips of PVC (Port Charlotte).

Figure 5-83.
The conductor connectors detached from the cap sheet on a hospital's BUR. The air terminal was also displaced (Port Charlotte).

Figure 5-84.
A failed prong-type splice connector with prongs permitted for roof heights up to 75 feet caused roof damage at this facility (Cape Coral).

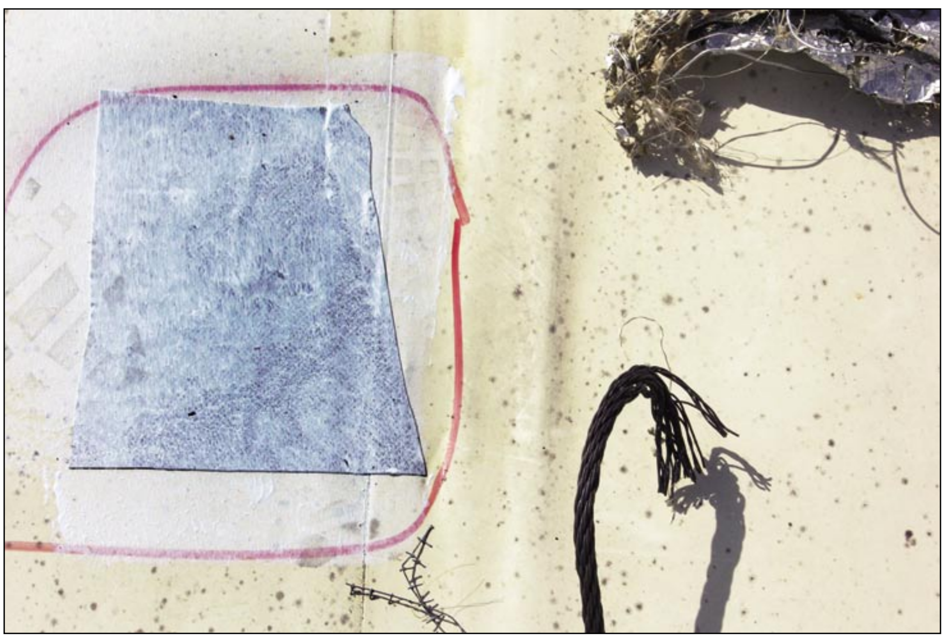


Figure 5-85.
When LPS conductors detach, the conductor ends can whip around and puncture and tear the roof membrane. The patch near this frayed conductor is likely a repair of damage caused by a whipped conductor (Punta Gorda).

6

Performance of Critical and Essential Facilities

Critical and essential facilities are needed to lead and manage response and recovery operations during and/or after an event. Hurricane Charley had a significant impact on critical and essential facilities within the path of highest winds; overall, the facilities experienced damages that resulted in these facilities being unable to be utilized for their intended function(s) for days, weeks, or several months after the hurricane.

According to Table 1606 of Section 1606 of the 2001 FBC, critical and essential facilities are facilities including, but not limited to, hospitals (and other medical facilities), fire and police stations, primary communication facilities, disaster (emergency) operations centers, and power stations and other utilities required in an emergency.[1]

[1] Schools are listed in the IBC and NFPA 5000, not the FBC.

Hurricane Charley produced a narrow band of winds from Charlotte Harbor to Orlando that can be said to have met or exceeded a design wind event for many buildings designed and constructed for use as critical and essential facilities. Although many of these facilities were older, they should have been designed to perform well at higher wind speeds.

Critical and essential facilities that were damaged include EOCs, fire and police stations, hospitals, schools, and shelters. Most damage was to older facilities; however, newer facilities experienced some failures in both their structural and envelope systems (see Chapter 5 for photographs and discussion of envelope damage). The MAT observed some structural damage (and isolated instances of collapse), significant cladding and equipment damage (resulting in water intrusion), and significant loss of function due to the hurricane at these types of facilities. Except for occasional shuttering of glazed openings, the investigated buildings did not appear to have been designed and constructed with wind-resistance enhancements to the building envelope and rooftop equipment.

6.1 Emergency Operations Centers

EOCs are key buildings in preparing for and responding to an event from the local to the state level. Due to the risk of hurricanes in Florida, there is a State EOC in Tallahassee and EOCs in almost every county in the state. Numerous local EOCs (fire or police stations) and a county EOC were impacted by Hurricane Charley. As the storm made landfall and moved inland, the hurricane tracked just west of the Charlotte County Sheriff's office/EOC, exposing the facility to the northeast (strongest) quadrant of the storm. Both the county Emergency 911 and EOC were relocated from the county administrative building to this pre-engineered metal building in 1999 and 2000, respectively. This building experienced significant damage and could not function, leaving Charlotte County without its Sheriff's office and EOC. Damage to numerous fire and police stations that function as local/community EOCs was also observed and is discussed in Section 6.2.

The metal building housing the Charlotte County Sheriff's office/EOC was constructed in 1991 and 1992 to the SBC for use by a private company. This building is a pre-engineered metal structure with a long span, shallow pitched gable end roof. The building roof covering and wall cladding (on the upper portion of the wall) is composed of metal panels attached to purlins (roof areas) and wood studs (wall areas). The lower portion of the building exterior is composed of masonry units.

Before moving into the building in 1999 and 2000, the county had consulted with the Florida Department of Community Affairs (FL DCA) for advice on design criteria for critical and essential facilities. FL DCA provided the county building hardening guidance used by the state to design and retrofit buildings for use as Enhanced Hurricane Protection Areas (EHPAs) since the mid-1990s. County emergency management staff was aware of the vulnerabilities and limitations of this facility; it was designed for office use with an Importance Factor of I = 1.0 as opposed to 1.15 for essential facility use. The county determined that mitigation of the existing structure to meet EHPA requirements was not cost-effective. To address these vulnerabilities, the county installed shutters on the existing facility to provide improved protection and performance and moved forward with a project to design and construct a new and hardened EOC adjacent to the existing facility. At the time the hurricane struck, architectural floor plans had been developed, but funding for the facility was still being secured.

6.1.1 General Damage

Most of the damage that was observed at the Charlotte County EOC (Figure 6-1) was to the building's envelope (i.e., the roof and wall coverings). Examples of this damage can be seen in Figures 6-1 and 6-2, which illustrate typical roof panel loss and wall panel loss, respectively. Roof damage appeared to center around the failure of the clips that either released from the purlins (Figure 6-2) or from a failure of the clip/panel connection. Additional roof failures were observed at the overhangs located at the rear of the facility at the two large rolling and sectional doors. Figure 6-3 shows the overhang on the southwest building corner.

**Figure 6-1.
Exterior wall and roof damage at Charlotte County EOC**

Figure 6-2.
Failure of wood stud wall supporting wall panels above masonry wall (Charlotte County EOC)

Wind induced wall damage was limited to the upper portions of the exterior walls constructed of metal panels attached to the steel frame and to wood studs acting as purlins between the frame and the top of the masonry walls. Failures observed varied from clip and connection failures, similar to those observed with the roof panels, to complete failures of stud-supported sections (Figure 6-3).

Some isolated structural damage was observed in the roof framing. Damage to the frame was observed in areas where the roof panels were removed from the building by the wind. Damage was typically limited to deformed purlin members, but a few of the primary structural members were also damaged.

The damage to building components described above is avoidable and these systems can be designed and constructed to resist wind loads and windborne debris. The failure of the building envelope at the EOC should not have occurred. The damage around the site is consistent with a wind speed in the range of 120 to 140 mph 3-second peak gust. This wind speed is close to the design wind speed for this portion of the county for which at the time the building was designed in accordance with the 1991 SBC (110 mph fastest mile wind speed = 130 mph 3-second peak gust).

Figure 6-3.
Failure of roof and soffit panels at rear awning (Charlotte County EOC)

6.1.2 Functional Loss

The failure of the building envelope did not lead to an immediate or catastrophic failure of the structural framing system, but allowed damaging amounts of rain and debris to enter the facility. This slow failure of the building envelope allowed individuals within the building to take shelter elsewhere, but should not be considered a "success" for a critical or essential facility, especially an EOC. In addition to the loss of county records, documents, computer equipment, and communications equipment, the community lost its ability to respond to and manage the disaster without outside assistance. Unstable roof framing, missing roof and wall panels, and ponding water on the floor crippled the facility and the ability of the county to respond on its own. Only portions of the building could be used during the response and other county, state, and Federal resources had to be brought to the site to provide communications, assessment, and control functions.

Communities understand how important EOCs or other critical facilities are when they are lost. The damage and loss of function experienced at the Charlotte County EOC underscores the importance of proper design and construction of critical and essential facilities and also the appropriate selection of materials and building systems. This EOC was housed in a building that was constructed with a building system known for economy and not its redundancy or robust strength. Pre-engineered buildings with light-metal panel exteriors are susceptible to damage and loss of function because they provide a relatively small factor of safety for the structural system (widespread use of one-third stress increase at least until 2002) that is reduced further by fastening the metal panels using fastener schedules that provide factors of safety.

Other building systems can be selected that provide larger factors of safety against structural failure and are more resistant to progressive collapse. Further, this building system utilized a combined roof deck and roof covering in the form of the metal roof panels. Thus, loss of the roof covering led to loss of roof deck and significant interior damage. When separate roof covering systems are used atop structural decks, additional and secondary levels of strength and protection are provided. Loss of the roof covering in buildings with separate structural decks and secondary layers of moisture protection would expose the roof deck to wind, rain, and debris. However, the separate roof deck and the secondary layer of protection on the deck would resist most water intrusion and likely prevent loss of function within the facility.

6.2 Fire and Police Stations

If fire and police stations cannot remain operational during an event, the community loses a valuable and important part of its emergency response capability. Several fire and police stations in Charlotte and Lee Counties were damaged during the hurricane from high winds and windborne debris. Of the nine stations documented in this section, five of them experienced enough damage to take them off-line for the event and for weeks or months following the event.

6.2.1 General Damage

The MAT observed significant damage in fire and police stations in the path of Hurricane Charley. Although older facilities tended to perform poorly, there were new buildings that sustained significant damage as well. With these types of facilities, it is expected that they will not only survive a hurricane, but remain operational throughout the storm. If damage does occur to the building, even seemingly insignificant damage (e.g., broken roof tiles or blown in sectional doors) can lead to an interruption in emergency services, thus affecting the post-disaster recovery. Table 6-1 summarizes the damages and loss of functions at the stations, and whether the facilities operations were interrupted as a result of the damage. Figures 6-4 through 6-7 illustrate some of the observations of the facilities. Additional photos taken at these sites are presented and discussed in sections of this report specific to the building structural type (Chapter 4) or the cladding or equipment damage (Chapter 5).

6.2.2 Functional Loss

Most of the fire and police stations that were damaged were unable to immediately respond to emergencies related to the hurricane. Further, many of these stations lost the ability to perform some or all of their functions. In many cases, service functions were returned within a few weeks through the repair of damaged equipment and dispatching and operational support provided from other facilities. However, long-term impacts to housing, response time, and loss of specialized equipment are being experienced and cannot be remedied until the fire and police stations are repaired or replaced.

Figure 6-4. Overview of west side of Port Charlotte Fire Station No. 12

Table 6-1. Summary of Fire/Police Station Damage and Functional Loss from Hurricane Charley

Fire/Police Station Year of Construction	Roof Covering Damage	Roof Deck Damage	Other Envelope Damage
Port Charlotte: Charlotte County Fire/ EMS No. 12 **Early 1998**	Metal panel roof covering loss in areas where structure did not fail. Primary damage was observed at hip flashing; additional damage at clip fasteners to deck. Clips were not installed at even spacing.	Loss of wood trusses and wood panel roof deck over apparatus bays (likely cause was pressurization of bay due to loss of rolling and sectional doors). See Figure 6-4 (note that clips/straps were used to secure trusses to walls).	Loss of all three bay doors on east side of station during period of positive pressure acting on doors. Two of the three doors' tracks remained in place. Broken windows around building exterior.
Port Charlotte: Fire Station No. 1 **1980**	BUR covering (mineral surface) was damaged due to uplift failure of deck system below. Base sheet of covering was attached to deck with tube-nails.	Numerous cement-fiber deck panels (secured with clips) failed from uplift forces. Openings and unstable sections of roof deck were located over apparatus bay and functional areas.	Two of three sectional doors (fully glazed) had broken glazing and were blown into apparatus bays. Windows and doors were broken or damaged. See Figure 6-5.
Fort Meade Fire Station	Tile roof covering loss and damage		
Punta Gorda: Fire Station No. 1 and Public Safety Complex **2002**	Tile roof covering loss and damage. See Figure 6-6.		Soffit damage and failures. See Figure 6-7. Damage to rolling and sectional doors at several bays.
Punta Gorda: Aqui Esta Fire Station **2000**	Minor damage to V-crimp metal roof panel system. Observed damage was noted at a hip lap.		Minor damage to V-crimp metal roof panel system. Observed damage was noted at a hip lap.
Port Charlotte: Charlotte County Fire and EMS Station No. 7 **1976**	Asphalt roof shingles failed across roof. Some covering loss was initiated due to gable end wall failure; however, other shingle loss was due to poor installation of shingles with staples, some observed to be at 45 degree angle to shingles.	Damage at gable included loss of wood panel roof decking	The two bay doors were in-place, but damaged. The rear bay door was blown into the apparatus bay and one personnel door was suctioned off the building. Window breakage and damage to perforated soffit was observed.
Punta Gorda Fire Station No. 2	Loss of some metal panel roof covering. Roof panels of this pre-engineered metal building were R-panel system.		Three of four sectional doors were blown into apparatus bays or were damaged. Undamaged newer door was heavily reinforced and attached to the wall at 18 inches on center with 1/4-inch lag bolts.
Matlacha/Pine Island Fire Department	Significant loss of V-crimp metal roof panels across most of roof	Loss of more than 50 percent plywood roof decking (attached with staples)	Three of four sectional doors were blown into apparatus bays. The door that did not fail was installed in 2002.
Cape Coral Fire Department	Isolated areas of shingle loss		Shutters prevented window damage. One bay door of six was damaged - track and door detached. Track was secured at 4 feet and greater on center with lag bolts. Failed door in apparatus bay appeared to be inadequately connected to wall.

Water Intrusion Damage	Structural Damage	Damage to Equipment	Off-line/Unable to Respond	Additional Comments
Primary water intrusion as a result of loss of bay roof and gable ends. Lower roof sections remained with minimal water intrusion issues. Additional water damage from pipe broken during roof blow-o ff.	Loss of gable roof structure over apparatus bays. Damage observed at bond beam above garage doors due to roof failure.	Equipment in apparatus bay was damaged. Broken windows and windshields were most prevalent. These vehicles were considered operational and moved to other fire stations.	The station was taken off-line during the hurricane, and remained off-line since the event.	This fire station was sheltering approximately 60 people during the storm and at the time of the roof failure. FEMA mitigation funding is being provided to assist with the reconstruction of this station.
Water infiltration occurred when building roof deck separated from building.	Structural damage appeared limited to roof deck loss. Steel joists and walls supporting decks appeared to experience only water damage.		The station was taken off-line during the hurricane and has remained off-line since the event.	This fire station was under contract for renovation when Charley struck. Repairs will be incorporated into the renovation project.
			The station remained operational.	
Significant water damage was observed related to the loss of soffits. Water damage in both roof and wall systems.		Approximately 40 to 50 police vehicles experienced body damage and glass damage from tile debris.	The station remained operational during the hurricane, but water damage limited some operations and response ability.	Functioned as town EOC during the event - approximate staff level was 100 personnel.
Significant water damage was observed related to the loss of soffits. Water damage in both roof and wall systems.	No storm induced structural damage was observed. Pre-cast concrete twin-tee roof structure over apparatus bay did not appear damaged.	Antenna structure was damaged.	The station was taken off-line during the hurricane and has remained off-line since the event.	Station is being evaluated for mitigation. Alternate site out of floodplain is being considered.
Building experienced significant water intrusion due to roof deck loss and soffit damage. Some light water damage due to debris impact that penetrated building exterior.	Loss of significant percentage of roof deck wood panels and structural roof members.	No damage to firefighting equipment. An outside compressor unit was damaged when it was displaced off its pad. Antenna unit collapsed onto roof of station.	The station was taken off-line during the hurricane and remained off-line for several months after the event.	Repairs and mitigation to existing station have been put on hold since the County is considering relocation of this station to improve community response.
Interior water damage due to loss of roof covering to operational areas.	Structural damage to walls and girts of the pre-engineered metal building at the main door area. Evidence of spalling failure between wall and slab connections was evident.	No damage to firefighting equipment. Antenna unit collapsed onto roof of station.	The station was taken off-line during the hurricane and remained off-line for several months after the event.	One of the two towers that collapsed just missed impacting the emergency generator.
Interior water damage due to loss of roof covering to operational and sleeping areas was sign ificant.	Loss of roof decking on upper levels; however, remainder of structure did not experience damage.	No damage to firefighting equipment moved prior to the storm's arrival. Two communications towers collapsed during the hurricane.	The station remained operational.	
Isolated water leaks due to roof shingle loss. Most water leaks occurred in the computer room of the facility.	No structural damage observed.	No damage to firefighting equipment. An outside compressor unit was damaged when it was displaced off its pad.	The station remained operational.	According to on-site fire station staff, the facility had been retrofitted for use as an EOC. Windows were protected with shutters.

Figure 6-5.
View of damaged garage door and interior of Port Charlotte Fire Station No. 1; note missing roof deck panels over apparatus bay.

Figure 6-6.
Overview of Punta Gorda Fire Station No. 1. The tile roof had been removed and a new roof was being installed. Note the damaged doors.

Figure 6-7. Damaged soffit at Punta Gorda Public Safety Complex

6.3 Hospitals

The MAT assessed a number of hospitals in Punta Gorda, Port Charlotte, and Arcadia. Structurally, these facilities performed well, with the exception of the collapse of a pre-engineered ancillary building at a hospital in Arcadia; however, the most significant damage resulted from water intrusion due to roof covering and rooftop equipment failure, and window damage from roof aggregate. The aggregate also caused damage to adjacent buildings and hospital staff vehicles.

6.3.1 General Damage

The most disruptive damage was caused by the loss of roof coverings and rooftop equipment, and the loss/breakage of unprotected glazing. This damage to the building envelope led to extensive internal damage in key hospital areas such as emergency rooms, intensive care units (ICUs), and general use areas (i.e., patient rooms and offices).

Each of the hospitals had sections of the facility built at different times, constructed with a variety of roof coverings, including aggregate surfaced built-up roof (BUR), modified bitumen, and single-ply membranes. In many cases, failure was initiated with the metal edge flashing that led to the loss of the roof covering. Figures 6-8 and 6-9 show some of the damage.

Figure 6-8.
Aggregate damaged the windows to ICU rooms at a hospital (Arcadia)

The gutters lying on the lower roof in Figure 6-8 came from the right side of the upper roof and may have caused some of the glass breakage. However, the majority of the damage was broken by flying aggregate from the hospital's BURs.

Figure 6-9.
Roof covering damage resulting in water intrusion, which required evacuation of a skilled nursing facility (Arcadia)

6.3.2 Functional Loss

Hospitals experienced a significant loss of function. First, almost all critical care facilities were impacted and lost (taken off-line) during the hurricane and in the days immediately following the event. Extensive damage occurred at a number of the hospital facilities, affecting both urgent/critical care units and general patient care rooms. At the Charlotte County Regional Medical Center, temporary resources were required to restore critical care operations after the hurricane. Cost implications and impacts to all hospital operations had not been calculated at the time of this report.

6.4 Schools

The MAT evaluated nine schools in Charlotte, Lee, and De Soto Counties. The schools included elementary, middle, and high schools composed of one or more buildings, one- to three-stories high, and constructed between the mid-1920s and the present. In addition to their traditional role as educational facilities, schools often play an import role in providing space for emergency response and recovery after a hurricane; therefore, their loss can greatly impact a community.

This section provides a discussion of damages observed at the schools visited by the MAT. A more detailed discussion of schools specifically evaluated for and used as shelters is presented in Section 6.5.

6.4.1 General Damage

Damages to structural walls of schools evaluated by the MAT were limited to a few older buildings with walls or parapets constructed of URM or hollow clay tile. At one high school, the collapse of hollow clay tile walls and URM parapets caused extensive damage (Figures 6-10 and 6-11). Most exterior wall surfaces observed at school buildings did not suffer significant damage.

Damages to roof framing systems at schools occurred at large, gable end roofs with light-metal trusses where the gable end was pushed into the building due to inadequate lateral bracing and collapsed (Figure 6-12). A few plywood and OSB roof sheathing damages were also encountered along the edges and at the corners of older school buildings. Roof coverings and soffits were the most commonly damaged elements of school buildings evaluated by the MAT. Typical roof covering damages included loss of roof membrane systems due to inadequate connection to the roof deck, loss of edge flashing or coping, or tearing of the membrane from debris impact. Metal roof coverings were lost or damaged due to inadequate connections or a loss of the edge flashing. Thin metal panel soffits and lightweight composite panel overhangs (which functioned as soffits) were often lost due to inadequate connections or excessive deflections caused by wind pressures along the edges and corners of the building (Figure 6-13).

