Mitigation Assessment Team Report

Hurricane Ivan in Alabama and Florida

Observations, Recommendations, and Technical Guidance

FEMA 489 / August 2005

ADECA
Alabama Department of Economic & Community Affairs

U.S. Department of Homeland Security

FEMA

Florida Department of Community Affairs

In response to Hurricane Ivan, 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 engineers and other experts from FEMA Headquarters and the Regional Offices and 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 cover photograph is a NASA image courtesy of the Moderate Resolution Imaging Spectroradiometer (MODIS) Land Rapid Response Team at the National Aeronautics and Space Administration's (NASA) Goddard Space Flight Center. The MODIS instrument flying aboard NASA's Aqua satellite captured this true-color image of Hurricane Ivan on September 15, 2004, at 2:50 p.m. Eastern Daylight Time. At the time this image was taken, Ivan was located approximately 170 miles south of the Alabama coastline and was moving northward at 14 miles per hour. Ivan made landfall as a Category 3 storm with maximum sustained winds near 121 mph with higher gusts.

(IMAGE COURTESY OF NASA EARTH OBSERVATORY)

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FEMA

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Dedication

Jim Delahay (1958-2005)

Jim Delahay was a person you did not forget once you met him. He was an outstanding engineer, a dedicated professional, and a true friend. He was also an expert in wind-resistant design, structural engineering, and building codes and standards. Although a young man, he was well-known throughout the engineering profession, and he was recognized by his peers on many occasions. Among his many accomplishments: Jim was the first engineer elected as chairman of the Structural Committee of the International Code Council; Jim was chair of the Code Advisory Committee of the National Council of Structural Engineers Associations; he was co-chair of the ASCE 7 Wind Load Task Committee; he was past president of the Applied Technology Council; and he was president and CEO of Lane Bishop York Delahay (LBYD, Inc.) of Birmingham, Alabama. In 2003, he was named a Distinguished Engineering Fellow by the University of Alabama College of Engineering, from which he earned both his BS and MS degrees in Civil Engineering.

Jim made his first post-storm deployment for FEMA after Hurricane Ivan, and he was an indispensable member of the Hurricane Ivan Mitigation Assessment Team. We all learned from Jim, and this report is all the better because of him. Those who read and use this report will benefit directly from Jim's expertise and knowledge.

FEMA and the Hurricane Ivan Mitigation Assessment Team are honored to dedicate this report to the memory of Jim, who passed away suddenly on April 16, 2005.

Executive Summary

Hurricane Ivan made landfall on Thursday, September 16, 2004, just west of Gulf Shores, Alabama. The hurricane brought 1-minute sustained wind speeds (over open water) of 121 miles per hour (mph) (as estimated by the National Hurricane Center [NHC]), torrential rains, coastal storm surge flooding of 10 to 16 feet above normal high tide, and large and battering waves along the western Florida Panhandle and Alabama coastline. In its *Tropical Cyclone Report, Hurricane Ivan, 2-26 September 2004* (NHC, 16 December 2004, Revised 6 January 2005), the NHC categorized Hurricane Ivan as a Category 3 hurricane, as measured by the Saffir-Simpson Hurricane Scale. The National Weather Service reported that from September 15 through 16, Ivan spawned 23 tornadoes in Florida and produced as much as 10 to 15 inches of rainfall in some areas (National Weather Service Mobile – Pensacola, "Powerful Hurricane Ivan Slams the US Central Gulf Coast as Upper Category-3 Storm," www.srh.noaa.gov/mob/ivan_page/Ivan-main.htm). After landfall, Hurricane Ivan gradually weakened over the next week, moving northeastward over the Southeastern United States and eventually emerging off the Delmarva Peninsula as an extratropical low on September 19, 2004.

On September 18, 2005, the Federal Emergency Management Agency's (FEMA's) Mitigation Division deployed a Mitigation Assessment Team (MAT) to Alabama and Florida to evaluate building performance during Hurricane Ivan and the adequacy of current building codes, other construction requirements, and building practices and materials. This report presents the MAT's observations, conclusions, and recommendations as a result of those field investigations.

Several maps in Chapter 1 illustrate the path of the storm, the depth of storm surge along the path, and the wind field estimates. Hurricane Ivan approximated a design flood event on the barrier islands and exceeded design flood conditions in sound and back bay areas. This provided a good opportunity to assess the adequacy of National Flood Insurance Program (NFIP) floodplain management requirements as well as current construction practices in resisting storm surge and wave damage. FEMA was particularly interested in evaluating damages to buildings in coastal A Zones where V-Zone construction methods are not required.