Figure 6-10.
Hollow clay tile wall/ parapet damage to roof of a high school auditorium (Punta Gorda)

Figure 6-11.
URM parapet damage to front façade of a high school (Punta Gorda)

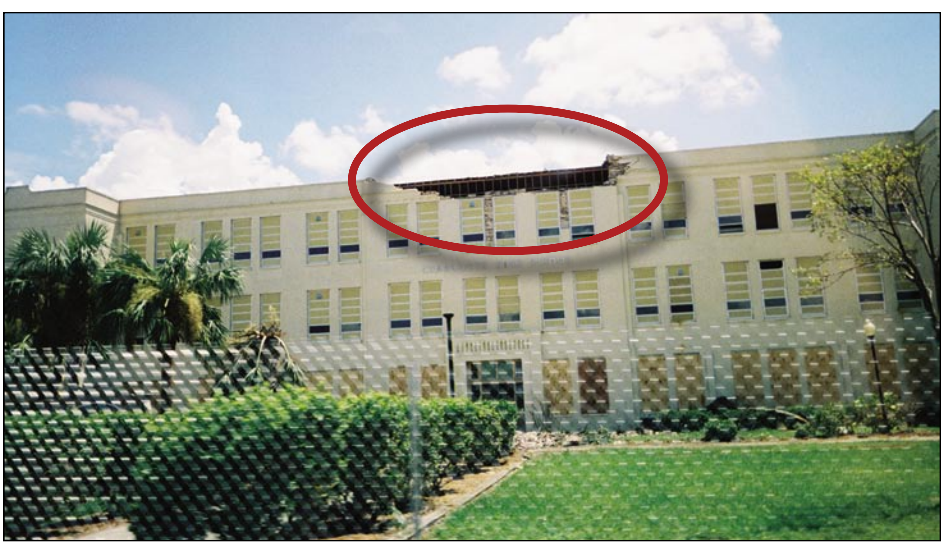


Figure 6-12. Collapsed gable end wall at an elementary school (Deep Creek)

Figure 6-13. Loss of lightweight composite panel overhang at an elementary school (Charlotte Harbor)

A few single and double metal entry doors in school buildings evaluated by the MAT were damaged due to inadequate locks or door frames that were not properly connected to the walls, which caused the doors to blow open or out during the storm. Some metal-framed windows constructed with annealed glass panes were broken due to debris impact and/or bending of the frames that supported the panels (Figure 6-14).

Figure 6-14.
Broken window damage at a high school (Punta Gorda)

Damages to rooftop mechanical equipment were noted at several schools. Most damages occurred when rooftop HVAC units and vents were knocked over or blown off by the wind, which caused tears in the roof coverings.

Many school buildings evaluated by the MAT suffered damage or collapse of metal awnings and walkway canopies, typically due to inadequate anchorage of the roof sheathing or the posts that supported the awnings and canopies (Figure 6-15). Several portable classrooms were damaged by debris impact or destroyed, presumably due to inadequate foundation anchorage (Figure 6-16). Some sections of chain-link fencing collapsed due to wind-blown debris that accumulated. A few pre-stressed concrete light poles at school athletic facilities were cracked or snapped due to inadequate steel shear ties.

Figure 6-15.
Collapsed metal walkway canopy at a high school (Punta Gorda)

Figure 6-16.
Damaged portable classroom unit at an elementary school (Charlotte Harbor)

6.4.2 Functional Loss

Functional losses to school buildings observed by the MAT included loss of building contents, loss or disruption of school functions and, in some cases, a loss of storm shelters. The majority of school building content damages and functional losses occurred when elements of the building envelope were breached. The most common damages observed by the MAT were roof covering loss or damage by wind pressures or torn by windborne debris and the associated water intrusion damage. In other cases, doors blown open by wind pressures or windows shattered by debris impact allowed wind and water to enter the building. Both events led to widespread water and wind damage to ceilings, lighting, floors and contents, and a disruption or loss of school operations. Because most building envelope damages occurred over long span roofs or at entrances, the parts of the school that were most often impacted by building envelope damage included larger areas such as cafeterias, gymnasiums, auditoriums, and main entrance corridors.

Other school building content damages and functional losses occurred as a result of major structural failures from wind pressures and debris impact forces. Examples of major structural damages observed by the MAT included the collapse of older unreinforced masonry walls, failure of long span gable end roofs due to lack of bracing, and destruction of portable classroom units. These types of structural failures led to additional contents damages and long-term functional losses as damaged sections or units were repaired, redesigned, and/or replaced.

6.5 Shelters

Shelters can be defined in many ways, depending on their use. A shelter is a place where people go to take refuge during an event (often called storm shelters) or to recover when they cannot return to their homes immediately after an event due to widespread storm damage. For the purposes of this report, the term "shelters" refers to storm shelters or buildings where people went to take refuge from the winds and storm surge during Hurricane Charley. The MAT assessed the performance of these storm shelters to document how these critical and essential facilities performed and to provide feedback to FL DCA and local emergency managers who make decisions on opening and using shelters during storm events.

Further, because several school buildings evaluated by the MAT were designated as storm shelters, damages to schools in some communities led to a loss of shelters that could protect residents from injury during subsequent hurricanes. The loss of schools that function as storm shelters is particularly difficult in smaller communities where they often serve as convenient places to provide recovery assistance to residents in the days and weeks immediately after a disaster event.

The remainder of this section presents observations from site inspections of several shelters that were impacted by Hurricane Charley. Following these observations is a section that outlines the Florida Statewide Emergency Shelter Plan (SESP). This plan provides a listing of shelters that have been evaluated with minimum criteria for shelter performance, as well as the design guidance for the design and construction of hurricane shelters and EHPAs (also covered by the 2001 FBC in Section 423). Since the mid-1990s, FL DCA, through the Division of Emergency Management, has assessed and mitigated buildings for use as hurricane shelters and, since 2000, has increased shelter capacity in the state by over 500,000 spaces.

6.5.1 General Damage

The MAT was provided information on the shelters used in response to Hurricane Charley. Three buildings in Charlotte and De Soto Counties used as shelters during the event were visited to document their performance. These shelters include the recently constructed and largest shelter on the De Soto County shelter list (Turner Agri-Civic Center in Arcadia) and the only two shelters on the Charlotte County shelter list (Port Charlotte Middle School and Liberty Elementary School).

6.5.1.1 Turner Agri-Civic Center, Arcadia

Records from the FL DCA hurricane shelter program indicate that this building, which was completed in September 2002, was designed by an architect with a design wind speed of 140-mph 3-second peak gust per ASCE 7-98 with an importance factor of I=1.0. The intent was to design a facility to the minimum EHPA standards (see Table F-1 in Appendix F). The building was identified in the FL DCA 2004 SESP report as having 1,523 available shelter spaces and was providing shelter for approximately 1,400 people when it began to fail during the event (Figure 6-17). This shelter facility was included in the 2004 SESP shelter list because a letter from the architect of record stated that the shelter area was designed in compliance with the EHPA minimum requirements; in fact, this building had not yet been evaluated by FL DCA for compliance with the EHPA design requirements.

The MAT documented the damage observed at the shelter as a result of Hurricane Charley. Due to the limited access to the site, the MAT did not perform an analysis to evaluate the adequacy of the design assumptions used.

Figure 6-17. Aerial view of Turner Agri-Civic Center damage caused by Hurricane Charley (Arcadia)

(FL DCA)

Based on the limited observations of the MAT at the site, the building is pre-engineered metal with a structural steel frame with reinforced masonry infill walls. The upper portion of the exterior walls and the roof are composed of structural standing seam trapezoidal panels (3-inch high ribs at 24 inches on center), over fiberglass batts over a plastic vapor retarder over light-gauge purlins. Steel frames support the purlins, creating the large, open area of the building. Maximum roof spans are approximately 200 feet. Exterior walls were reinforced masonry that extended from the foundation to a series of bond beams connected to the structural steel framing. At the end walls, intermediate steel framing extended from the top of the bond beam, up the gable end walls to steel frame elements at the top of the end wall. Figure 6-18 shows the building after it experienced a partial collapse during Hurricane Charley.

This building experienced damage to the cladding systems (evident at numerous places where panels were missing) and in the structural frame, which partially collapsed at one end of the facility. The MAT's inspection of the damage noted that, for the roof, the failure of the plane of the roof system was typically a separation of the two-piece clip that connected the panels to the purlins. A few clips were observed that were still intact, with clip screws pulled from the purlins. In addition, metal panels were observed to be missing from the soffit at the entry canopy. The on-site representative meeting with the MAT reported that the roof panels were lifting off the frame prior to the collapse of the end wall.

Figure 6-18.
End wall failure at Turner Agri-Civic Center (Arcadia)

Structurally, purlin spacing was observed to be the same at the perimeter, corners, and field of the roof. The roof structure was braced with rod x-braces. No roof bracing was observed at gable end walls or in the direction of the long, steel frames. Reinforced masonry walls at one end wall failed. The MAT observed reinforcing in the masonry end wall that failed, but insufficient information was available to determine if the construction was compliant with the applicable building code.

According to the on-site representative meeting with the MAT, after the partial collapse, shelter staff and inhabitants were moved to a nearby high school while the eye of the storm passed by and only one injury was reported. The MAT's observations of the high school, the middle school, and pre-engineered metal buildings in the vicinity of the Turner Agri-Civic Center (Figures 6-19 and 6-20, respectively) showed minimal damage and no structural failures. Estimated 3-second peak wind gust speeds for the area are between 110 and 120 mph for Exposure B terrain and between 125 and 140 mph for Exposure C terrain. The large open field upwind of the Turner Agri-Civic Center likely created Exposure C wind conditions for the building. Other organizations with greater access to the site and design and construction documents are investigating more deeply into the failure of this facility.

Figure 6-19.
Middle school with minimal roof covering damage (Arcadia)

Figure 6-20.
Pre-engineered metal buildings with minimal damage located near the Turner Agri-Civic Center (Arcadia)

6.5.1.2 Port Charlotte Middle School, Port Charlotte

Constructed in 1971, this school is one of two on the state shelter list for Charlotte County. The building is generally constructed of reinforced masonry walls (8-inch CMU) supporting metal roof joists (Figure 6-21). The walls are reportedly reinforced using two #5 reinforcing rods (vertical) in adjacent cells at 10 feet on center maximum spacing; there is also a bond beam at the top of the wall. The roof deck is metal with lightweight insulating concrete. The school is located in a Category 3 storm surge zone, making it vulnerable to storms with high surge levels. The school was used as a shelter during the storm for an unknown number of occupants. The building was evaluated for use as a school shelter and has an American Red Cross (ARC) 4496 compliant shelter capacity of 1,000 persons; another 500-person capacity was proposed, but was found to not be ARC 4496 compliant.

Figure 6-21.
Exterior view of Port Charlotte Middle School showing both gymnasium area (tall section) and typical classroom (lower section, rear of photo)

During the MAT assessment, no structural damage was observed and minimal damage was observed on the designated shelter areas of the facility. However, roof covering and exterior wall, trim, and coping damage was observed at the school (Figure 6-22). Damage to mechanically attached single-ply membrane roof coverings occurred on the gymnasium roof and one of two lower roof areas adjacent to the gymnasium (see Section 5.3 for further discussion). It is important to note that the gymnasium was not identified as usable shelter space and was not being used for shelter during the height of the storm.

Figure 6-22.
Edge flashing failure at Port Charlotte Middle School

A failure of the lightning protection system (LPS) cables was also observed. A failed and loose LPS can puncture and damage roof coverings, leading to leakage issues, although such damage was not observed at this school.

As was observed at numerous other commercial and critical/essential facilities, many HVAC units were blown off supports/curbs at the school; equipment access panels were also blown off. The units were displaced due to inadequate connection to their supports and curbs. Mechanical systems and equipment that remained on the roof were minimally secured, but were not displaced by the wind.

6.5.1.3 Liberty Elementary School, Port Charlotte

Shelter areas of this school were constructed in 1986; this school is the second of two shelters on the state shelter list for Charlotte County (Figure 6-23). The shelter areas of the building are generally constructed of reinforced masonry (8-inch CMU) with a brick veneer. There is a bond beam at the top of the walls and two #5 reinforcing rods were reportedly set vertically in a cell a maximum of 8 feet on center. The roof of the cafeteria shelter area is a lightweight insulating concrete deck with a maximum roof span of 54 feet. The school is located in a Category 3 storm surge zone, making it vulnerable to storms with high surge levels. The school was used as a shelter during the storm for an unknown number of occupants. The building was evaluated for use as a school shelter and has an ARC 4496 compliant shelter capacity of 500 persons; another 1,000-person capacity was proposed, but was found not to be ARC 4496 compliant.

Figure 6-23.
Exterior view of Liberty Elementary (Port Charlotte)

During the MAT assessment, no structural damage was observed and minimal damage was observed on the designated shelter areas of the facility. There was no apparent structural damage to the shelter area and structural damage appeared to be limited to a failed canopy at a side entrance of the school. During the storm, electrical power to the school was lost. The school is not equipped with an emergency generator, so the day after the storm, the shelter staff and occupants were moved to another school that had power.

No significant roof covering or rooftop equipment damage was observed and there were no reported roof leaks in the shelter area; however, there were significant debris issues. The loss of metal panels over walkways between buildings and loss of aggregate surfacing from the BUR increased the debris hazard at this site and added to the debris field.

Some areas of the school have been retrofitted with shutters to protect windows from windborne debris. The shutters are roll-down, permanently installed systems that protect the windows during hurricanes. Although these shutters were not in place throughout the facility, they were placed on areas of the school that were identified for use as shelters. Figure 6-24 shows an example of a shutter system at the shelter area.

Figure 6-24.
Shutters installed at openings at Liberty Elementary School shelter area (Port Charlotte)

6.5.2 Functional Loss

All shelters visited by the MAT performed well enough to prevent loss of life, which is the primary purpose for the shelters, though the partial collapse of the Turner Agri-Civic Center was undoubtedly terrifying for the occupants. Quick action by the staff at the Turner Agri-Civic Center to move occupants away from the areas of roof failure prior to the collapse of the end wall of the building avoided any deaths or serious injuries. However, the schools visited, as well as a number of recovery shelters that were also visited during the post-event assessment, sustained damages. Most of this damage was limited to loss of roof coverings, loss of or damage to rooftop equipment, glazing breakage, and wall and soffit damage as documented above. However, when these shelter and non-shelter areas sustain damage from water intrusion, the ability of the facilities to return to their pre-storm functions may be compromised.

Many of the shelters used during Hurricane Charley were designed or mitigated to resist extreme wind events. Although Charley was a design wind event for some normal use buildings constructed to the 2001 FBC, these shelters did not experience a "design event." In several of the examples cited here and in Section 6.4, the envelopes on parts or all of buildings being used as shelters failed to perform as designed. With the exception of the Turner Agri-Civic Center, shelters evaluated by the MAT did not experience significant structural damage. Water intrusion into shelter areas was the most commonly observed issue and, although this is not a desired result, criteria used by FL DCA do not identify water intrusion as an event that would categorize the performance of the shelter as a "shelter failure," although water intrusion could be very uncomfortable for shelter occupants.

All of the shelters observed by the MAT experienced blow-off of building components. When building components are blown-off, there is a risk that people arriving at a shelter during the hurricane may be injured or killed. It is for this reason that buildings selected for sheltering should be designed and constructed to avoid loss of components. Items particularly susceptible to blow-off include aggregate roof surfacings. Roof coverings and rooftop equipment are also susceptible if adequate attention was not given to wind-resistant design and construction for these elements.

During investigations, the MAT observed that, in many cases, reports of shelter building damage and failures required clarification. Many buildings used for shelters are located in portions of larger buildings or on sites with a campus environment with multiple buildings. News media correctly reported that there was building damage at one site that was being used as a hurricane shelter. In a number of instances, this damage, however, did not occur at the area of the building being used as a shelter. For example, at the Port Charlotte Middle School, damage at the gymnasium and cafeteria was reported; however, these areas of the building are not designated for shelter use and were not being used at the time for this use. Thus, the damage reported at the site implied poor building performance with respect to the designated shelter space, which is not what actually occurred. This underlines the importance of properly identifying the shelter area at a building or campus prior to damage assessments to ensure the damage assessment is as accurate as possible.

It is important to recognize success and failure in buildings being used as shelters so that programs regulating the design, operation, and use of such facilities can be improved. In one disaster event, the Turner Agri-Civic Center had a loss of function that placed lives at risk. Non-functioning shelters or the reported poor performance of shelters may also result in the community's loss of confidence in shelter options provided for them. As a result, citizens in need of shelter may take undue risks and seek shelter at other inadequate facilities (or residences) or they may attempt to outrun the storm, both of which would increase their risk of injury during the event. Where shelters performed as expected, especially where the surrounding buildings or non-shelter portions of the building housing the shelter area received damage, it is important that the public understands that the shelters functioned properly to protect the inhabitants and perform as designed.

6.5.3 Buildings Selected for Shelter Use

Very few shelters were identified and opened in Charlotte and Lee Counties in response to Hurricane Charley because most of the shelters on the SESP listing are located in the storm surge inundation zones for Category 1 and 3 hurricanes. State and local emergency managers, in concert with the American Red Cross, work together to open and operate storm and recovery shelters during hurricanes. Further, FL DCA provides assistance to this decision-making process through its shelter program that culminates in the SESP shelter listing for the state. When a storm makes landfall, it is up to the communities and local emergency managers to assess the situation and open up shelters. Shelters are opened directly in the path of the hurricane if they are believed to be capable of providing safe refuge. Others, commonly called recovery shelters, are opened as a place for victims of the disaster to go who were forced to evacuate to areas outside the storm's projected path. Care should be taken to provide all available information at the

FL DCA has implemented a multifaceted program to assess shelters and work with communities to mitigate buildings to create and provide additional shelter space in their communities. This program includes: 1) survey of existing buildings, both public and private, to identify suitable shelter capacity; 2) where cost-effective (and practical), support mitigation and retrofitting of existing facilities to increase shelter capacity; 3) construction of new facilities to meet the public shelter design criteria; 4) shelter demand reduction through improved hurricane hazard models and behavioral studies; and 5) improve public information/education to reduce unnecessary "shadow" evacuations.

shelters and to protect operators during these events. Because Hurricane Charley was not categorized lower than a Category 2 hurricane as it approached Florida, it was reasonable for shelters in the projected path of Charley that were in storm surge inundation zones to not be opened as shelters.

The MAT visited the Diplomat Middle School in Cape Coral. This school was originally opened to displaced residents from the barrier islands of Fort Myers Beach, Sanibel Island, and Captiva Island. However, when the storm path changed, the building was affected by winds from Charley. Although the building was only slightly damaged (limited mainly to roof covering damage), school administrators were not aware that the school had been evaluated by FL DCA and had specific areas identified for use as shelter areas. This situation led to shelter occupants being placed in vulnerable areas of the building.

Although building strength and structural attributes of a facility are key elements in shelter selection during a disaster event, the location of the shelter is also critical. The state criteria for shelter space apply to both the building and the site. If the facility is in the 100-year floodplain, as defined on a FIRM, or in a storm surge zone identified by a SLOSH map, the site should not be used to host a shelter. In Charlotte County, there are only two shelters on the SESP listing, and both of these shelters are in Category 3 storm surge areas, vulnerable to flooding. Therefore, emergency managers had to make a subjective decision to open their only two shelters or to keep them closed because of the danger of surge flooding the shelters. Similarly, most of the shelters on the SESP listing for Lee County are in Category 1 and 3 storm surge zones and are vulnerable to flooding. For both counties, there is difficulty finding or siting shelters outside the storm surge inundation zones because of the flat geography of the counties and the underwater shelf offshore.

Hurricane Charley did not result in rising water across most of Charlotte Harbor and, therefore, very little coastal flooding was observed. It is important to note that most of the shelters on the Lee County list are in Category 1, 3, and 5 storm surge areas. Had the storm surge from Hurricane Charley remained at original forecasted heights, the shelters used in Charlotte and Lee Counties might have been flooded. This includes the many "recovery" shelters opened in schools in Lee

County (specifically in Cape Coral). These shelters were opened prior to Charley's landfall to support the evacuation of the barrier islands of Fort Myers Beach, Sanibel Island, and Captiva Island. Many of these shelters were opened, although they were in storm surge zones, because the track of the storm was forecasted to bring the eye of the hurricane over Tampa at landfall.[2] However, when the storm turned and the hurricane's eye made landfall in the Charlotte Harbor area (within the NOAA forecast landfall area), all of these shelters were at risk of flooding. Only the unique nature of Charley (a very compact storm prior to landfall) kept the damaging surge from occurring.

Questions regarding shelters and shelter evaluations should be directed to the Shelter and Retrofit Program administered by FL DCA and the State Emergency Management Office and information on this program may be found online at http://floridadisaster.org/DEMprograms.htm. Additional guidance on using shelters in or near floodplain or storm inundation areas is presented in the recommendations of Section 8.6.

6.5.4 The Florida SESP

Across Florida, shelter surveys and evacuation studies have determined that significant hurricane shelter space deficits exist in nearly all regions of the state. These regional deficits can have a significant impact on the ability of local agencies to protect citizenry when a major hurricane threatens or strikes Florida. Pursuant to Section 1013.372(2), Florida Statutes, FL DCA is responsible for preparing an SESP to guide local planning and provide consultative assistance with the construction of educational facilities that provide public shelter space. The purpose of this plan is to meet the statutory responsibility outlined in Section 1013.372(2), Florida Statutes. In accordance with the statute, the plan must:

- Identify the general location and square footage of existing shelters by Regional Planning Council regions;
- Identify the general location and square footage of needed shelters by Regional Planning Council regions for the next 5 years;
- Identify the types of facilities which should be constructed to comply with the public shelter design criteria; and
- Recommend an appropriate and available source of funding for the additional cost of constructing emergency shelters within those public facilities.

[2] Even when Hurricane Charley was forecast to track over Tampa, the Port Charlotte area was still included in the "zone of uncertainty."

Furthermore, FL DCA has statutory responsibility and authority to administer a statewide program to eliminate the deficit of "safe" hurricane shelter space. To ensure consistency with state and national standards, guidelines, and "best practices," the Division has recognized *Standards for Hurricane Evacuation Shelter Selection* (ARC 4496) as the minimum hurricane shelter survey and evaluation criteria. Therefore, at a minimum, meeting ARC 4496 criteria is a required condition for a public facility to be described as "safe," "suitable," or "appropriate" for use as a public hurricane shelter.

Cumulatively, since 1995, the FL DCA's hurricane shelter survey and retrofit program has identified, created, or otherwise documented approximately 434,000 hurricane shelter spaces that meet ARC 4496 guidelines. The total list of shelter space evaluated is compiled in the SESP plan of that year and identifies space meeting the ARC 4496 criteria as well as space evaluated, but not meeting the ARC 4496 criteria. Buildings on this list may not have been designed to the criteria now specified, but have areas in the buildings that meet the criteria of "safe," "suitable," or "appropriate" for use as a public hurricane shelter.

New public school construction programs have created an additional 209,654 hurricane shelter spaces. These spaces are in buildings that were designed to meet EHPA requirements as defined in Section 423, State Requirements for Education Facilities, of the 2001 FBC and as outlined in the state statutes presented in Appendix G of the SESP. The design requirements as presented in the code are provided below. Additional discussions regarding shelter design requirements of the FBC and FEMA 361 are provided in the SESP and Appendix F of this report.

From the 2001 FBC Section 423 (24), Public Shelter Design Criteria:

> "**(d) Structural Standard for Wind Loads.** At a minimum, EHPAs shall be designed for wind loads in accordance with ASCE 7-98, "Minimum Design Loads for Buildings and Other Structures, Category III (Essential Buildings)." Openings shall withstand the impact of windborne debris missiles in accordance with the impact and cyclic loading criteria per SBC/SSTD 12-99. Based on a research document, "Emergency Shelter Design Criteria for Education Facilities," 1993, by the University of Florida for the DOE, it is highly recommended by the Department that the shelter be designed using the map wind speed plus (40) mph, with an importance factor of 1.0."

7

Conclusions

The conclusions presented in Sections 7.1 through 7.6 are based on the MAT's observations; evaluations of relevant codes, statutes, and regulations; and meetings with state and local officials, building associations, contractors, and other interested parties. The conclusions presented in Sections 7.1 through 7.6 are based on the MAT's observations; evaluations of relevant codes, statutes, and regulations; and meetings with state and local officials, building associations, contractors, and other interested parties. These conclusions are intended to assist the State of Florida, local communities, businesses, and individuals in the reconstruction process and to help reduce future damage and impact from natural events similar to Hurricane Charley. Observed mitigation successes are presented in Section 7.7.

7.1 General Conclusions

Hurricane Charley was a powerful hurricane when it made landfall as a strong Category 3 or borderline Category 4 hurricane in southwestern Florida. Although waves and coastal surge caused erosion and damage along the beaches of the barrier islands in Charlotte and Lee Counties (including the breach that was cut across North Captiva Island), Hurricane Charley will be remembered mostly for its winds and wind-induced damage. In addition to the estimated 145 to 155 mph (3-second peak gust) winds associated with the eye of Hurricane Charley as it passed over North Captiva Island, communities around Charlotte Harbor, including Port Charlotte and Punta Gorda, were impacted with winds estimated at 125 to 140 mph (3-second peak gust) in densely populated areas. Hurricane force winds (with 3-second peak gust winds as high as 105 mph) in densely populated areas of Orlando continued to induce damage across the peninsula of Florida until Hurricane Charley exited into the Atlantic Ocean near Daytona Beach, still categorized as a hurricane.

The need for hardening, providing backup power, and data storage to the NOAA/NWS surface wind and weather monitoring system was demonstrated by Hurricane Charley. The assessment of the performance of buildings and infrastructure is tied to the estimates of wind speeds experienced throughout the area of impact. None of the Automated Surface Observing Systems (ASOSs) and other systems, as far inland as Orlando, that were impacted by the strongest winds continued to report wind information throughout the storm. In many cases, the ASOS operates more like an early warning system for hurricane force gusts (because the power is typically lost when wind gusts approach hurricane force) than as a reliable source of data on the winds during the heart of the storm.

The categorization of the storm by a single hurricane classification also has limited use in the post storm assessment and may lead people in the impacted areas to draw incorrect conclusions about the event they actually experienced at their site and the strength of their building. The development of wind field estimates and resulting wind speed swath maps (Figures 1-4 and 1-5) are critical to the proper assessment of an event and its implications for building construction and code development.

The response of buildings to the high winds varied due to their location in the wind field, building code in effect at the time of construction, level of code compliance, quality of construction, and mitigation efforts implemented on the building. The most severe damage and structural failures occurred along the path of the eyewall of the hurricane, where most of the structural collapses and severe damage to the structural elements of buildings was observed. However, based on MAT observations, the number of structural failures from the winds associated with Hurricane Charley was generally less than has been observed during damage assessments following previous hurricanes with similar wind speeds.

Performance of building envelope elements such as roof coverings, rooftop mounted equipment, unprotected glazing, soffits, and siding was generally poor and led to widespread damage to the interiors of residences, businesses, and critical/essential facilities. In the windborne debris regions (areas identified in the 2001 FBC with 3-second peak gust design wind speeds of 120 mph or greater), where glazing was not protected, debris often broke the unprotected glazing and resulted in damage to building interiors (and, in some cases, structural failure from an uncontrolled increase in air pressure). Damage to the contents of residential and commercial buildings, and critical/essential facilities is preventable, as are the resultant costly losses and claims.

7.2 Building Performance and Compliance with the Building Codes, Statutes, and Regulatory Requirements of the State of Florida

Most structural failures observed by the MAT appeared to be the result of inadequate design and construction methods commonly used before the 2001 FBC and other modern building codes and standards were adopted and enforced; some failures may be explained by lack of maintenance or poor condition of the building and its structural elements. Code changes implemented in response to Hurricane Andrew in 1992, such as improvements to the SBC and the adoption of the 2001 FBC, can be credited with improving the wind resistance of buildings that have been designed and constructed over the past 12 years. In addition, the improvements in ASCE 7, including the addition of windborne debris protection requirements and the elimination of the one-third stress factors, are further refining the loads that new buildings must resist, thus ensuring better performance in wind events.

Buildings constructed in accordance with older codes were typically vulnerable to envelope and equipment damage, because older codes lacked or had inadequate criteria (refer to Chapter 2). Where buildings were designed and constructed to newer codes and standards (such as the FBC, the SFBC, or ASCE 7-98 or later) with improved building envelope and equipment design criteria, some of the observed failures were due to failure to comply with code provisions in both the design and construction phases. Other failures were the result of installed materials and systems that are known to lack the ability to perform under high-wind loads (i.e., the use of unsecured soffit panels). These components either do not meet the new criteria or there is a lack of evidence, through either realistic laboratory testing or observed performance during hurricanes, that the product will work under high-wind loads. Because these components are not considered "structural elements," their design and construction is often overlooked during design, permitting, construction, and inspection. Therefore, improvements are needed in the design requirements of the codes themselves and with enforcement and code compliance to ensure that components and cladding (C&C) elements are being engineered and designed per the code requirements. The MAT's observations are presented in Chapters 4, 5, and 6, and provide details in support of this statement.

The 2001 FBC and the recently completed 2004 FBC (to be adopted statewide by administrative rule effective July 1, 2005) include several improvements to the structural design of buildings and attached structures, as well as improvements for the design of building envelope and equipment provisions. Based on the observations outlined in this report, design guidance provided by the code with regard to the design and construction of the building envelope and attached structures and equipment needs to be expanded and improved. Guidance for some of these issues is provided by current model codes and standards, including the International Building Code/International Residential Code (IBC/IRC), NFPA 5000, and ASCE 7-02.

Finally, performance of manufactured housing was also observed to be a function of age of the building and the regulations to which the units were designed, constructed, and installed. Widespread damage was observed to manufactured housing designed and constructed prior to the 1976 HUD regulations. The performance of units installed between 1976 when the first HUD regulations were enacted and the implementation of the 1994 HUD regulations was observed to be somewhat improved, but significant improvements in performance were observed in the units designed and installed to the HUD regulations implemented after 1994 in response to Hurricane Andrew. Although some instances of structural failure were observed, the newer manufactured housing units typically sustained minimal structural damage and remained secured to their foundations when installation followed state requirements (e.g., enforced by the Division of Motor Vehicles, Department of Highway Safety and Motor Vehicles, etc.) of unit tie-downs (anchors) at 5 feet 4 inches on center (if no ancillary structures were attached to the unit). Much of this improved performance was difficult to observe due to widespread damage caused by the failures of improperly designed and constructed attached structures (including screen enclosures, carports, and accessory structures). The failure of these attached structures, in many places occurring where wind speeds were below the design wind speed for the area, resulted in extensive damage to roof coverings, siding, windows, and doors of the manufactured units, and generated significant amounts of debris. Very few manufactured homes had glazing protection and, as a result, numerous unprotected windows on units along the path of the eye of the storm were damaged and broken. Had the Zone II and Zone III homes installed in areas where debris protection is required for site-built one- and two-family dwellings been shipped with appropriate glazing protection, these homes would have been protected from windborne debris.

7.3 Performance of Structural Systems (Residential and Commercial Construction)

Buildings designed and constructed to resist wind loads prescribed in the 2001 FBC and to the requirements of ASCE 7-98 performed well and showed how improvements to the building codes have been successful in Florida. Structural damage, however, is still occurring during code level events such as Hurricane Charley.

7.3.1 Internal Pressures

Breach of the building envelope through broken windows, failed doors, or loss of sheathing led to rapid and uncontrolled increases of the internal air pressure in buildings, which sometimes resulted in structural damage or failure. Research suggests that internal pressures are affected by openings as small as 1 percent of the wall area and that the internal pressure generally becomes equal to the external pressure at the opening when the area of the opening reaches or exceeds 5 percent of the wall area. Consequently, the loss of a large window, a sliding glass door, a double-entry door, or a garage door can expose the interior of a building to the full effect of the external wind pressure. When openings are breached on the windward face of the building by direct pressure-related failure or by impact from windborne debris, the internal pressure in the building rises toward and tends to follow the fluctuations in positive pressure that would have occurred on that window, door, or panel had it not failed. Because air is essentially incompressible at the wind speeds encountered in even the most severe wind storms, the pressure builds without the need for much wind flow through the opening. However, if other openings in the building are present, including panels covering ceiling access holes in attics, air pressure can escape from the building, but does so as rapidly moving air that whips through the building. Failures of windows and doors on the windward face of a building have been correlated with subsequent failures of partition walls, windows, and doors on side and leeward walls, attic access panels, roof sheathing, and even whole roof structures (refer to Chapter 4 for details of these types of failures).

The MAT found examples of all of these types of failures in Hurricane Charley. A number of newer homes had double-entry swinging doors that failed. Because these homes were built with reinforced masonry and had adequate roof strapping, the roofs remained intact, but the sliding glass doors on the leeward side of the homes came out of their tracks, opening the house to the hurricane winds. It was not uncommon to find furniture blown out of these homes. A church sanctuary in Punta Gorda was reduced to rubble when the entire roof separated from the walls and a house on Pine Island lost most of the roof over a central area with a cathedral ceiling when a window blew in on the windward side. The widespread failure of low-slope roof systems may have been impacted by the build-up of internal pressures after a window or door failed, but the roof was probably compromised and the internal pressure just hastened the failure.

7.3.2 Wind Mitigation for Existing Buildings

To minimize damage or prevent failure of older buildings (residential, commercial, and critical/essential facilities), mitigation to create a continuous load path from the roof to the foundation must be implemented. This type of mitigation can be expensive because it often requires demolition and replacement of interior building finishes, and may require displacement of occupants while the mitigation is performed. Justifying the cost may also be difficult because the building code or local ordinance may not require that the building be upgraded to current code requirements.

For homeowners, opportunities to perform mitigation retrofits that improve the building's continuous load path would be optimal during renovation work or roof replacement projects, when significant invasive work is already being performed and the cost to install extra clips, screws, or nails to secure decking to rafters/trusses would be minimized. Access to the roof structure/top of wall connection is often made accessible during these projects, and clips and straps may be installed to help with the creation of a continuous load path. Additional anchorage of the bottom of the walls may still be required to develop a complete load path. Mitigation projects stated above would address the roof decking and roof structure failures observed after Hurricane Charley.

In commercial and critical/essential facility buildings, mitigation retrofit costs may be minimized if these types of projects are performed during tenant fit-out projects or major capital improvement projects. Prioritization can be given to mitigating space used for critical and essential functions. Public schools are examples of where these types of mitigation projects have occurred. As part of their efforts to increase safe public shelter space, FL DCA has evaluated schools, and sponsored structural and non-structural mitigation projects to strengthen buildings and provide debris impact protection to mitigate existing buildings once vulnerable to damage from wind and windborne debris.

7.4 Performance of Accessory Structures/ Attachments

Historically, aluminum accessory structures have had little rigorous engineering applied to them because they have been regarded as auxiliary and even expendable structures. Since the mid-1970s, the design of aluminum accessory structures has been most often accomplished through the use of prescriptive guidelines promulgated by a few professional engineers apparently without adequate formal peer review or industry consensus. Consequently, the widespread failure of these structures observed after Hurricane Charley (refer to Chapter 4) was unfortunate, but not surprising.

Another issue affecting the survivability of aluminum accessory structures is that, in general, installers and building department personnel (plan reviewers or inspectors) may not be sufficiently knowledgeable about the design of aluminum accessory structures. Although attention has been given to the size and spacing of members, little effort seemed to be focused on the connection details between the members and anchoring. Field observations point to connection detail failures, inadequate bracing as being frequent initiation points, and overturning/sliding for the ultimate failure of these aluminum accessory structures.

In addition to the damage and failures of the structures themselves, damage occurred to the site-built and manufactured housing to which they were attached. The failure and destruction of accessory structures and attachments contributed large pieces of windborne debris that impacted the surrounding homes. Manufactured homes that had a collapse or partially collapsed attached structure, significant damages to roof covering, roof decking, and siding were commonly observed. Further, the widespread failure of these structures created large amounts of debris that had to be cleaned up and disposed.

Sound guidance for the design of these types of structures was developed with the preparation of the 2001 FBC. The Aluminum Association of Florida (AAF) commissioned research that involved wind tunnel testing of both screened structures with screened roofs and screened structures with solid roofs. This research established wind design pressures that should be applied to these aluminum structures and these results are included in Table 2002.4 of the 2001 FBC. The AAF document, *Aluminum Design Manual*, referred to in the code in Section 2002.2, should be used by engineers and building officials to learn the engineering properties of the components that comprise a completed structure. The document does not deal with particular extrusions or assemblies of parts, but rather with the criteria for evaluating the connections.

It is important to note that Table 2002.4 of the 2001 FBC (submitted by the AAF) does not address the issue of the particulars of the design, just the applied pressures. In recognition of the limited guidance available and in preparation for the 2004 FBC, the *AAF Guide to Aluminum Construction in High Wind Areas* was developed. Although it is not a consensus standard, this guide is based on wind tunnel testing and rigorous engineering that has been constructively peer reviewed, making it the best guidance available at the time of issuance of this report. Designs based on this guide would substantially address the shortcomings in the current way aluminum accessory structures are being designed and the way they will ultimately perform. The results contained in the AAF document have been incorporated into the 2004 FBC. However, because most attached structures and pool enclosures were constructed prior to the 2001 FBC code, the MAT could not determine if the industry has moved to fully support the guidance in the existing FBC code and the 2004 Edition.

In addition to the guidance from the aluminum structure industry, changes in wind loads for open and partially enclosed canopy roofs are set to appear in the next edition of the wind load section of ASCE 7 (2005). Furthermore, the ASCE 7 standard has been revised to make it very clear that the one-third stress increase frequently used for short duration loads, such as wind loads, should not be applied unless it can be clearly demonstrated that the material capacity clearly increases as the load duration decreases. Thus, the common practice of reducing safety margins for metal or concrete structures by taking a one-third increase in allowable stress is no longer allowed. This should lead to stronger frames for screen enclosures and stronger carports and metal roof canopies in the future.

7.5 Performance of Building Envelope, Mechanical and Electrical Equipment

Although structural system failures tend to be perceived by the public and the building industry as the dominant issue of concern, the greatly improved performance of houses built in accordance with the FBC 2001 and other model codes have, in general, resolved many structural performance issues. Now, the arena in which improvements can and must be made are those related to rain water intrusion and protection of the building envelope (refer to Chapter 5). Protection of the building envelope is important in minimizing losses and damages to building contents, but also because of the importance of the building envelope with respect to internal pressurization of a building.

Poor performance of building envelopes and rooftop equipment was common on residential, commercial, and critical/essential buildings. Envelope and equipment damage was more widespread and significant on older buildings, although new buildings were also damaged in many cases. Damage was noted throughout all areas observed. Ramifications of poor performance include:

- **Property damage.** Property damage was extensive, requiring repair and/or replacement of the damaged envelope and equipment components; repair and/or replacement of interior building components; and mold remediation and furniture and equipment replacement as a result of rain water and/or wind damage in the interior of the building. Even when damage to the building envelope or equipment was limited, such as blow-off of a portion of the roof covering or broken glazing, substantial rain water damage frequently resulted because of the heavy rains accompanying the hurricane and rains occurring in the following days and weeks. Rain water entered the buildings through the breaches in the building envelope.

- **Loss of function.** Depending upon the magnitude of the wind and rain water damage, repairs can take days or months. As a result, residents may not be able to return home, businesses may not be able to reopen, and critical/essential facilities may be incapable of providing their vital services. In addition to the costs associated with repairing the damage and/or replacing the damaged property, other financial ramifications related to interrupted use of the building can include rental costs of temporary facilities or lost revenue due to business interruption. These additional costs can be quite substantial.

7.5.1 Building Envelope

Poor performance was a function of both inadequate wind resistance and damage from debris impact. Inadequate resistance to high-wind pressures on building envelopes and rooftop equipment was responsible for much of the damage caused by Hurricane Charley. In addition, windborne debris caused significant envelope damage (and virtually all of the glazing damage) that the MAT observed where wind speeds from the event were thought to be 120 mph 3-second peak gust and greater. Damaged and fallen trees, and failed building envelope components and rooftop equipment (such as roof coverings, gutters, HVAC equipment, and wall coverings) also became windborne debris that damaged the buildings they blew off of, as well as other buildings in the vicinity.

7.5.1.1 Roof Coverings, Wall Coverings, and Soffits

Observations showed that roof coverings of all types continue to fail at unacceptable rates during hurricane events. Some of these failures were 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) while other failures were due to design and construction related issues or debris impact. With respect to roof coverings, wall coverings, and soffits, the MAT concluded that

- Wind damage to roof coverings and wall cladding was widespread, even with wind speeds below design levels. Improved performance of roof and wall coverings was generally observed on the newer buildings and is likely due to improved codes and standards, product and test method improvements, a more educated designer and contractor workforce, and reduced detrimental effects of weathering (on newer buildings).
- Asphalt composition roof shingles continued to fail at or below design level winds. In general, it appeared that shingles installed within the past few years performed better than shingles installed prior to the mid-1990s. The enhanced performance is likely due to product improvements and less degradation of physical properties due to limited weathering time. In most cases, observed shingle failures were attributed to inadequate self-seal adhesive bond strength or installation that did not comply with recommended methods for resisting blow-off in high-wind areas. Failures of shingle roof systems applied over previously installed shingles were frequently observed.
- Tile roof systems experienced varied levels of performance from complete resistance to wind to substantial loss of tiles. Variation in performance was primarily related to installation and attachment methods with mortar-set tile system failure most frequently observed

as compared to foam set and mechanically attached tiles. Tile failures on roofs with foam-adhesive were observed, in most cases, to not comply with manufacturers' installation recommendations. All types of tile (concrete and clay) are vulnerable to breakage from debris impact, regardless of installation methods used. Tiles lifted by wind or broken from windborne debris often lead to cascading failures. Tiles on hips, ridges, and edges of the roof were a frequent point of failure. Hip and ridge tiles rarely were attached using mechanical anchors.

- Aggregate roof surfacing continued to cause debris damage when aggregate was blown off the roofs by high winds.
- For all roof systems, inadequate attention was typically given to edge flashing, coping, and gutter/downspout design and installation despite being located in the roof areas subject to the highest wind pressures. Failure of these roofing components often initiated roof membrane lifting and peeling.
- Wall cladding of all types (EIFS, vinyl and aluminum siding, masonry, etc.) appeared to have typically received minimal attention during design and construction, and continues to be an initiation point for progressive failures leading to interior contents damage or pressurization of the building.
- In numerous buildings, wind-driven rain was driven into attic spaces because of soffit failures. Widespread loss of soffits was observed in residential construction. In many of these instances, water intrusion occurred from wind-driven rain through areas where soffits were displaced or lost.

7.5.1.2 Windows, Doors, and Shutters

Windows and glazed doors can be protected in all wind regions using shutter systems, laminated glazing systems, and other means of opening protection. Large amounts of debris and loss of many unprotected windows and doors in areas along the path of the eye of Charley support the required protection of these openings in areas within the FBC windborne debris region. Further, many buildings in the areas outside the windborne debris regions would have benefited had the glazing been protected. Using glazing protection to prevent internal pressurization and wind-driven rain water intrusion protects interior contents from being damaged. Specifically; with respect to windows, doors, and shutters, the MAT concluded :

- The benefits of shutters are two-fold. First, they minimize an inrush of air that might cause a building not designed for internal pressures to fail structurally and they protect against the intrusion of wind-driven rain that could enter an unshuttered broken window. Although the public generally understands the importance of minimizing the inrush of air that might damage or cause a structure to fail, it is not clear that the public appreciates the dramatic damage that can be caused by rain entering a residence. Code prescribed shutters capable of withstanding penetration by windborne debris and both negative and positive wind pressures would eliminate water intrusion that would otherwise result from broken windows.

- Many homes and businesses that experienced only contents damage could have prevented these losses if their openings had been protected. Success in designing the structural frame to resist wind loads and internal pressures was negated by significant losses to building interiors and contents.
- Most shutters observed on buildings performed well during Hurricane Charley.

7.5.1.3 Attached Equipment (Rooftop and Ground Level)

Much like the building envelope systems already discussed, rooftop and ground level equipment is not typically receiving the design, installation, or code attention needed. Design guidance in ASCE 7-02 provides basic information to calculate wind loads on these elements to determine connection and support anchoring systems, but detailed guidance is needed. The lack of design and installation attention caused displacement or damage to these units across the wind field of the hurricane. This not only resulted in the loss of function associated with the damaged units, but in many cases led to the loss of function of the occupied space due to rain water infiltration at displaced rooftop equipment.

7.5.2 The Need for High-Wind Design and Construction Guidance

Designers, contractors, and building officials need additional education and resources to promote wind-resistance design and construction. Although many successes of design and construction were observed across the path of Hurricane Charley, it was apparent that the load path concept was not fully understood in all cases. It was also clear that many designers, contractors, and building officials do not fully understand the devastating effects that hurricanes can have on envelopes and equipment. It was common to see fasteners spaced too far apart, fasteners that were too small, and weak connections. Enhanced details were seldom seen. In contrast, there were numerous examples of failure to follow well established basic construction practices such as minimum edge distances for fasteners. Unless wind resistance issues are understood by designers, contractors, and building officials, envelope and equipment failures will continue to occur. In part, the envelope and equipment problem is due to lack of high-wind design guides for various envelope assemblies and various types of rooftop equipment.

7.6 Performance of Critical and Essential Facilities (Including Shelters)

Critical and essential facilities must remain operational before, during, and after significant hazard events, such as hurricanes, to serve their communities. As stated in Chapter 6, buildings that were considered critical and essential facilities were EOCs, fire and police stations, hospitals, schools, and shelters.

In general, buildings functioning as critical and essential facilities did not perform any better than their commercial-use counterparts. Despite codes of the past 10 years that require high design loads be used in the design of these facilities, the same flaws in construction, such as poor wall cladding, poor attachments of roof covering, and improper anchorage of rooftop mechanical equipment, were observed in critical and essential facilities. As a result, the operations and response at many critical and essential facilities discussed in Chapter 6 were hampered or shut down and taken off-line after the hurricane. In Charlotte County alone, over a half-dozen fire stations, three hospitals, numerous police stations, and the county EOC were significantly damaged and some were unable to respond in the days, weeks, and sometimes months after the event.

Most critical and essential facilities (shelters excluded) were housed in older existing buildings and most, if not all, apparently were not mitigated to resist known hurricane risks. If these critical and essential operations were housed in buildings constructed to the 2001 FBC, the 2004 FBC, or the model codes such as the IBC or NFPA 5000, designs for the structural and building envelope systems (including debris impact resistance) are required to provide levels of protection from wind and windborne debris. As a result, these design requirements may have prevented enough damage to allow these buildings to remain operational after the event. Alternatively, if key areas of the building had been mitigated or retrofitted for wind and windborne debris design requirements that are specified in the current code, building damage and loss of function would have most likely been reduced.

Widespread damage to large rolling and sectional doors and roof systems at fire stations is preventable. If these older buildings had been designed or mitigated to the 2001 FBC for 120 mph (3-second peak gust) winds and associated windborne debris impact protection over openings applicable in most of Charlotte County, the observed damage may have been avoided. Furthermore, many critical facilities were housed in lightly engineered buildings such as pre-engineered metal buildings. When this was the case, few if any of these lightly engineered structures were mitigated or retrofitted to design levels other than minimum code requirements for general use buildings in place at the time of construction.

The performance of buildings used as hurricane shelters also varied widely during Hurricane Charley. In Charlotte County, the MAT visited the two shelters (schools) on the state approved list that tracks and identifies shelters (the yearly Statewide Emergency Shelter Plan [SESP]); these shelters are on the list despite being located within the storm surge inundation zone for a Category 3 hurricane. At these two schools, the county was operating shelters in the areas of the school designated by the SESP. These areas only experienced minor roof covering (with some water leakage problems) damage during the storm; the structural systems, roof deck, and shutter systems performed without failure.

However, in De Soto County, the new multi-purpose Turner Agri-Civic Center designed for use as a shelter experienced a partial end wall/roof collapse. In Lee County, the county opened shelters for residents of the barrier islands with the belief that these shelters were "recovery shelters" that would not be impacted by hurricane force winds; most of these shelters were also located in Category 3 storm surge inundation zones, but these buildings experienced tropical force winds (with gusts near hurricane strength) and roof covering damage with associated rain water intrusion damage. Fortunately, due to the compact size of Hurricane Charley, only limited significant storm surge was generated by the hurricane and none of shelters in Charlotte and Lee Counties were flooded.

The building damage to critical and essential facilities experienced during Hurricane Charley led to a significant, and avoidable, loss of function. Specific conclusions for critical and essential facilities based on these observations are:

- When older buildings are used as critical and essential facilities, damage will likely occur to the roof covering, wall coverings, window and door systems, and rooftop equipment. This damage will often lead to significant loss of function at the facilities.

- Some buildings designed to critical and essential facility requirements experienced damage and partial failures during the hurricane due to lack of protection from windborne debris. Lack of protection of windows was common at hospital and medical buildings, and led to window failures and severe damage to building interiors and contents.
- Large rolling and sectional doors at fire stations can be purchased and installed to provide protection from high-wind and debris impact, but catastrophic failure of the doors can occur when these systems are not installed correctly and when track systems are not reinforced for the larger wind loads. These door failures led to pressurization of the buildings and, in some cases, roof collapse that should have been prevented by proper installation of the high-wind rated doors.
- Rooftop equipment loss such as loss of HVAC units and vents, antennas, communication dishes, and lightning protection systems was prevalent. All of these failures caused damage to roof coverings (and sometimes supporting structural systems) that often resulted in rain water intrusion into the facilities.
- Critical facilities housed in lightly engineered buildings such as pre-engineered metal buildings will continue to experience damage and loss of function unless the designs are substantially improved and close attention is given to all connections of the structure and the building envelope.
- Windborne debris could injure or kill first responders at fire and police stations, as well as EOCs, late arrivers at shelters, or those seeking medical attention at hospitals. Although people are not usually outdoors during hurricanes, buildings used as critical and essential facilities can be the exception. It is common for people to arrive at these facilities during a hurricane and additional efforts should be made to reduce the potential for windborne debris at these sites.
- In some communities, shelters sited in a storm surge inundation zone and located in the projected landfall area were used during the hurricane. Only the unique nature of this storm with a small radius of maximum winds and landfall near low tide kept the shelters from being flooded. Shelters located in the projected landfall area and sited in storm surge zones place large numbers of individuals at risk of injury or death due to flooding from the storm surge.
- Designing to minimum Enhanced Hurricane Protection Area (EHPA) requirements does not guarantee that a building being

used as a shelter will be properly designed and constructed to resist extreme wind events.

- ARC 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 all hurricanes.
- Peer review of the design of critical and essential facilities would greatly improve the likelihood that a building has been adequately designed to resist extreme winds.
- Special inspections for key structural items and connections, and for installation of envelope components would help ensure the performance of critical and essential facilities.

7.7 Observed Mitigation Successes

In addition to the successful performance of structures built to the 2001 FBC, successes in older structures and structures mitigated to resist wind and flood loads were observed. Examples of successful residential, commercial, and critical/essential facility mitigation are provided in this section. In addition to these observed mitigation successes, additional examples of mitigation successes can be found on the DHS/FEMA Mitigation web site at http://www.fema.gov/fima/bp.shtm.

7.7.1 Mitigation Success in Residential Construction

Two examples of well-executed mitigation against flood and wind were observed. First, on North Captiva Island, where Hurricane Charley battered buildings with estimated winds in excess of the 130 mph (3-second peak gust) winds required by the 2001 FBC, many homes withstood the winds with minimal damage. Figure 7-1 shows a residence constructed to the design requirements of the 2001 FBC. This building had a well-secured standing seam metal roof that performed well and only experienced some light trim damage (shown in the center of the photo). The windows and doors were protected with a combination of impact resistant, laminated glazing products and shutters. In addition, the residence was elevated above the predicted 100-year flood level on an open pile foundation.

Second, many residences and businesses on the north end of Fort Myers Beach have been elevated on pile foundations to allow water to pass beneath these V-zone structures. In one of the few areas investigated by the MAT that experienced flooding and overwash, Fort Myers Beach experienced storm surge from Charley. The house in Figure 7-2 is one of eight residential units located along the beach in this small development. During Charley's storm surge, water approximately 2 to 3 feet deep washed through the development (see water mark on door of enclosure below house). These older residences, however, were atop pile foundations that allowed the floodwaters to pass safely beneath the houses. As a result, only minor damage to enclosures and access stairways was experienced. This success illustrates the use of best practices on older homes that has been recommended by FEMA in publications such as FEMA 55, *Coastal Construction Manual*.

Figure 7-1.
Residence constructed to the design requirements of the 2001 FBC performed well and only experienced some light trim damage (shown in the center of the photo) (North Captiva Island).

Figure 7-2.
Older residence atop pile foundation that allowed floodwaters to pass safely underneath, resulting in only minor damage to enclosures and access stairways (Fort Myers Beach)

7.7.2 Mitigation Success in Commercial Construction

When Hurricane Charley hit Fort Myers Beach, the Lighthouse Resort Inn and Suites shown in Figure 7-3 remained dry, undamaged, and full of customers, while other hotels and motels on the island were damaged or flooded, and closed. In the past, the Lighthouse Resort would also have been closed. Over the last two decades, seven hurricanes have caused flood and wind-related damage to the resort, resulting in nearly $100,000 in repair costs per event. The resort, which sits 200 feet from the beach, had been elevated as part of a joint State of Florida, Federal, and local mitigation project. In approximately 1 year, the owners have saved nearly $200,000 in repair costs alone, almost 50 percent of their mitigation investment.

At the Charlotte County South Annex building, significant damage and loss of function was prevented when new shutters were installed to protect the building during Hurricane Charley. The galvanized metal shutters were funded in part by a grant to the State of Florida under FEMA's Hazard Mitigation Grant Program (HMGP). With the shutters in place, the Annex suffered only minimal damage. An investment of less than $10,000 saved the taxpayers over half a million dollars in losses avoided in just one hurricane event.

Figure 7-3.
Exterior view of the elevated Lighthouse Resort Inn and Suites, which remained dry and undamaged after Hurricane Charley (Fort Myers Beach)

The county's grant application was approved in 2003. Shutters were purchased for $9,546, using a combination of local funds and the HMGP grant and installed for the first time on August 11, 2004, in anticipation of Hurricane Charley. Two days later, they were severely tested when 125 mph winds slammed the coastal city.

"If it wasn't for the shutters," said George Dahlke, Charlotte County Facilities Construction and Maintenance Project Manager, "all the glass in the building would have been gone. Without the windows, we feel that the uplift [of the wind] would have taken the roof off." (Figure 7-4)

Only one shutter was damaged. Hit hard by flying debris, the shutter panel was dented, breaking the glass behind it, but remained in place and prevented the wind from penetrating the building and causing major wind and water damage. Although windborne debris damaged the roof, creating some leaks and damaging some of the building's contents, this damage was minimal in contrast to other buildings according to Charlotte County Facilities Manager, Michael Sheridan.

Figure 7-4.
Exterior view of the galvanized shutters that protected the Charlotte County South Annex (Punta Gorda)

"The Health Department Building, without shutters, located about a mile away, is badly damaged—broken glass panels, roof and ceiling uplifted—they're still not in service [nearly 5 weeks later]. It may cost $500,000 to repair," he related. Mr. Sheridan credited the shutters on the 20,000-square foot South Annex building with saving the county approximately $600,000 in repairs. That is the amount that would have been needed had the glass panels been broken, allowing wind and rain water to penetrate the building. The total repair estimate for the South Annex is $80,000. Eighty percent is earmarked for roof repairs due to damage from windborne debris. The remainder is for damage to the contents from the roof leaks. The monetary loss avoided by installing the shutters is $520,000.

Employees and the community also avoided losses in time off from work and interruption of services due to lengthy repairs. Just 2 days after Hurricane Charley, with minimal repairs still in progress, the South Annex was up and running. Employees were back at work, providing much-needed services to Charlotte County residents.

7.7.3 Mitigation Success in Critical and Essential Facility Construction

A success in school design and construction that resulted in no loss of function was observed at the Sanibel School on Sanibel Island (Figure 7-5). Dedicated on August 10, 2004, less than a week prior to the landfall of the storm, this school was designed and constructed to the 2001 FBC. Although the school building likely experienced wind speeds that were below the 130 mph (3-second peak gust) design wind speed for the site, the building did experience hurricane force winds around the level of Category 2 winds and sustained little damage.

Damage at the school was limited to loss of gutters on the east side of the building and some wind-driven rain issues. At the time of the MAT visit, the school was preparing for an on-time school opening and did not experience a loss of function as a result of the hurricane. In addition to avoiding significant damage to the school building itself, the successful performance of the design allowed residents of Sanibel Island to move forward with their rebuilding process because the school was functioning.

Figure 7-5.
Courtyard of the newly constructed Sanibel School that was operational immediately after Hurricane Charley passed

8 Recommendations

The recommendations in this report are based solely on the observations and conclusions of the MAT, and are intended to assist the State of Florida, local communities, businesses, and individuals in the reconstruction process and to help reduce damage and impact from future natural events similar to Hurricane Charley. The general recommendations presented in Section 8.1 relate to policies and education/outreach that are needed to ensure that designers, contractors, and building officials understand the requirements for disaster resistance construction in hurricane-prone regions. Proposed changes to codes and statutes are presented in Section 8.2.

In addition to these general and code related recommendations, specific recommendations for improving the performance of the building structural system and envelope, as well as the protection of critical and essential facilities (to prevent loss of function) are provided later in this chapter. Implementing these specific recommendations in combination with the general recommendations of Section 8.1 and the code and statute recommendations of Section 8.2 would significantly improve the ability of the built environment to resist damage from hurricane force winds. Recommendations specific to building structural and envelope issues, critical and essential facilities, and education and outreach have also been provided.

8.1 General Recommendations

As the people of Florida rebuild their lives, homes, and businesses, there are a number of ways they can avoid the effects of future natural hazards, including:

- Design and construct facilities to at least the minimum design requirements in the 2001 FBC and the 2004 FBC (after it becomes effective in the summer of 2005)
- When renovating or remodeling for a building's structural or envelope improvements (both residential and commercial), involve a structural engineer/design professional/licensed contractor in the design and planning
- Assure code compliance through increased enforcement of construction inspection requirements such as the Florida Threshold Inspection Law or the IBC Special Inspections Provisions
- Perform follow-up inspections after a hurricane to look for interior moisture that may affect the structure or building envelope
- Use the necessity of roof repairs to damaged buildings as an opportunity to significantly increase the future wind resistance of the structure

The following recommendations are specifically provided for state and Federal government agencies:

- The government should place a high priority on and allocate resources to hardening, providing backup power and data storage to NOAA's/NWS's surface weather monitoring systems, including ASOSs located in hurricane-prone regions. Continued support is also needed for maintenance, expansion, and deployment of stand-alone unmanned surface observation systems that can be safely and reliably placed in advance of a landfalling hurricane. Support should be provided for the real-time communication of data from all these systems to forecasters and wind field modeling efforts.
- The government should place a high priority on continuing to fund the development of several different tools for estimating and mapping wind fields associated with hurricanes and for making these products available to interested parties as quickly as possible after a hurricane strikes.

8.2 Proposed Changes to Codes and Statutes

Buildings constructed in accordance with 2001 FBC (and those that had been mitigated to resist high-wind loads) were observed to perform substantially better than typical buildings constructed to earlier codes, but their performance was not without exception. The study of buildings and their interaction with high winds associated with hurricanes is a continuous process and much has been learned since the current FBC was developed and adopted. Incorporating these recommendations into the next available code cycle is key to setting the new standard in hurricane-resistant construction in Florida and all hurricane-prone regions.

The following is a list of recommendations specific to the codes and statutes currently adopted and being enforced in the State of Florida. If these recommendations are not codified by the state in response to the hurricanes of 2004, the design changes recommended herein should be considered "best practices" in hurricane-resistant construction and incorporated in all new construction and mitigation projects to the maximum extent possible. The preliminary conclusions and recommendations from this MAT report were presented to the Florida Building Commission and to FL DCA in December 2004 at the Hurricanes Charley, Frances, Ivan, and Jeanne Workshop sponsored by the Commission and IBHS.

In response to Hurricane Season 2004, the Florida Building Commission established a Hurricane Research Advisory Committee composed of researchers, engineers, academics, material suppliers, code officials, and the insurance industry. The Commission invited FEMA to be a member of the Committee. At its first meeting on March 15, 2005, the various members of the Committee made presentations to the Commission on their observations of building performance and the status of their various studies and reports; FEMA also delivered its comprehensive report FEMA 490, *Summary Report on Building Performance 2004 Hurricane Season*. The report provides the Committee with the recommendations of the MATs on design and construction, building code and regulations, public outreach, and critical/essential facilities issues. With FEMA's input and that of its other members, the Committee will produce a report that presents consensus recommendations on needed changes to Florida's building codes, standards, and statutes. The Florida Building Commission will consider these changes as it begins its building code update cycle in the summer of 2005.

8.2.1 Statutory Building Code Provisions

The following design criteria are recommended for inclusion into statewide design requirements for all construction. The criteria are addressed in Ch. 553.71 and Ch. 2000-141 of the *Laws of Florida* (and presented in Section 2.2 of this report).

- Evaluate and adopt updated versions of ASCE 7 for design-load determination of building structures, building envelope systems, attached equipment, accessory structures, and critical and essential facilities. Specific improvements related to the design of building envelopes, attached structures, and open structures that could mitigate damage observed in Hurricane Charley are not available in ASCE 7-98.
- Adopt the windborne debris region defined in ASCE 7 2005 and the debris-impact design criteria provided in ASCE 7 2005. The findings of this MAT and the Hurricane Ivan MAT determined that these code improvements would have a significant effect in reducing damage from windborne debris to buildings and contents when a high-wind event strikes.
- Review the exemption in windborne debris regions that allows for residences to be designed as "partially-enclosed" structures with unprotected openings. The MAT observed numerous instances where the breach of unprotected glazing led to significant damage to building contents that would have been prevented if the damaged buildings had been equipped with protected glazing to resist windborne debris. The next version of the IRC does not allow for the design of partially enclosed structures without protecting glazing. Based on observed damages in Hurricane Charley, this exemption should not be allowed for any use (residential or commercial) in windborne debris regions.
- Define the Exposure Categories used in design in a manner consistent with ASCE 7. Refinements to design guidance for Exposure Categories have been included in the most recent revisions of ASCE 7. Use of the proper Exposure Category would help ensure that full-wind loads are calculated in open areas (Exposure C) where speed reductions are not appropriate.
- 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.

8.2.2 General Code Changes Proposed for FBC Consideration

The MAT observed damages across the hurricane wind field that may have been prevented had existing code sections been enforced for all design wind speed regions or if the code had provided additional design or testing guidance with respect to the building envelope and attached structures and equipment. In response to the observations, the following items are recommended for inclusion in future updates of the FBC and consideration should also be given to incorporating applicable modifications into the national model building codes for other areas of the country exposed to high-wind speeds:

- Develop and adopt wind resistance and wind-load criteria regarding wind resistance for soffits. Wind-driven rain resistance of ventilated soffit panels should also be added. Testing Application Standard (TAS) 110 may be a suitable test method, although it may require modification.
- FBC Section 1503 (Weather Protection) should require compliance with American National Standards Institute (ANSI)/Single Ply Roofing Industry (now just known as SPRI) ES-1 for edge flashings and copings.
- Develop and adopt criteria regarding uplift resistance of gutters and add to FBC Section 1503 (Weather Protection)
- Criteria regarding wind and wind-driven rain resistance of ridge vents should be added to FBC Section 1503 (Weather Protection). Attachment criteria need to be developed, but TAS 110 could be referenced for rain resistance.
- FBC Section 1504 (Performance Requirements) should require compliance with American Society for Testing and Materials (ASTM) E 1592 for testing the uplift resistance of metal panel roof systems.
- FBC Section 1507.2 (Roof Covering Application) should require compliance with Underwriters Laboratories (UL) 2390 and six nails per shingle where the basic wind speed is 110 mph or greater, and it should require use of asphalt roof cement at eaves, rakes, hips, and ridges (refer to FEMA *Hurricane Recovery Advisory No. 2* in Appendix D for details).
- Technically-based criteria regarding blow-off resistance of aggregate on built-up and sprayed polyurethane foam roofs should be added to FBC Section 1508 (Roof Coverings with Slopes Less Than 2:12).
- In areas where the basic wind speed is 110 mph or greater, FBC Section 1510.3 (Recovering vs. Replacement) should require

removal of the existing roof covering down to the deck and replacement of deteriorated decking. In addition, if the existing decking attachment does not comply with the loads derived from Chapter 16, installation of additional fasteners to meet the Chapter 16 loads should be required.

- FBC Section 1522.2 (Rooftop Mounted Equipment) pertaining to anchoring rooftop equipment should be applicable throughout the State of Florida for all wind speeds. Criteria should be added that pertain to attaching lightning protection systems; however, the criteria need to be developed. These provisions should also be included in the mechanical and electrical codes.
- Where shutters other than wood are provided to comply with FBC Section 1606.1.4 (Protection of Openings), a requirement to label the shutters with code described performance information should be added to this section. Without a label, is it difficult for building owners to know if their shutters are suitable.

8.2.3 Code Changes Proposed for Critical/Essential Facilities and Shelters

To address the poor performance and loss of function of critical and essential facilities during Hurricane Charley, the following code changes are recommended. Some changes in this section are not directly attributed to damage observed from the hurricane, but rather to the resulting loss of function that was observed. These types of facilities are expected to perform better than standard construction (i.e., these buildings are expected to withstand design events such as Hurricane Charley with minimal damage or loss of function). These facilities are expected to be functional and operational after hurricanes of significant magnitude.

For shelters and Enhanced Hurricane Protection Areas (EHPAs), the need for assurance against failure is significant because these facilities are opened and people are invited into a building deemed capable of preserving life and protecting against harm during an event. Recommended design guidance and best practices for the critical and essential facilities, in addition to the code changes cited below, are presented in Section 8.6.

- Critical and essential facilities, at a minimum, should be designed with wind loads using an importance factor of 1.15 in accordance with ASCE 7. In addition, all code changes proposed in Section 8.2.2 should be required (if they are not adopted for all buildings).

- In the SESP, the FL DCA recommends that the design wind speed used for the design of hurricane shelters and EHPAs should be the 2001 FBC basic wind speed plus 40 mph (Performance Criteria 3, shown in Table F-1 in Appendix F). This is also the *recommended* best practice for shelter design provided in the 2001 FBC, Section 423, Part 24 (State Requirements for Educational Facilities–Public Shelter Design Criteria). To better ensure the adequate performance of shelters, the MAT recommends that this guidance be changed to a *requirement*.
- For shelters and EHPAs, the minimum debris impact protection should be per ASTM E 1996 Category E for a 9-pound 2x4 (nominal) missile traveling at 50 mph. These criteria should be required by the SESP and should be used until the International Code Council's (ICC's) High Wind Shelter Standard is completed in 2006/2007 and available for adoption.

8.3 Structural (Residential and Commercial Construction)

The generally good performance of structural systems implies that the structural design of buildings in high-wind areas has been improved. This improvement is the result of implementation of code requirements that better account for the forces acting on buildings from wind and windborne debris. In addition to considerations recommended in Section 8.2, the following best practices regarding the design of new structures and mitigation of older structures are strongly recommended.

8.3.1 New Residential and Commercial Structures

It is essential that new buildings be constructed to the 2001 FBC and then to the revised 2004 Edition. In addition to the proposed changes to codes and statutes presented in Section 8.2, the following should also be considered during the design and construction of new buildings:

- Detailing for connections that clearly specifies the continuous load path through a building should be provided on residential construction drawings.
- Structural attachments, such as carports, and additions to manufactured homes should only be constructed when properly designed and permitted documents show the addition is capable of withstanding the wind loads generated. If the addition or attachment

is not free-standing and is connected to the manufactured home for structural support, plans should be prepared that clearly detail the connection between the unit and the structure being attached. The design and construction should be approved, permitted, and inspected by building officials.

- Design professionals, building officials, and contractors need to work together to improve quality control and inspections during the design and construction of buildings in high-wind areas. Codifying additional inspections does not guarantee improved construction unless building officials are provided the resources or funds for these inspections. All parties need to look at ways to ensure buildings are constructed as designed and permitted in hurricane-prone regions.

8.3.2 Wind Mitigation for Existing Residential Buildings

Some of the existing residences that performed well in Hurricane Charley were older residences that had been retrofitted to resist wind and windborne debris. In many instances, the mitigation measures observed by the MAT in these older homes were key to the improved performance of the structures. However, in some cases, these retrofits were incorrectly performed or were incomplete, and damage or failure occurred.

The most common mitigation measure for existing residential buildings observed was the installation of metal framing connectors such as clips and straps between rafters/trusses and bearing walls. However, in each of the observed buildings, the mitigation effort did not address other connections between the roof deck and the rafters/trusses. Therefore, only part of the load path between the roof covering and the foundation was strengthened.

At many other existing residences, the attachment of the roof covering system to the roof structure below had not been upgraded along with other mitigation efforts; most of the houses inspected experienced roof covering damage and subsequent damage to their interiors and contents from rain. The MAT concluded that mitigation measures should have been part of an overall mitigation plan and each measure should have been completely, rather than partially, carried out.

The IBHS (http://www.ibhs.org) and the Federal Alliance for Safe Homes (FLASH) (http://www.flash.org) have comprehensive guidelines and plans for retrofitting existing homes for wind resistance. The mission of both organizations is to reduce the loss of life and property damage from natural disasters by promoting construction techniques that typically exceed those of the minimum adopted building code. Their guidelines are strongly recommended and highly relevant for mitigating damage from events such as hurricanes. The programs provide recommendations for retrofitting existing buildings from the roof deck to the foundations. Some of the highlights and focuses of their mitigation programs are outlined below.

For wall openings:

- Windows – Cover windows with impact-resistant shutters or replace them with impact-resistant windows
- Garage doors – Replace garage doors with wind and impact-resistant garage doors or have a design professional specify bracing for the garage door and strengthen methods for the track. Figures 8-1 and 8-2 show a plan view of a typical garage door and a recommended reinforced horizontal latch system for a typical garage door, respectively.

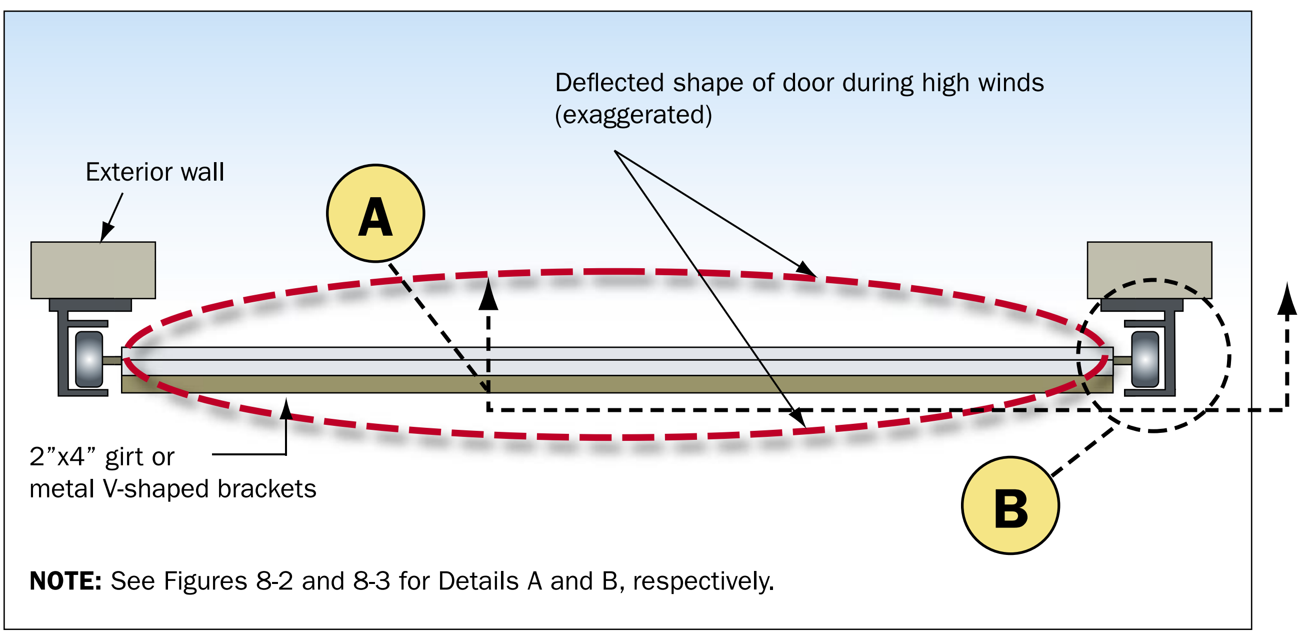


Figure 8-1. Plan view of a typical garage door

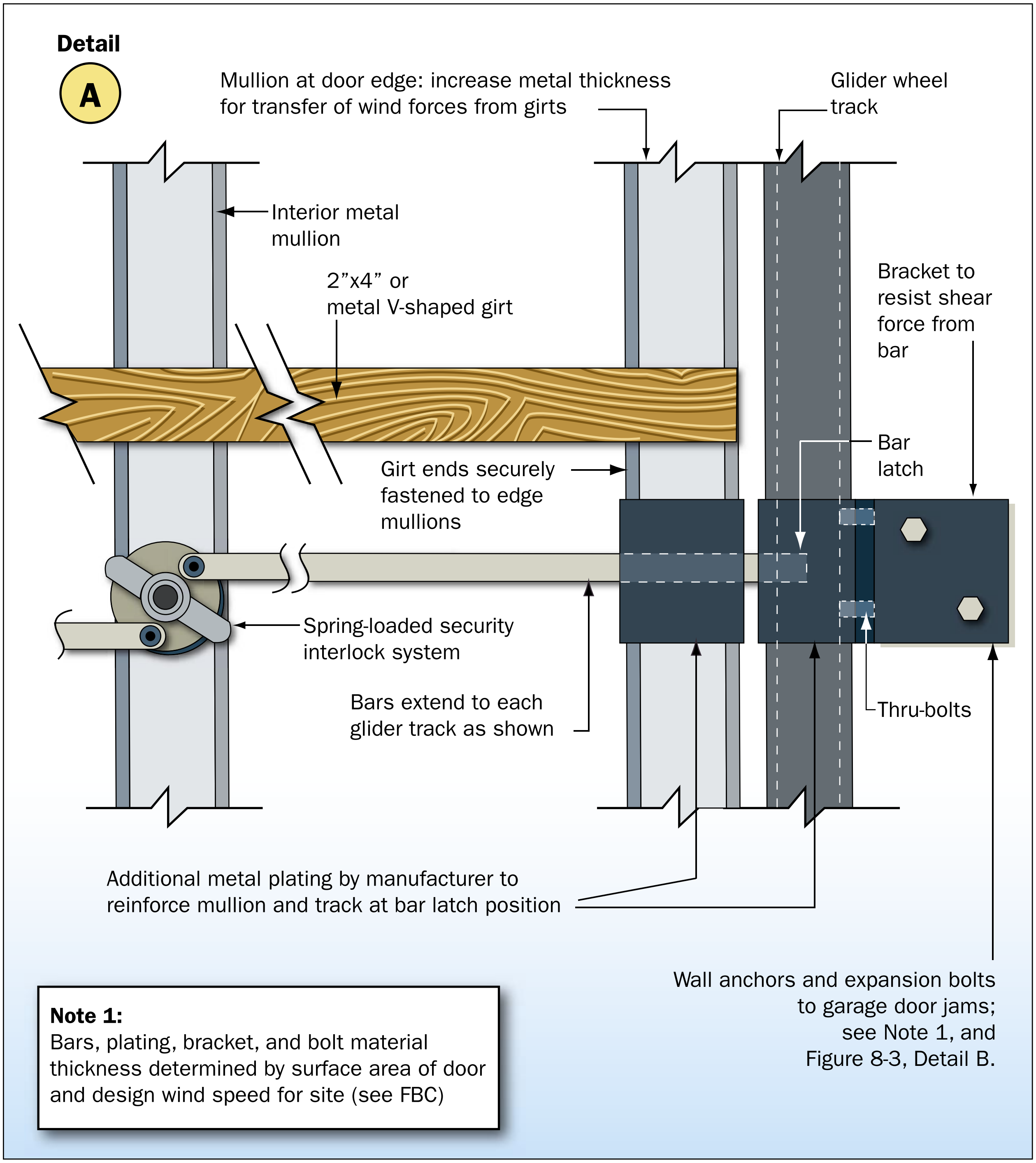


Figure 8-2. Detail A – recommended reinforced horizontal latch system for a typical garage door

- Replace doors with wind and impact-resistant doors or install head and foot bolts to engage door frames with a longer throw length (a minimum of 1 inch); use additional connectors to secure door frames to supporting walls

For roof coverings and roof decks (see FEMA *Hurricane Recovery Advisories Nos. 1 and 2* in Appendix D):

- When installing new asphalt shingle roof covering, perform the following activities:
  - Remove the existing roof covering to expose the roof sheathing
  - Remove the bottom row of sheathing at the eave
  - Install straps/clips at the roof-to-wall connections
  - Brace the gable end walls
  - Replace any damaged or deteriorated sheathing panels
  - Refasten all sheathing with 10d common or 8d ring shank nails spaced at 4 inches on center on the edges and 6 inches on center in the field
- If the roof covering is not being replaced, perform the following activities:
  - Strengthen the roof deck from inside the attic by using a caulking gun to apply a 1/4-inch bead of wood construction adhesive (certified to AFG-01 or ASTM D 3498) at the intersection of the roof deck and truss/rafter on both sides
  - Brace the gable end walls and ensure the bottom chord of the gable end trusses are secured to the top of the wall
  - Install straps/clips at the roof to wall intersection from inside the attic or by gaining access from the exterior

8.3.3 Wind Mitigation for Existing Commercial Buildings

The MAT observed some existing commercial (non-residential) buildings that were mitigated to resist additional wind loads or to protect glazing from windborne debris. Although this report clearly states that significant contents damage claims may be reduced by installing protection systems for glazing, the building structure or other portions of the building envelope should still be evaluated. At the Charlotte

County Sheriff's office and EOC, the roof of this pre-engineered building was lost over the front third to half of the building, despite having shutters protecting the glazing. Even if this facility was not used for critical or essential operations, the end result for any tenant would have been the same; that is, the contents of the building were completely destroyed when the roof covering was lost and rain soaked the interior. It is important to remember when retrofitting existing buildings that the building will remain vulnerable unless all structural and envelope issues are addressed comprehensively.

The MAT observed many rolling and sectional garage doors on critical or essential facilities and at commercial and industrial buildings that failed during the hurricane, resulting in large openings in the building envelope. A typical failure point was the roller and track connection. Designers should ensure that wind-resistant doors, all tracks, closure mechanisms, and attachments to the building structure are properly designed and installed. For these doors, the tracks need to be reinforced (along with the attachment of the tracks to the wall and ceiling) or the door itself needs to be supported by removable columns or supports that will reduce the loads being transmitted through the roller/track connection. These removable supports should be installed on garage doors when a hurricane warning is issued. Figure 8-3 shows a typical garage door failure and recommended assembly improvements applicable for commercial and residential applications.

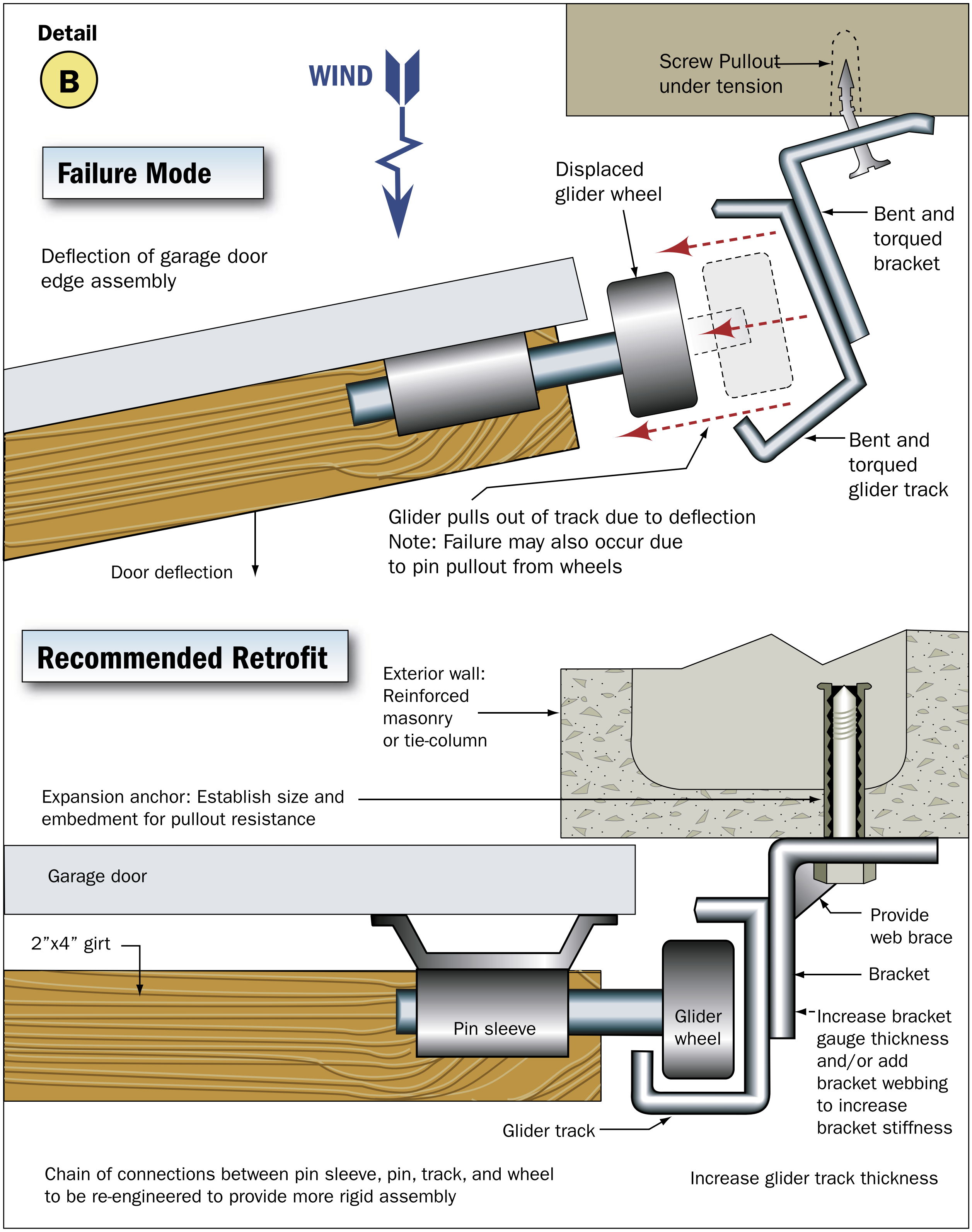


Figure 8-3. Detail B – typical garage door failure at the edge and recommended assembly improvements

8.4 Accessory Structures/Attachments

Given the prevalence of failures of aluminum structures (such as pool cages and carports), consideration should be given to improving their designs. Until the 2004 FBC is adopted (and statutes restricting the referencing of improvements to ASCE 7 and the IRC are rescinded), fabricators and engineers of aluminum structures can opt to use the readily available *AAF Guide to Aluminum Construction in High Wind Areas.* Alternatively, the MAT recommends the following: 1) provide additional anchors at the corner post connections to the concrete (these posts should be more securely fastened to the concrete than the intermediate posts); 2) ensure that walls parallel to the primary building are more resistant to wind forces parallel to those walls by using tension cable bracing, solid "K" bracing, or other methods; 3) provide lateral bracing in roof planes by using rigid diagonal structural members; and 4) use stainless steel screws to avoid commonly observed corrosion.

For existing attached structures, it is recommended that these structures be evaluated to determine if they are structurally sound for the wind region in which they are located. Because prescriptive analysis guidance may not be available, it may be advantageous to have a design professional analyze the structures to determine whether they are capable of withstanding wind pressures without failure and to determine the implications to the attached buildings if attached structures collapse or are torn away. In addition, it is recommended that detached structures be analyzed by a professional to determine their ability to withstand windstorm events. This analysis should include a review of the anchoring of lightweight structures. The attention to the code guidelines for wind-resistant design is often neglected in these structures.

Some contractors may view the use of best practices that meet or exceed code minimums, such as the *AAF Guide to Aluminum Construction in High Wind Areas,* as an impediment due to a false perception of high costs associated with these engineering practices in the competitive arena of home contracting. However, some contractors understand that providing durable structures is a sound business practice that enhances their reputations and reduces their liabilities. Some measures to improve the survivability of aluminum structures are simple and inexpensive (e.g., strengthening the anchoring of corner posts and installing additional bracing). For this reason, they should be utilized by all aluminum contractors.

8.5 Architectural, Mechanical, and Electrical

To improve the performance of the building envelope and rooftop equipment, the following action items are recommended in addition to the code revisions identified previously.

- **Wind design guides.** Design guides need to be developed for gutters and downspouts, soffits, metal panel systems, continuous ridge vents (including means to provide secondary protection from water intrusion if the vent blows off), rooftop mechanical and electrical equipment, and lightning protection systems (LPSs). The guidance in FEMA *Hurricane Recovery Advisories No. 1* and *No. 2* (Appendix D) should be added to the *Residential Asphalt Roofing Manual* published by the Asphalt Roofing Manufacturer's Association) and to *The NRCA Steep-Slope Roofing Manual* published by the National Roofing Contractors Association (NRCA). The guidance in FEMA *Hurricane Recovery Advisory No. 3* (Appendix D) should be considered for incorporation into the *Concrete and Clay Tile Installation Manual* published by the Florida Roofing, Sheet Metal and Air Conditioning Contractors Association, Inc. (FRSA) and Roof Tile Institute (RTI).

- **Loads and attachment.** It is recommended that designers calculate loads on the building envelope and rooftop equipment and specify/detail adequate attachment to resist the loads. A minimum safety factor of 2 is typically recommended.

- **Roof coverings.** When re-roofing, tear-off rather than re-covering is recommended in areas where the basic wind speed is 110 mph or greater. This will allow inspection of the integrity and attachment of the roof sheathing. If the existing decking attachment does not comply with the loads derived from the current building code, installation of additional fasteners to meet the code loads is recommended; contractors are reminded that in-process inspections are required by many jurisdictions. Further, it provides access to the roof deck so secondary underlayments may be installed to improve the roof deck's resistance to water intrusion. Specific system/component recommendations are:

  <u>Asphalt shingles</u>. Guidance given in FEMA *Hurricane Recovery Advisories No. 1* and *No. 2* (Appendix D) is recommended. In addition, installers need to follow manufacturer's installation instructions with respect to starter strips and nail locations. Manufacturers should re-evaluate the attachment of factory-laminated tabs (Figure 5-27). Loss and blow-off of the tabs may be reduced if additional

quantities of adhesive, or a stronger adhesive, is used during the production of the shingles.

Metal panels. It is recommended that uplift resistance be based on ASTM E 1592. For panels with concealed clips, it is recommended that clip locations be chalk-lined to ensure that they are not excessively spaced or different from manufacturers' recommendations. It is also recommended that designers specify close spacing of fasteners at eaves, and hip and ridge flashings (e.g., spacing in the range of 3 to 6 inches on center, commensurate with the design wind loads).

Tiles: It is recommended that foam-set manufacturers re-evaluate their installation recommendations in order to simplify the number of options and to clarify the requirements. It is also recommended that they re-evaluate their training and certification programs, because it was evident that many foam-set roofs were installed improperly, most likely by inadequately trained workers. Guidance given in FEMA *Hurricane Recovery Advisory No. 3* (Appendix D) addresses both of these issues and should be implemented.

It is recommended that FRSA and RTI re-evaluate the use of a safety factor of 2 for mechanically attached systems. Field observations of some roofs indicated that tile blow-off occurred at wind speeds less than those predicted by the resistance tables in the *Concrete and Clay Tile Installation Manual*. This difference between predicted and actual performance may be due to the static test method used to evaluate wind resistance. However, tiles are dynamically loaded during hurricanes. With dynamic loading, minor oscillating of down-slope ends of the tiles may induce fatigue loading, which, during a hurricane, allows the oscillating tiles to jack the fasteners out of the deck, or allows the nail holes through the tiles to be enlarged enough to allow tiles to pull over the fasteners. Until a dynamic test method can be developed, the existing test method could be used with a higher safety factor (e.g., 3) applied to the ultimate resistance.

Similarly, it is recommended that the foam-set manufacturers re-evaluate the use of a safety factor of 2. With foam-set attachment, there is an opportunity for variation in size and placement of the foam paddies. Also, as discussed above, the static test method may over-predict actual performance. A higher safety factor (e.g., 4) may be a more appropriate value to use to account for these application and testing concerns.

Edge flashings, copings, and gutters. Successful performance of edge flashings, copings, and gutters is vital to avoid progressive lifting and peeling of roof membranes. For edge flashings and copings, compliance with 2003ANSI/SPRI ES-1 is recommended. However, because ES-1 does not incorporate a safety factor, it is recommended that a safety factor of 2 be applied to the ultimate resistance values obtained from testing (a safety factor of 3 is recommended for critical and essential facilities).

Further, to avoid progressive failure in the event of gutter, edge flashing or coping uplift, it is recommended that a bar be placed over the roof membrane near the edge flashing or coping (Figure 8-4). The purpose of the bar is to provide secondary protection against membrane lifting and peeling in the event that the edge flashing/coping fails. A robust bar specifically made for bar-over mechanically-attached single-ply systems is recommended. The bar needs to be very well anchored to the parapet or deck. Depending upon design wind loads, spacing between 4 and 12 inches on center is recommended for the bar anchors. A gap of a few inches should be left between each bar to allow for water flow across the membrane. After the bar is attached, it is stripped over with a stripping ply.

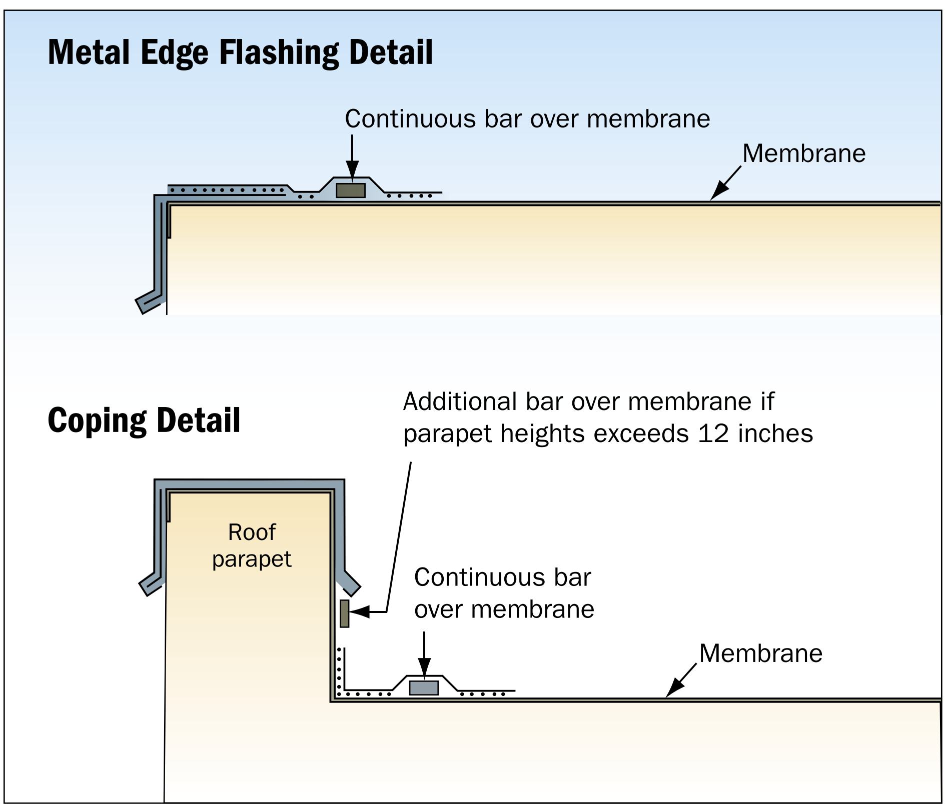


Figure 8-4. **Continuous bar near the edge of edge flashing or coping. If the edge flashing or coping is blown off, the bar may prevent a catastrophic progressive failure.**

SOURCE: FEMA 55, *COASTAL CONSTRUCTION MANUAL*, 2000

Design guidance and test methods are lacking for gutters. Therefore, it is recommended that designers exercise their professional judgment in specifying and detailing gutter uplift resistance.

- **Windows**. It is recommended that the window/curtain wall industry re-evaluate the test pressures that are currently used to assess resistance to wind-driven rain. Although this has not been an issue in the past, as building performance is improved and water infiltration due to failed envelopes is reduced, the damage due to wind-driven rain infiltration is becoming more pronounced. With incorporation of more realistic test pressures, development of more water-resistance assemblies is necessary.
- **Motorized shutters.** Motorized shutters should be manufactured with a manual override. This will allow deployment of the shutters prior to a hurricane, even if power has been lost. After a hurricane, they can be rolled up even if the electrical power has not been restored; this will facilitate drying the building if water infiltration has occurred and speed recovery.
- **Rooftop mechanical and electrical equipment.** For attachment of rooftop equipment, a minimum safety factor of 2 is recommended due to uncertainties pertaining to load and resistance in currently required codes. It is recommended that cowlings on exhaust fans be anchored with cables to curbs, and that access panels that are not securely attached by the manufacturer be field modified (guidance is provided in FEMA 424, *Design Guide for Improving School Safety in Earthquakes, Floods, and High Winds*). It is also recommended that special attention be given to attachment of LPSs, per guidance provided in FEMA 424.
- **Weatherstripping at exterior doors.** Specifying wind-driven rain-resistant weatherstripping at exterior doors is recommended. Although it has not been an issue in the past, as building performance is improved and water infiltration due to failed envelopes is reduced, the damage due to wind-driven rain infiltration at doors is becoming a more significant problem. FEMA 424 provides weatherstripping guidance.

  When the basic wind speed is greater than 120 mph, some leakage should be anticipated when design wind-speed conditions are approached. One approach to minimize infiltration damage would be to design a vestibule to provide more than one level of protection against rain water infiltration, in addition to robust weatherstripping. With this approach, both the inner and outer doors can be equipped with weatherstripping, and the vestibule itself can be designed to tolerate rain water intrusion.

8.6 Critical and Essential Facilities (Including Shelters)

Designers should be reminded that codes and standards recommend the minimum design requirements for facilities (even critical and essential facilities); thus, implementing known best practices for high-wind design above the required minimums is prudent. To achieve building performance that will not result in the loss of function of the facility, the following are recommended in addition to the proposed code revisions provided in Section 8.2.3.

- **Expand the use of the critical and essential facility designation.** ASCE 7 Table 1 defines which buildings are required to be classified as critical and essential facilities (i.e., Category III and IV buildings). However, building owners and their design professionals should not consider Categories III and IV to be an all-inclusive list. Other buildings may be vital in the response before and during, and recovery following a hurricane, or they may house functions that need to remain operational during an event. For example, a medical office building (MOB) is not a Category III or IV building, but the poor performance of a MOB could adversely affect the functioning of the hospital. Therefore, classifying MOBs that are integrated with hospitals as critical or essential is recommended. Similarly, nursing homes are not specially mentioned in ASCE 7 Table 1; however, health care facilities with 50 or more resident patients are classified as Category III. Although an independent living or assisted living facility would typically not be considered Category III, a skilled nursing or Alzheimer's facility (regardless of size) would benefit from being classified as Category III.

- **Prioritize the critical and essential facilities.** All critical and essential facilities are important, yet some are more critical than others. Because of the realities of funding limitations to mitigate wind effects for both new and existing buildings, building owners and their design professionals should prioritize their facilities. For example, 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 could also receive the highest priority for mitigation (retrofit) projects.

- **Siting.** New critical and essential facilities and, specifically, shelters should not be constructed below the 500-year flood elevations or within a designated storm surge inundation area. Evaluation of existing shelters located in storm surge inundation zones that were opened during Hurricane Charley is an operational issue that was beyond the scope of this building-focused MAT report.

- **Detailing and notations on the building plans.** Designers should clearly indicate on the plans the area of the facility that was designed to function as a high-wind shelter or hardened area. Further, the designer should provide additional details of the portions of the building's structure and envelope elements to ensure that the construction requirements or differences for this portion of the building are clearly understood by the builder and the building official. Additional notes should also be provided that clearly indicate the design criteria used for this facility (or portion thereof) and maximum design pressures should be stated for the main wind force resisting system (MWFRS) and for components and cladding (C&C) systems. Specific references to design assumptions from ASCE 7 and FEMA 361, *Design and Construction Guidance for Community Shelters should be provided.*

- **Material selection.** Regardless of whether the FBC, ASCE 7, model building codes, or FEMA 361 is used to design the critical or essential facility, other design measures should be taken for design of the building's structural and envelope systems, and rooftop equipment. Structural systems that have a proven record of excellent high-wind performance include reinforced cast-in-place concrete structures (including insulated concrete forms), reinforced masonry structures with concrete or heavy metal decks, and steel frame systems with debris-resistant exteriors. Both FEMA 361 and FEMA 424, *Design Guide for Improving School Safety in Earthquakes, Floods, and High Winds,* provide detailed guidance on material selection for structural and building envelope systems. Although FEMA 361 was developed for shelter design and FEMA 424 was developed for schools, much of the information is applicable to other types of critical and essential facilities. Finally, a comprehensive design guide addressing retrofitting and mitigation of existing essential facilities should be developed. This guide would benefit many communities with older facilities.

- **Peer review process.** To improve the quality of design, contract drawings and specifications for new construction and remedial work on existing building envelopes and rooftop equipment should undergo rigorous peer review prior to permitting and construction. This would ensure important details are not overlooked or under-designed.

- **Construction contract administration.** For new construction and remedial work on existing building envelopes and rooftop equipment, more rigorous submittal review and field observation (inspection) should occur than is the case with non-critical and essential buildings. This is imperative for maintaining the integrity of the building envelope.

- **Code requirements.** The only special criteria for critical and essential facilities in the FBC, ASCE 7, and the model building codes is the importance factor (I). The importance factor adjusts the mean recurrence interval to the facility type being designed. However, for these facilities, this adjustment will typically increase the loads by only 15 percent. Other criteria need to be added to the code and were presented in Section 8.2.
- **Maintenance and repair.** To protect from adverse facility degradation as they age, critical and essential facilities should be periodically inspected, maintained, and repaired. Emphasis should be on the building's envelope and rooftop equipment because these are the components most prone to degradation. The roof and rooftop equipment should be inspected twice a year. Windows, doors, and wall coverings should be inspected at 5-year intervals. In addition, special inspections of the entire facility (both building structural and envelope systems) should be conducted after storms with wind speeds in excess of 90 mph 3-second peak gust winds.

8.7 Design Guidance and Public Education

In order to reduce the damages caused by building structural and envelope failures, better guidance and public education needs to be developed and provided to design professionals, contractors, and the general public who design, construct, and live in hurricane-prone regions. The following items are provided for consideration:

8.7.1 Design and Construction Guidance

Design professionals are in need of additional guides to provide methodologies and best practices when code guidance is vague or unclear. For instance, it was common to see fasteners for roof coverings and wall cladding spaced too far apart, fasteners that were too small, and connections that were too weak. Enhanced details were seldom observed. Numerous examples of building envelope component failure were observed, especially when well-established basic construction practices were not implemented, such as compliance with minimum edge distance spacing for fasteners. Unless designers and contractors understand wind-resistance issues, envelope and equipment failures will continue to occur. The following list identifies where improved design, construction, and testing guidance is needed so that code compliance can be better achieved.

- **Pre-engineered metal buildings.** The MAT observed numerous pre-engineered metal building failures due to corrosion of the main structural framing members. To improve the performance of these buildings, main framing members of all pre-engineered buildings that are 10 years of age and older should be inspected at 3-year intervals by a registered structural engineer. A report of the building's structural adequacy should be submitted to the building official and the building owner or manager. This type of evaluation could be combined with a building maintenance program to ensure the buildings will perform as originally designed.
- **Roof coverings, gutters, and downspouts.** A design guide, test method, and building code criteria need to be developed for gutters. The design guide should also address attachment of downspouts. Technically-based criteria need to be developed and codified for aggregate surfacing on built-up and sprayed polyurethane foam roofs. To decrease susceptibility of tiles to windborne debris damage and subsequent blow-off from the roof, development of tiles with improved ductility via internal or backside reinforcement or bonding film is recommended in hurricane-prone regions (i.e., development of a tile akin to laminated glass). Although it is currently a low priority, research is needed on wind resistance of roof walkway pads.
- **Rolling and sectional doors.** Because of their large size, high loads can be induced on frame fasteners. Designers and contractors should give special attention to fastener type, and size and spacing used to attach the frame. If the frame is attached to wood blocking, attention should also be given to the blocking attachment. If the fasteners are placed in concrete or masonry, adequate edge distances should be maintained.
- **Soffits.** Design guidance is needed for the attachment of soffits, including design of baffles or filter media to prevent wind-driven rain from entering attics.
- **Rooftop equipment.** Design guidance and building code criteria are needed for the attachment of condensers and rooftop mechanical equipment (including outside ductwork). Air conditioning condensers can be anchored to a secure mounting for little cost. Such anchoring would greatly reduce damage to the Freon and electrical connections to the compressors, thus decreasing the amount of time occupants would be without air conditioning.

Building owners and homeowners also need to be educated to inspect exterior connections and fasteners for wear, corrosion, and other deterioration that weakens the integrity and becomes breakable in a hurricane.

- **Other exterior devices and equipment.** Other exterior devices, such as pool equipment, gas heaters, and heat pumps, should be evaluated and secured as needed. These devices may already be anchored well enough by plumbing lines, and additional anchoring may not be necessary. However, property owners should be educated about performing an appropriate inspection of their homes to evaluate the need to secure objects, including children's swing sets, aboveground pools (not filled), barbeque grills, and storage sheds. Because of the number of roof-mounted solar water heater collectors that were torn off homes during hurricanes, it is recommended that their attachment to the roof be carefully inspected by a qualified professional to be sure they are secured well enough to withstand anticipated wind pressures.

- **Electrical and communications equipment.** Design guidance and code criteria are needed for attachment of LPSs, communications towers, and satellite dishes.

- **Test methods.** Some of the methods used to test building envelope assemblies are inadequate. Virtually all of them are static tests. Static testing is suitable for some assemblies, but other assemblies should be dynamically tested in order to obtain a more realistic measure of their wind resistance. For those assemblies where it would be prudent to test dynamically, but dynamic test methods are not currently available, higher safety factors should be used.

- **Manufacturers' instructions.** There were numerous instances of products being installed in a manner that was a significant deviation from manufacturers' installation instructions. This points to a need for better training of the workforce, establishing better quality control (i.e., contractors inspecting their work) and more frequent quality assurance (i.e., field observations by a qualified party other than the contractor, such as an engineer or building official).

- **Human intervention.** Building owners and homeowners need to be educated about pre-storm activities, such as installation of shutters (if glazing is not laminated), installation of removable stiffener bars at garage doors (where applicable), and tying down or removing loose items from roofs and yards. They should also be educated about post-storm activities, such as quickly removing wet materials from within buildings and drying out the buildings.

8.7.2 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, it is clear that many of the failures observed after Hurricane Charley were not caused by current code inadequacies, but caused by instead from the failure of designers, manufacturers, building officials, and contractors to implement the current state of knowledge with respect to buildings located in hurricane-prone regions. A renewed, state-wide comprehensive educational effort is needed to avoid the hurricane building damage cycle, wherein buildings are constructed, damaged, repaired, or rebuilt, and then damaged again in a future severe weather event. The following specific action items are recommended:

- **Building owners and homeowners.** Owners need to be educated in a number of areas:
    - The need to adequately budget for a construction project, so that appropriate mitigation measures can be implemented
    - The need to select a design and construction team that is knowledgeable about designing and constructing in hurricane-prone regions, and who will execute the work in a diligent and technically proficient manner utilizing state-of-the-art best practices
    - Preparations to be taken prior to hurricane landfall
    - Steps to be taken after the hurricane passes (e.g., having the building inspected for damage, having emergency repairs performed, and drying out the building)
    - If the building is damaged, having it rebuilt in a manner that protects against future damage
    - The need to periodically inspect exterior connections and fasteners for wear, corrosion, and other deterioration that weakens the integrity and becomes breakable in a hurricane

To facilitate these educational goals, pamphlets tailored to homeowners and commercial/governmental owners should be developed, along with strategies for distributing this information to owners (possibly during the sale of a home or business). Enlisting the assistance of real-estate companies and organizations such as the Building Owners and Managers Association (BOMA) and providing public service notices to television programs at the start of each hurricane season should be pursued.

- **Architects/engineers/consultants.** From the damage observed to both old and new buildings, it is clear that some design professionals working in hurricane-prone regions still struggle with the design and detailing of hazard-resistant construction. Although it appears that in most cases the structural systems (MWFRS) are receiving proper attention, many design professionals falter and struggle with the design of building envelopes and rooftop equipment; this indicates a need for substantial improvement in their technical proficiency in this aspect of building design. A variety of educational tools could be used to assist the designers, including monographs, web-based tutorials, and seminars. Colleges and universities located in hurricane-prone regions should consider a curriculum that emphasizes hurricane-resistant design for current students and continuing education for design professionals.

- **Building officials.** Coastal area building officials, plan reviewers, and inspectors should be required to attend annual seminars specially designed to share "lessons learned" and to train the building officials to look for items that may cause failure of a structure or building components during hurricane events. These items include unbraced gable ends, missing truss bracing, truss anchorage, and anchorage of the windows and doors. Quality of construction also depends upon knowledge of the building officials and enforcement techniques of the building department.

- **Contractors.** Many contractors, particularly those involved in constructing building envelopes and installing rooftop equipment, could be better trained in the installation and use of fastening and anchoring systems. For construction trades, visual tools that use videos/DVDs and on-the-job or classroom mock-up training that highlights the failures that occur when simple anchoring techniques are not applied may be beneficial. Trade schools in hurricane-prone regions should include courses on hurricane-resistant construction in their curriculum.

- **Manufacturers.** Many manufacturers of building envelope materials and rooftop equipment are also in need of education regarding performance of their products during hurricanes. With increased knowledge, manufacturers will be better equipped to provide special guidance for use of their products in hurricane-prone regions and will be better equipped to develop improved products and systems for these areas. With a better educated manufacturing sector, manufacturers could serve a vital educational role when they interface with designers and contractors.

- **Associations.** It is recommended that associations, institutes, and societies representing design professionals, contractors, and manufacturers take an active role in developing hurricane-resistant design and/or construction educational materials and promote them, along with educational materials developed by others, to their members.

- **Incentives.** 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 (Federal, state, and local) funding 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.

- **Public education on rain water damage.** To reduce property losses and the negative impact to business owners whose businesses and homeowners whose homes were damaged, business owners and homeowners should be educated on how rain water damage can occur to buildings. The purpose of the education would be to encourage all property owners to protect their businesses and homes from the entry of rain water. Key points to highlight include:

  - Prolonged rain falling on damaged buildings can result in significant water damage to their business or home.
  - It is not uncommon for wind-driven rain, sometimes traveling in excess of 100 mph, to wet all interior surfaces of a building.
  - Associated pressure differences across walls, windows, doors, soffits, etc., can lead to the entry of damaging amounts of rain water into a business or residence.
  - Wet or flooded buildings are unlikely to have electricity for several weeks; this can present long- and short-term problems for drying the building if auxiliary power is not available.
  - Basic ventilation and removal of water may not be possible if motorized shutters cannot be opened; there is typically no means for dehumidification without power.
  - High temperatures and high humidity are conducive to the growth of mold and odors.

Similarly, builders and remodelers might benefit from education related to best practices and methodologies to minimize rain water-entry issues. If they are aware of these issues, they may be encouraged to suggest to business owners and homeowners cost-effective measures to make buildings more water- and wind-resistant. Even though there are several relatively inexpensive means that can be taken to minimize rain water entry, most builders and remodelers are not aware of the vulnerabilities of buildings.

A

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C

Acronyms and Abbreviations

A

AAF	Aluminum Association of Florida
ANSI	American National Standards Institute
ARA	Applied Research Associates
ARC	American Red Cross
ASCE	American Society of Civil Engineers
asl	above sea level
ASOS	Automated Surface Observing System
ASTM	American Society for Testing and Materials
AWOS	Automated Weather Observing System

B

BFE	base flood elevation
BOAF	Building Officials Association of Florida
BOMA	Building Owners and Managers Association
BUR	built-up roof

C

C&C	components and cladding
CFR	Code of Federal Regulations
CMU	concrete masonry unit

D

DEM	Department of Environmental Management
DFO	Disaster Field Office

E

EDT	Eastern Daylight Time
EHPA	Enhanced Hurricane Protection Area
EIFS	exterior insulation and finish system
EMS	Emergency Medical Services
EOC	Emergency Operations Center
EPDM	ethylene propylene diene monomer
ESRI	Environmental Systems Research Institute

F

FBC	Florida Building Code
FCMP	Florida Coastal Monitoring Program
FEMA	Federal Emergency Management Agency
FHBA	Florida Home Builders Association
FIRM	Flood Insurance Rate Map
FLASH	Federal Alliance for Safe Homes
FL DCA	Florida Department of Community Affairs
FRSA	Florida Roofing, Sheet Metal and Air Conditioning Contractors Association

G

GDT	Geographic Data Technology
GPS	global positioning system

H

HAZUS-MH	Hazards U.S. – Multi-Hazard
HMGP	Hazard Mitigation Grant Program
HRD	Hurricane Research Division
HUD	U.S. Department of Housing and Urban Development
HVAC	heating, ventilation, and air conditioning
HVHZ	High Velocity Hurricane Zone

I

I	importance factor
IBC	International Building Code
IBHS	Institute for Building & Home Safety
ICC	International Code Council
ICU	intensive care unit
IRC	International Residential Code
ISO	Insurance Services Office

L

LPS	lightning protection system
LWIC	lightweight insulating concrete

M

MAT	Mitigation Assessment Team
MOB	medical office building
MODIS	Moderate Resolution Imaging Spectroradiometer
mph	miles per hour
MWFRS	main wind force resisting system

N

NAHB	National Association of Home Builders
NASA	National Aeronautics and Space Administration
NAVD	North America Vertical Datum
NFIP	National Flood Insurance Program
NFPA	National Fire Protection Association
NHC	National Hurricane Center
NIST	National Institute of Standards and Technology
NOAA	National Oceanic and Atmospheric Administration
NRCA	National Roofing Contractors Association
NWS	National Weather Service

O

OSB	oriented-strand board

P

PC	Performance Category
psf	pounds per square foot
PVC	polyvinyl chloride

R

R_{max} radius of maximum winds

RTI Roof Tile Institute

S

SBC Standard Building Code

SBCCI Southern Building Code Congress International, Inc.

SESP Statewide Emergency Shelter Plan (Florida)

SFBC South Florida Building Code

SFHA Special Flood Hazards Area

SLOSH Sea, Lake, and Overland Surges from Hurricanes

SPF sprayed polyurethane foam

SPRI Single Ply Roofing Institute

T

TAS Testing Application Standard

U

UL Underwriters Laboratories

URM unreinforced masonry

U.S. United States

D

FEMA Hurricane Recovery Advisories

Roof Underlayment for Asphalt Shingle Roofs

FEMA
www.fema.gov

HURRICANE RECOVERY ADVISORY *Recovery Advisory No. 1*

Purpose: To provide recommended practices for use of roofing underlayment as an enhanced secondary water barrier in hurricane-prone areas (both coastal and inland).

> **Note: *The underlayment options illustrated here are for asphalt shingle roofs***. See FEMA publication 55, *Coastal Construction Manual*, for guidance concerning underlayment for other types of roofs.

Key Issues

- Verify proper attachment of roof sheathing before installing underlayment
- Lapping and fastening of underlayment and roof edge flashing
- Selection of underlayment material type

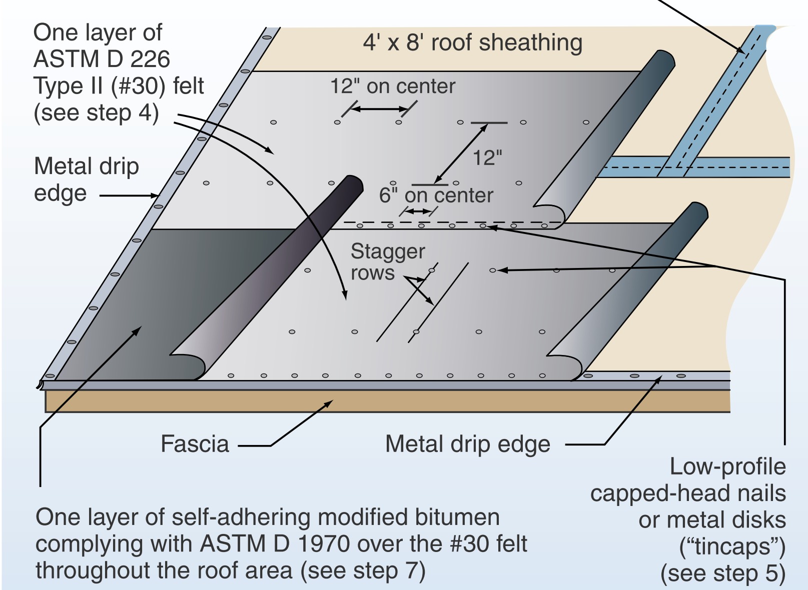
> **Note:** This fact sheet provides general guidelines and recommended enhancements for improving upon typical practice. It is advisable to ***consult local building requirements*** for type and installation of underlayment, particularly if specific enhanced underlayment practices are required locally.

Sheathing Installation Options

The following three options are listed in order of decreasing resistance to long-term weather exposure following the loss of the roof covering. Option 1 provides the greatest reliability for long-term exposure; it is advocated in heavily populated areas where the design wind speed is equal to or greater than 120 mph (3-second peak gust). Option 3 provides limited protection and is advocated only in areas with a modest population density and a design wind speed less than or equal to 110 mph (3-second peak gust).

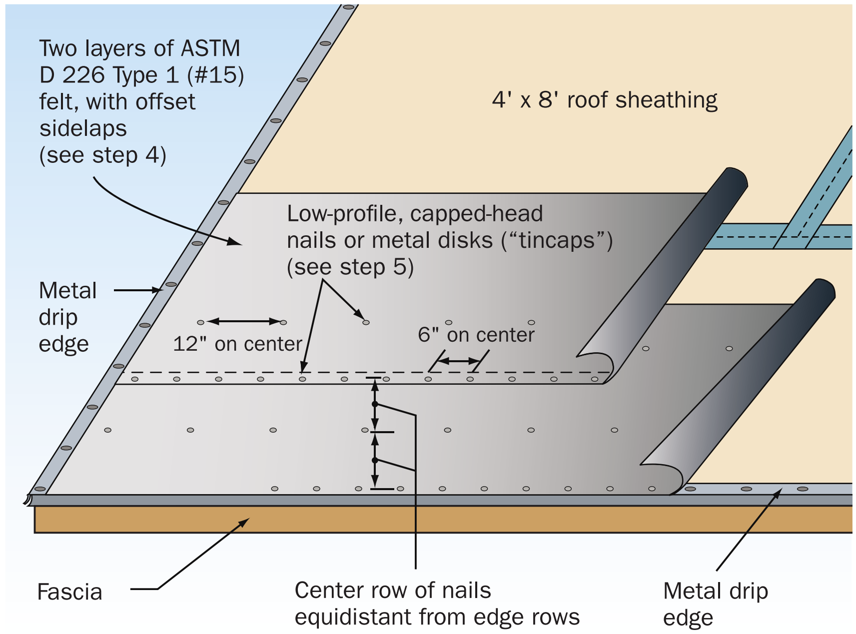
Installation Sequence – Option 1[1]

1. Before the roof covering is installed, have the deck inspected to verify that it is nailed as specified on the drawings.
2. Install self-adhering modified bitumen tape (4 inches wide, minimum) over sheathing joints; seal around deck penetrations with roof tape.
3. Broom clean deck before taping; roll tape with roller.
4. ***Apply a single layer of ASTM D 226 Type II (#30) felt.***
5. Secure felt with low-profile, capped-head nails or thin metal disks ("tincaps") attached with roofing nails.
6. Fasten at approximately 6 inches on center along the laps and at approximately 12 inches on center along two rows in the field of the sheet between the side laps.
7. ***Apply a single layer of self-adhering modified bitumen complying with ASTM D 1970 over the #30 felt throughout the roof area.***
8. Seal the self-adhering sheet to the deck penetrations with roof tape or asphalt roof cement.



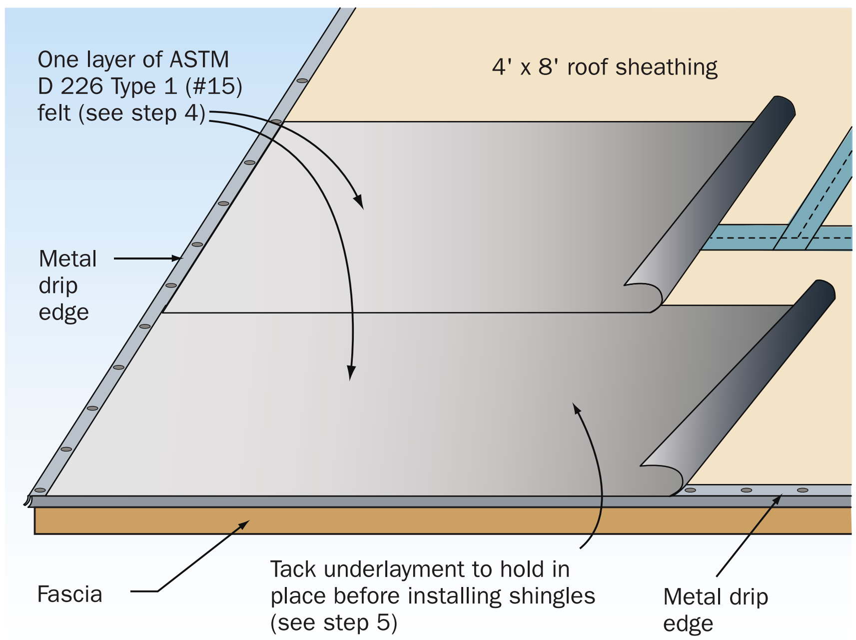
Installation Sequence – Option 2[1]

1. Before the roof covering is installed, have the deck inspected to verify that it is nailed as specified on the drawings.
2. Install self-adhering modified bitumen tape (4 inches wide, minimum) over sheathing joints; seal around deck penetrations with roof tape.
3. Broom clean deck before taping; roll tape with roller.
4. ***Apply two layers of ASTM D 226 Type I (#15) felt with offset side laps.***
5. Secure felt with low-profile, capped-head nails or thin metal disks ("tincaps") attached with roofing nails.
6. Fasten at approximately 6 inches on center along the laps and at approximately 12 inches on center along a row in the field of the sheet between the side laps.



Installation Sequence – Option 3[1,2]

1. Before the roof covering is installed, have the deck inspected to verify that it is nailed as specified on the drawings.
2. Install self-adhering modified bitumen tape (4 inches wide, minimum) over sheathing joints; seal around deck penetrations with roof tape.
3. Broom clean deck before taping; roll tape with roller.
4. ***Apply a single layer of ASTM D 226 Type I (#15) felt.***
5. Tack underlayment to hold in place before applying shingles.



1 **Note:** If the building is within 3,000 feet of saltwater, stainless steel or hot-dip galvanized fasteners are recommended for the underlayment attachment.

2 **Note:** (1) If the roof slope is less than 4:12, tape and seal the deck at penetrations and follow the recommendations given in *The NRCA Roofing and Waterproofing Manual*, by the National Roofing Contractors Association. (2) With this option, the underlayment has limited blowoff resistance. Water infiltration resistance is provided by the taped and sealed sheathing panels. This option is intended for use where temporary or permanent repairs are likely to be made within several days after the roof covering is blown off.

General Notes

- Weave underlayment across valleys.
- Double-lap underlayment across ridges (unless there is a continuous ridge vent).
- Lap underlayment with minimum 6-inch leg "turned up" at wall intersections; lap wall weather barrier over turned-up roof underlayment.

Additional Resources

National Roofing Contractors Association (NRCA). *The NRCA Roofing and Waterproofing Manual*. (www.NRCA.net)

Asphalt Shingle Roofing for High-Wind Regions

FEMA
www.fema.gov

HURRICANE RECOVERY ADVISORY *Recovery Advisory No. 2*

Purpose: To recommend practices for installing asphalt roof shingles that will enhance wind resistance in high-wind, hurricane-prone areas (both coastal and inland).

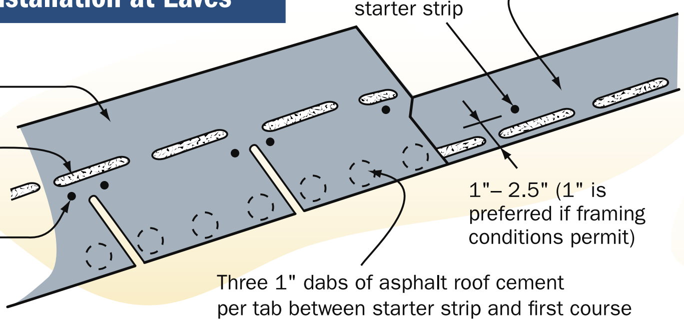
Key Issues

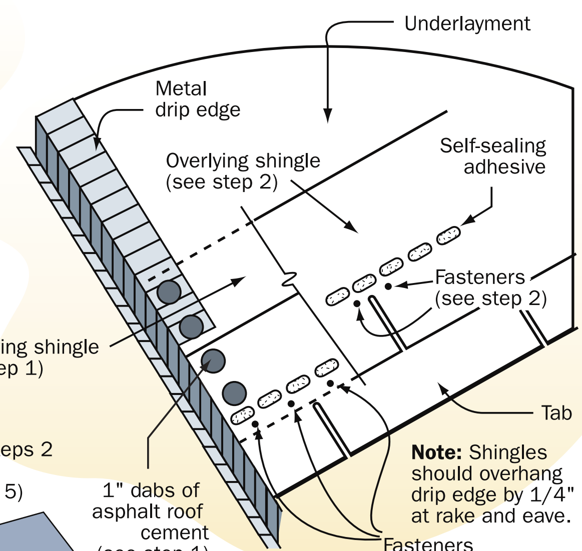
- Special installation methods are recommended for asphalt roof shingles used in high-wind, hurricane-prone areas (i.e., greater than 90-mph, 3-second peak gust design wind speed).
- Use wind-resistance ratings to choose among shingles, but do not rely on ratings for performance.
- Consult local building code for specific installation requirements. Requirements may vary locally.
- Always use underlayment. See Fact Sheet No. 1 for installation techniques in hurricane-prone areas.

Construction Guidance

1 Follow shingle installation procedures for enhanced wind resistance.

Shingle Installation at Eaves

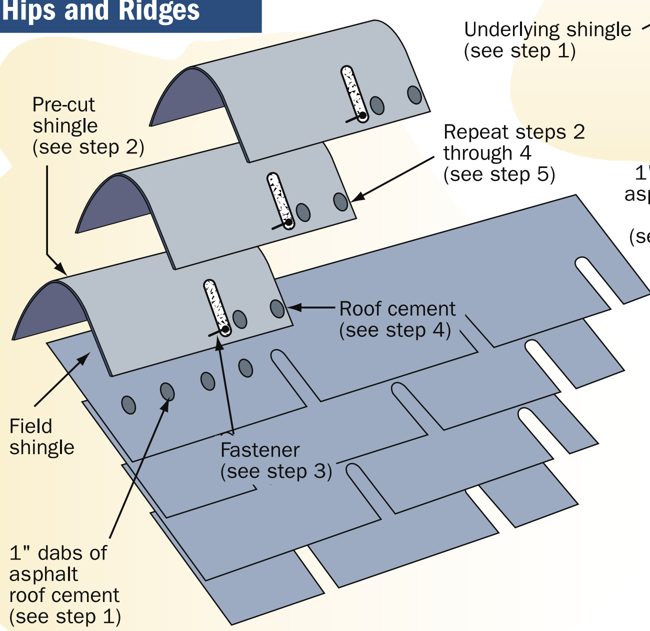




Note: Shingles should overhang drip edge by 1/4" at rake and eave.

Shingle Installation at Hips and Ridges

1. Apply four 1-inch dabs of roof cement to field shingle.
2. ***Set pre-cut shingle in place and press down in dabs of roof cement before installing fasteners.***
3. Install fastener on each side of ridge. Note: Because of extra thickness of shingles at hips and ridges, longer nails may be needed.
4. Apply two 1-inch dabs of roof cement to shingle where shown.
5. Repeat steps 2 through 4.



Enhanced shingle securement

Shingle Installation at Rakes

1. Apply two 1-inch dabs of asphalt roof cement on underlying shingle, and two 1-inch dabs on metal drip edge as shown.
2. Set overlying shingle in place and install fasteners except for last fastener at rake.
3. ***Press shingle down to set in dabs of asphalt cement before installing final fastener.***
4. Install final fastener at rake edge.
5. Repeat steps for each course.

2 Consider shingle physical properties.

Properties	Design Wind Speed[1] >90 to 120 mph	Design Wind Speed[1] >120 mph
Fastener Pull-Through[2] Resistance	Minimum Recommended 25 lb at 70 degrees Fahrenheit (F)	Minimum Recommended 30 lb
Bond Strength[3]	Minimum Recommended 12 lb	Minimum Recommended 17 lb

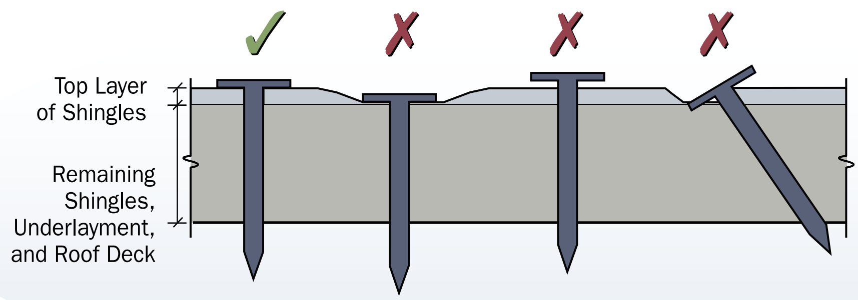
1. Design wind speed based on 3-second peak gust.
2. ASTM D 3462 specifies a minimum fastener pull-through resistance of 20 lb at 70° F. If a higher resistance is desired, it must be specified.
3. Neither ASTM D 225 or D 3462 specify minimum bond strength. If minimum bond strength is desired, it must be specified.

Shingle Type	Standard	Characteristics
Organic-Reinforced	ASTM D 225	Relatively high fastener pull-through resistance
Fiberglass-Reinforced	ASTM D 3462	Considerable variation in fastener pull-through resistance offered by different products
SBS Modified Bitumen	A standard does not exist for this product. It is recommended that SBS Modified Bitumen Shingles meet the physical properties specified in ASTM 3462.	Because of the flexibility imparted by the SBS polymers, this type of shingle is less likely to tear if the tabs are lifted in a windstorm.

3 Ensure that the fastening equipment and method results in properly driven roofing nails for maximum blow-off resistance. The minimum required bond strength must be specified (see **Wind-Resistance Ratings**, below).

Fastener Guidelines

- Use roofing nails that extend through the underside of the roof sheathing, or a minimum of 3/4 inch into planking.
- Use roofing nails instead of staples.
- Use stainless steel nails when building within 3,000 feet of saltwater.



"The good, the bad, and the ugly" – **Properly driving roofing nails.**

Weathering and Durability

Durability ratings are relative and are not standardized among manufacturers. However, selecting a shingle with a longer warranty (e.g., 30-year instead of 20-year) should provide greater durability in hurricane-prone climates and elsewhere.

Organic-reinforced shingles are generally more resistant to tab tear-off, but tend to degrade faster in warm climates. Use fiberglass-reinforced shingles in warm, hurricane-prone climates and consider organic shingles only in cool, hurricane-prone climates. Modified bitumen shingles may also be considered for improved tear-off resistance of tabs. Organic-reinforced shingles have limited fire resistance – verify compliance with code and avoid using in areas prone to wildfires.

After the shingles have been exposed to sufficient sunshine to activate the sealant, inspect roofing to ensure that the tabs have sealed. Also, shingles should be of "interlocking" type if seal strips are not present.

Wind-Resistance Ratings

Wind resistance determined by test methods ASTM D 3161 and UL 997 does not provide adequate information regarding the wind performance of shingles, even when shingles are tested at the highest fan speed prescribed in the standard. Rather than rely on D 3161 or UL 997 test data, shingle uplift loads should be calculated in accordance with UL 2390. Shingles having a bond strength (as determined from test method ASTM D 6381) that is at least twice as high (i.e., a minimum safety factor of 2) as the load calculated from UL 2390 should be specified/purchased.

Tile Roofing for Hurricane-Prone Areas

FEMA
www.fema.gov

HURRICANE RECOVERY ADVISORY *Recovery Advisory No. 3*

Purpose: To provide recommended practices for designing and installing extruded concrete and clay tiles that will enhance wind resistance in hurricane-prone areas (both coastal and inland).

Key Issues

Missiles: Tile roofs are very vulnerable to breakage from wind-borne debris (missiles). Even when well attached, they can be easily broken by missiles. If a tile is broken, debris from a single tile can impact other tiles on the roof, which can lead to a progressive cascading failure. In addition, tile missiles can be blown a considerable distance and a substantial number have sufficient energy to penetrate shutters and glazing, and potentially cause injury. Where the basic wind speed is equal to or greater than 110 mph (3-second peak gust), the wind-borne debris issue is of greater concern than in lower wind speed regions. Note: There are currently no testing standards requiring roof tile systems to be debris impact resistant.

Attachment methods: Storm damage investigations revealed performance problems with mortar-set, mechanically-attached (screws or nails and supplementary clips when necessary) and foam-adhesive (adhesive-set) attachment methods. In many instances, the damage was due to poor installation. Investigations revealed that the mortar-set attachment method is typically much more susceptible to damage than are the other attachment methods. Therefore, in lieu of mortar-set, the mechanically-attached or foam-adhesive attachment methods in accordance with this Advisory are recommended.

To ensure quality installation, licensed contractors should be retained. This will help ensure proper permits are filed and local building code requirements are met. For foam-adhesive systems, it is highly recommended that installers be trained and certified by the foam manufacturer.

Uplift loads and resistance: Calculate uplift loads and resistance in accordance with the "Design and Construction Guidance" section below. Load and resistance calculations should be performed by a qualified person (i.e., someone who is familiar with the calculation procedures and code requirements).

Corner and perimeter enhancements: Uplift loads are greatest in corners, followed by the perimeter and then the field of the roof (see Figure 1). However, for simplicity of application on smaller roof areas (e.g., most residences and smaller commercial buildings), use the attachment designed for the corner area throughout the entire roof area.

Hips and ridges: Storm damage investigations have revealed that hip and ridge tiles attached with mortar are very susceptible to blow-off. Refer to the attachment guidance below for improved attachment methodology.

Quality control: During roof installation, installers should implement a quality control program in accordance with the "Quality Control" section below.

Design and Construction Guidance

1. Uplift Loads

In Florida, calculate loads and pressures on tiles in accordance with the current edition of the *Florida Building Code* (Section 1606.3.3). In other states, calculate loads in accordance with the current edition of the *International Building Code* (Section 1609.7.3).

As an alternate to calculating loads, design uplift pressures for the corner zones of Category II buildings are provided in tabular form in the Addendum to the Third Edition of the *Concrete and Clay Roof Tile Installation Manual* (see Tables 6, 6A, 7, and 7A).[1]

Classification of Buildings

Category I	-	Buildings that represent a low hazard to human life in the event of a failure
Category II	-	All other buildings not in Categories I, III, and IV
Category III	-	Buildings that represent a substantial hazard to human life
Category IV	-	Essential facilities

Note: In addition to the tables referenced above, the *Concrete and Clay Roof Tile Installation Manual* contains other useful information pertaining to tile roofs. Accordingly, it is recommended that designers and installers of tile obtain a copy of the Manual and the Addendum. Hence, the tables are not incorporated in this Advisory.

2. Uplift Resistance

For mechanical attachment, the *Concrete and Clay Roof Tile Installation Manual* provides uplift resistance data for different types and numbers of fasteners and different deck thicknesses. For foam-adhesive-set systems, the Manual refers to the foam-adhesive manufacturers for uplift resistance data. Further, to improve performance where the basic wind speed is equal to or greater than 110 mph, it is recommended that a clip be installed on each tile in the first row of tiles at the eave for both mechanically-attached and foam-adhesive systems.

For tiles mechanically attached to battens, it is recommended that the tile fasteners be of sufficient length to penetrate the underside of the sheathing by ¼" minimum. For tiles mechanically attached to counter battens, it is recommended that the tile fasteners be of sufficient length to penetrate the underside of the horizontal counter battens by ¼" minimum. It is recommended that the batten-to-batten connections be engineered.

For roofs within 3,000 feet of the ocean, straps, fasteners, and clips should be fabricated from stainless steel to ensure durability from the corrosive effects of salt spray.

3. Hips and Ridges

The *Concrete and Clay Roof Tile Installation Manual* gives guidance on two attachment methods for hip and ridge tiles: mortar-set or attachment to a ridge board. Based on post-disaster field investigations, use of a ridge board is recommended. For attachment of the board, refer to Table 21 in the Addendum to the *Concrete and Clay Roof Tile Installation Manual*.

Fasten the tiles to the ridge board with screws (1" minimum penetration into the ridge board) and use both adhesive and clips at the overlaps.

For roofs within 3,000 feet of the ocean, straps, fasteners, and clips should be fabricated from stainless steel to ensure durability from the corrosive effects of salt spray.

4. Critical and Essential Buildings (Category III or IV)

Critical and essential buildings are buildings that are expected to remain operational during a severe wind event such as a hurricane. It is possible that people may be arriving or departing from the critical or essential facility during a hurricane. If a missile strikes a tile roof when people are outside the building, those people may be struck by tile debris dislodged by the missile strike. Tile debris may also damage the facility. It is for these reasons that tiles are not recommended on critical or essential buildings.

If it is decided to use tile on a critical or essential facility and if the tiles are mechanically attached, it is recommended that clips be installed at all tiles in the corner, ridge, perimeter, and hip zones (see ASCE 7-02 for the width of these zones). (See Figure 1)

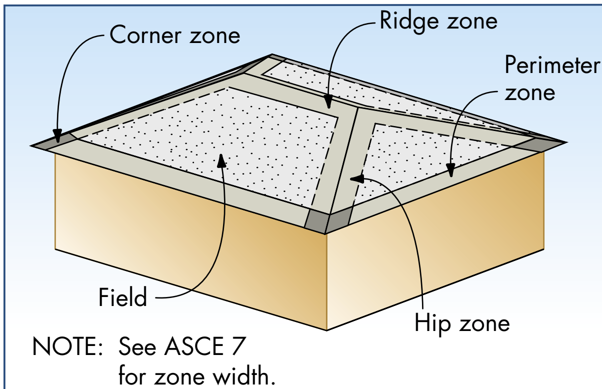


Figure 1. For critical and essential facilities, clip all tiles in the corner, ridge, perimeter, and hip zones.

5. Quality Control

It is recommended that the applicator designate an individual to perform quality control (QC) inspections. That person should be on the roof during the tile installation process (the QC person could be a working member of the crew). The QC person should understand the attachment requirements for the system being installed (e.g., the type and number of fasteners per tile for mechanically attached systems and the size and location of the adhesive for foam-adhesive systems) and have authority to correct noncompliant work. The QC person should ensure that the correct type, size, and quantity of fasteners are being installed.

For foam-adhesive systems, the QC person should ensure that the foam is being applied by properly trained applicators and that the work is in accordance with the foam manufacturer's application instructions. At least one tile per square (100 square feet) should be pulled up to confirm the foam provides the minimum required contact area and is correctly located.

If tile is installed on a critical or essential building, it is recommended that the owner retain a qualified architect, engineer, or roof consultant to provide full-time field observations during application.

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[1] The Manual can be purchased online from the Florida Roofing, Sheet Metal and Air Conditioning Contractor's Association, Inc. at www.floridaroof.com or by calling (407) 671-3772. Holders of the Third Edition of the Manual who do not have a copy of the Addendum can download it from this web site.

E

The History of Hurricanes in Southwest Florida

Frequency of Hurricanes and Tropical Storms in Southwest Florida

Fort Myers, Port Charlotte, and Sarasota are three major cities in Florida that have been affected or directly hit by past hurricanes that made landfall in the vicinity of Hurricane Charley's landfall. Hurricane City (http://www.hurric anecity.com) has compiled the historical hurricane database from many reliable sources. The database shows that both Fort Myers and Port Charlotte have been affected or brushed by a hurricane or tropical storm approximately once every 3 years; Sarasota has been affected less often (once every 4.5 years). For a direct landfall (within 40 miles), the statistics show the likelihood as once every 13 years for Fort Myers and Port Charlotte, and once every 26.5 years for Sarasota. Figure E-1 highlights some of these hurricanes and storms with paths similar to those of Hurricane Charley; these hurricanes are described below. Figure E-2 shows landfalling hurricanes in the continental U.S. for the period 1950-2004.

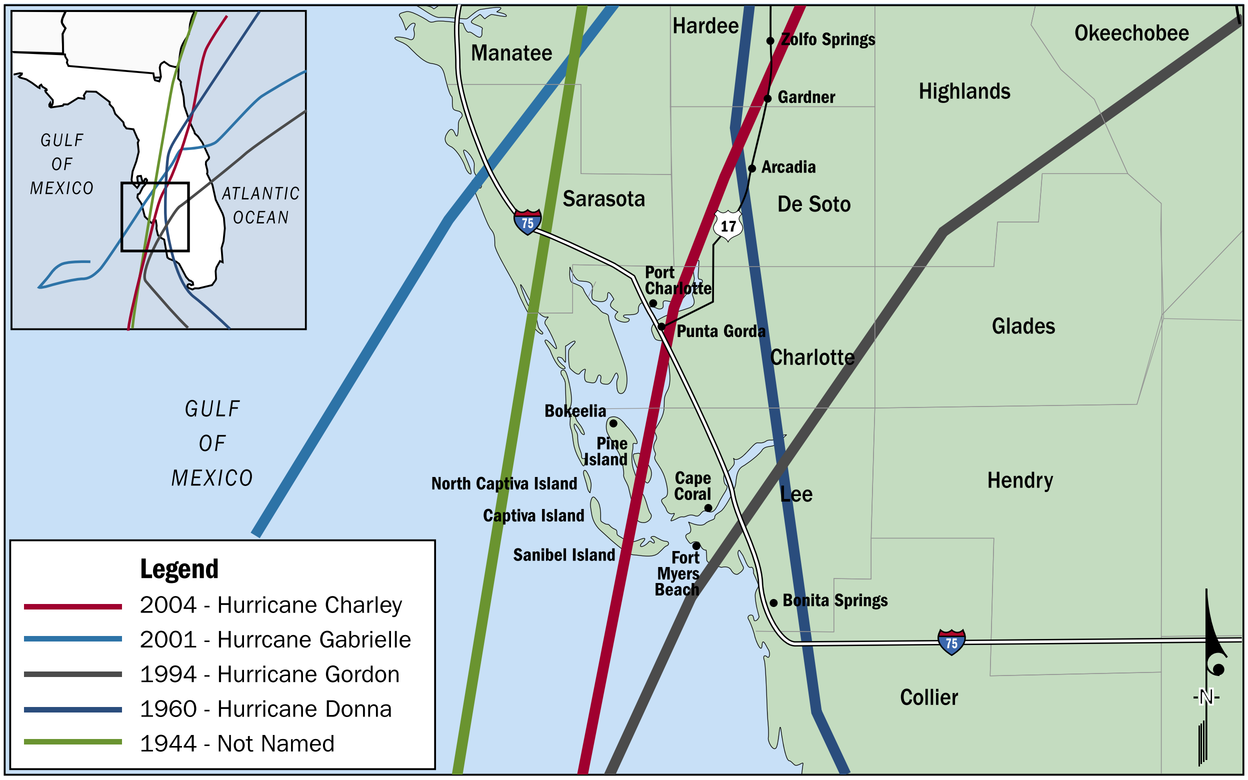

Figure E-1. Historical hurricane and tropical storm paths

Unnamed Hurricane, 1944

This unnamed Category 3 hurricane was one of the 10 costliest and deadliest hurricanes in Florida history. The storm made landfall south of Sarasota and maintained hurricane strength northward while crossing Florida. Thirty deaths were reported and the loss (mainly in central Florida and the northeast peninsula) was estimated to be $725 million (year 2000 dollars).

Hurricane Donna, 1960

The fifth strongest hurricane of record to hit the U.S., Donna was also the only hurricane of record to produce hurricane-force winds in Florida, the Mid-Atlantic states, and New England. Donna caused storm surges of up to 13 feet in the Florida Keys and 11-foot surges along the southwest coast of Florida. According to the NHC, the storm caused 50 deaths, and losses were $2.4 billion (year 2000 dollars) in property damage.

Tropical Storm Gordon, 1994

After a serpentine track through the Caribbean, Gordon moved slowly west-northwest, reaching the lower Florida Keys, and then turned northeast, accelerated, and moved inland near Fort Myers, Lee County. Gordon directly caused 8 fatalities and 43 injuries. The total damage was estimated to be approximately $400 million (year 1994 dollars). Volusia County was hit hard by inland flooding. Flood damages to 1,236 buildings (977 single-family homes, 68 manufactured homes, 139 multi-family homes, and 52 other buildings) were reported and losses were over $26 million.

Tropical Storm Gabrielle, 2001

Gabrielle tracked across Florida on September 14, spawning tornadoes and causing heavy rain with significant flooding. Downtown Sarasota was flooded, schools along the coast were closed, and more than 300,000 homes and businesses were without power along the coast south of Tampa and into central Florida. According to the NHC, total damage from Gabrielle across the 15-county area impacted by the hurricane in (southwest and west central) Florida was estimated to be nearly $17 million.

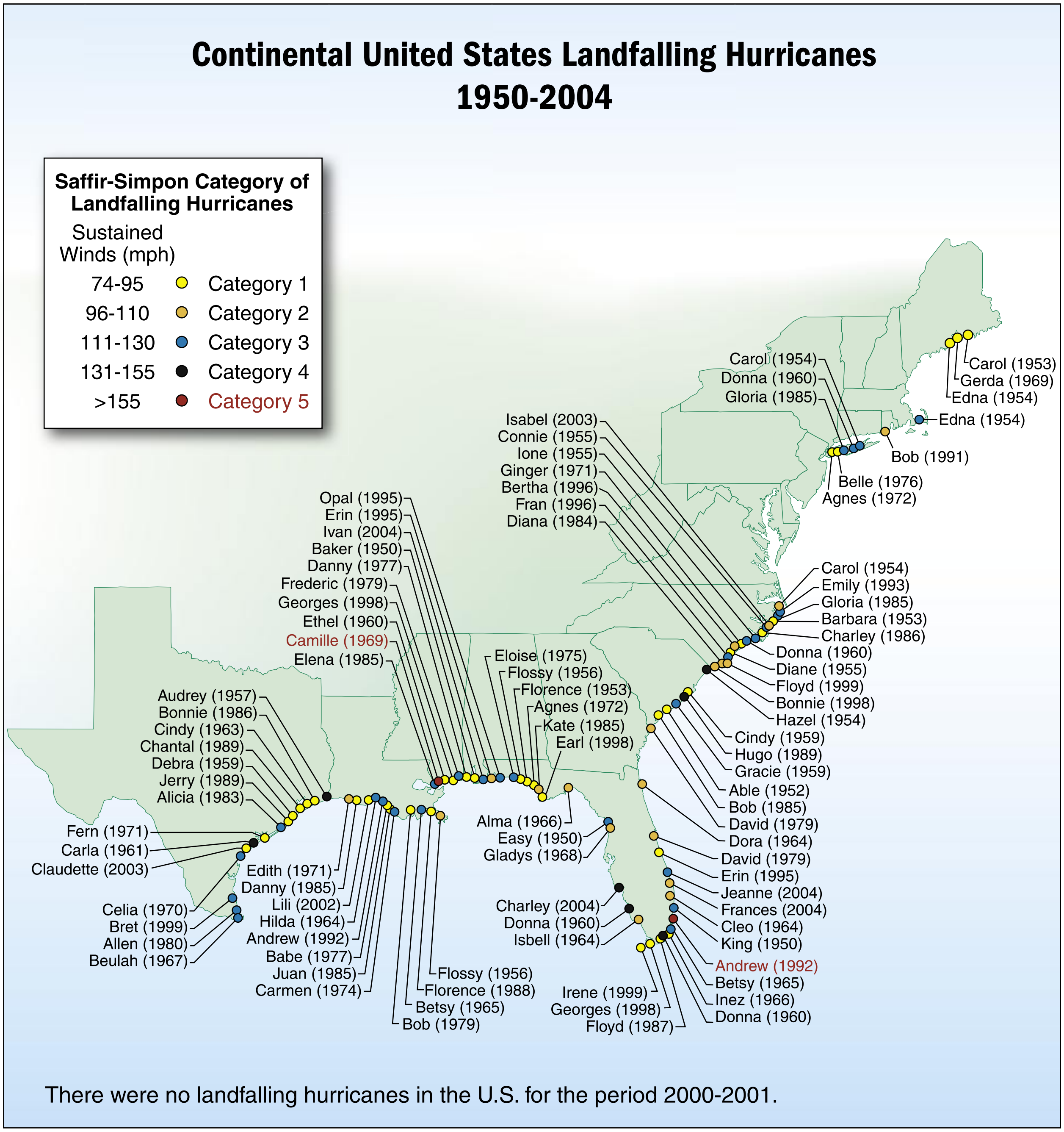

Figure E-2. Continental U.S. landfalling hurricanes, 1950-2004

(NOAA/NCDC)

F

Guidance and Statute Requirements for Design and Construction of EHPAs

The Florida Statewide Emergency Shelter Plan (SESP) provides guidance and statute requirements for the design and construction of Enhanced Hurricane Protection Areas (EHPAs) and compares them to other requirements. From Appendix G, Consultative Guidance for Implementation of Public Shelter Design Criteria:

> "EHPAs are required to be designed and constructed in accordance with the wind load provisions of the American Society of Civil Engineers Standard 7, Minimum Design Loads for Buildings and Other Structures (ASCE 7). The minimum design wind speed is per ASCE 7's basic wind speed map, using the importance factor (I) for a Category III or IV (essential facility) building occupancy. Also, to ensure that the EHPA remains an enclosed structure (and avoid a partially enclosed condition, which would invalidate the design), building openings are also required to withstand impact by windborne debris in accordance with Test Standard for Determining Resistance From Windborne Debris SSTD 12 (SSTD 12)."

[1] The presumption that 50 years is the useful life expectancy of a facility may be incorrect.

> The selection of an appropriate design wind speed is critical to the performance of public hurricane shelters. ASCE 7's wind speed map is based upon a 50-year recurrence level, which presumes that 50 years is the useful life expectancy of a facility.[1] The Category III/IV importance factor (1.15) is used to adjust the wind speed design up to a 100+ year recurrence level to account for a greater degree of hazard due to the nature of a facility's occupancy. This is the minimum wind design and construction requirement for EHPAs, and reflects the **minimum** national design standard for designated hurricane shelters.
>
> However, the EHPA code provisions highly recommend that the ASCE 7 map wind speed be increased by 40 miles per hour, with an importance factor of 1.00. The Department also highly recommends the 40 mile per hour increase in base wind speed. The 40 mile per hour increase in base wind speed translates into wind designs of as high as 200 miles per hour in the Florida Keys, to as low as 140 miles per hour in inland north-central Florida. The 40 mile per hour increase in base wind speed is used to adjust the wind speed design up to about a 1,000+ year recurrence level, and is consistent with the Department of Energy's DOE-STD-1020 hurricane wind Performance Category (PC) 3 criteria. The Department of Energy's enhanced performance expectations are that its facilities not only resist collapse, but that occupants, critical equipment and contents be protected from wind, windborne and falling debris, rainwater intrusion, and continue to maintain operation as an essential facility. The Department of Energy's enhanced performance expectations are more consistent with public hurricane shelter design and construction performance expectations than ASCE 7's minimum design standard."

Furthermore, the SESP design requirements provide commentary of minimum design levels and "best practices" for the design of high-wind shelters as presented in additional text from Appendix G of the SESP and in the summary table provided herein as Table F-1 (SESP Table G-2). Using a scale of "Performance Criteria" the table identifies different levels of design, provides comments and provides references for the standard from which the criteria was provided. The criteria for these performance criteria are taken from the SESP itself, the Department of Energy STD-1020 standard for hazard-resistant construction, and ASCE 7. Additional commentary on the design assumptions shown in the table, including the different wind hazard return periods, are found in each of the reference documents. From Appendix G of the SESP:

"…Therefore, to ensure that public hurricane shelters are designed and constructed to resist major hurricanes, the 40 mile per hour increase in base wind speed is critical to achieve the EHPA performance expectation. Table G-2 provides a comparison summary of hurricane shelter performance objectives to be considered when selecting an appropriate design wind speed.

The 40 mile per hour increase in design wind speed is especially important for certain types of buildings. Buildings with tall exterior walls, long span lightweight roof systems, wide roof overhangs, located in open areas with minimal sheltering, etc., are particularly vulnerable to damage in "design level events." The Department strongly recommends use of the 40 mile per hour increase in design wind speed for buildings that possess these characteristics."

Table F-1. Summary of EHPA Wind Design Criteria

Crosswalk of EHPA, DOE-STD-1020 and FEMA 361 Performance Criteria						
Performance Category	**X**	**0**	**PC 1**	**PC 2 (EHPA min)**	**PC 3 (EHPA rec)**	**PC 4 (FEMA 361)**
Wind Hazard Return Period (yrs)	<50	<50	>50	>100	>1,000	>10,000
Design Wind Speed	Does not meet ARC 4496	Code and meets ARC 4496	ASCE 7 or Code and ARC 4496	ASCE 7, essential facility and ARC 4496	ASCE 7 plus 40 mph	ASCE 7 plus 80 mph
Design Wind Speed, V (mph), 3-second peak gust	<90	100±	100 -150	100 -150	140-200 (tornado @ 160+)	200-230 (tornado @ 200+)
Importance Factor, I	<1.00	<1.00	1.00	1.15	1.00	1.00
Exposure Category	N/A	N/A	Code	ASCE 7 (Exposure C)	ASCE 7 (Exposure C)	C
Directionality Factor, K_d	N/A	N/A	Code	ASCE 7 (0.85)	1.00	1.00
Internal Pressure Coefficient, GCpi	N/A	N/A	Code	ASCE 7 (hurr. @ ±0.18, or tornado @ ±0.55)	ASCE 7 (hurr. @ ±0.18, or tornado @ ±0.55)	ASCE 7 (hurr. @ ±0.18, or tornado @ ±0.55)
Load Combinations	N/A	N/A	Code	ASCE 7	ASCE 7	ASCE 7
Hurricane Windborne Debris Impact Criteria	N/A	Equivalent to ½-in plywood; max. height 30* ft.	2x4 timber plank, 9 lb @ 34 mph; max. height 30* ft.	2x4 timber plank, 9 lb @ 34 mph; max. height 60* ft.	2x4 timber plank, 15 lb @ 50 mph w/ max. height 60* ft	2x4 timber plank, 15 lb @ 50 mph w/ max. height 60* ft
Tornado Windborne Debris Impact Criteria	N/A	N/A	N/A	2x4 timber plank, 15 lb @ 50 mph; max. height 60* ft.	2x4 timber plank, 15 lb @ 100 mph w/ max. height 150 ft.	2x4 timber plank, 15 lb @ 100 mph w/ max. height 200 ft.

* Glazed openings in exterior envelope of hurricane shelters and critical support areas located above large missile protection height indicated in this table should resist penetration to small missile standards.

Note: PC 2 ª EHPA minimum requirement; PC 3 ª EHPA recommended requirement; and PC 4 ª FEMA 361 “near absolute protection” requirement.