Although the NHC categorized Hurricane Ivan as a Category 3 hurricane, surface observation sites throughout the coastal region provided data that indicate that most of the region impacted by the storm likely experienced Category 1 intensity winds with some areas near the Alabama-Florida border experiencing Category 2 intensity winds. None of the surface wind measurements for overland conditions correspond to Category 3 intensity winds. Although Hurricane Ivan was not a design wind event when analyzed with respect to the 2001 Florida Building Code (FBC) or the 2000/2003 International Building Code (IBC) and International Residential Code (IRC), it caused extensive wind-related damage to buildings constructed under earlier codes.

Floodplain Management Regulations in Alabama and Florida

All of the communities visited by the MAT participate in the NFIP and have adopted floodplain management regulations that meet or exceed minimum NFIP requirements. Up until 2000, these requirements generally were contained only in community floodplain management ordinances. Starting in 2000, however, flood-resistant provisions and floodplain management requirements began to be incorporated into model building codes used in the affected areas (e.g., the IBC, the IRC, and the FBC).

The MAT determined that the area flooded by Ivan exceeded the Special Flood Hazard Area (SFHA) shown on the effective Flood Insurance Rate Maps (FIRMs) for many communities, from Gulf Shores, Alabama, to Okaloosa County, Florida, and that flood elevations in many areas exceeded the 100-year Base Flood Elevations (BFEs) depicted on the FIRMs by 2 to 4 feet. The initial flood studies for these communities were completed in the mid 1970s and were based on National Oceanographic and Atmospheric Administration (NOAA) tide gauge frequency analyses. The next studies were completed in the mid 1980s and were based on FEMA's storm surge model. This second round of flood studies also mapped wave crest elevations (as opposed to stillwater elevations), due in large part to observed damages to new construction at the time of Hurricane Frederic (1979). For the most part, this second round of studies resulted in decreased BFEs and a smaller SFHA when compared to the studies completed in the 1970s. The most recent flood studies were completed in the late 1990s (after Hurricane Opal) and added wave setup and extended the V Zone to include the primary frontal dune. The most recent studies generally increased the BFEs and the SFHA when compared to the studies completed in the 1980s, but not to the extent of the studies from the 1970s. The coastal FIRM changes over time likely resulted in a variety of coastal construction practices over the years, as most buildings were constructed to the minimum regulatory requirements, and could have contributed to flood and erosion damages the MAT observed.

Building Codes and Standards in Alabama and Florida

Alabama adopts building codes on a statewide basis only for state-owned buildings, such as schools. Local jurisdictions determine the adoption of building codes for private buildings. All Alabama jurisdictions have traditionally adopted editions of the Standard Building Code (SBC) published by the Southern Building Code Congress International. The City of Orange Beach adopted the 2003 IBC in the summer of 2004, just prior to Hurricane Ivan. The City of Gulf Shores adopted the 2003 IBC as an emergency measure after Hurricane Ivan – to improve the quality of the reconstruction. Most other affected Alabama communities, such as those in unincorporated Baldwin County, were still enforcing the 1997 or 1999 SBC at the time of Hurricane Ivan.

In the Florida Panhandle, the SBC – with local amendments – was used to regulate construction until early 2002 when the FBC 2001 Edition was adopted statewide. The FBC, administered by the Florida Building Commission, governs the design and construction of residential and non-residential (commercial, industrial, critical/essential, etc.) buildings in Florida. In December 2004, the Florida Building Commission completed the 2004 Edition of the FBC. However, additional changes to the 2004 Edition are being made in response to the 2004 hurricanes, and the 2004 Edition will not replace the earlier edition until fall 2005. Buildings constructed along Florida's Gulf of Mexico shoreline were also subject to the provisions of the state's Coastal Construction Control Line, which have been incorporated into the FBC.

Damage Assessment Observations

Flood

Because Hurricane Ivan approximated or exceeded a design flood event, the resultant storm damage provides valuable evidence about the adequacy of NFIP maps, floodplain management requirements, the reliability of the A-Zone delineation in coastal areas, building codes, and design practices. Flood levels from Hurricane Ivan exceeded the mapped BFEs throughout many bays and sounds by several feet. Flood levels along Gulf-front shorelines also exceeded the mapped BFEs but to a lesser extent, and the flooding extended beyond the SFHAs in most communities investigated. Many of the barrier islands were submerged and overwashed. Buildings constructed before the adoption of the NFIP and many buildings located outside the SFHA were severely impacted by the high storm-surge elevations and increased inundation area caused by Ivan.

Floodborne debris and wave damage (characteristic of V-Zone damage) was extensive in A Zones, especially along bay and sound shorelines. Floodborne debris from buildings, docks, and piers destroyed lower-level enclosures, stairs, and some buildings. Buildings that were not elevated above the wave crest elevation were damaged during Ivan not only by storm surge, but also by waves and floodborne debris.

Erosion was severe along the barrier islands of Alabama and Florida. Areas that had wide beaches and dunes before Ivan were less impacted than those with smaller, narrower beaches and dunes. Erosion along bay and sound shorelines was generally minimal, and structural damage there was predominantly due to storm surge, waves, and floodborne debris. The erosion along the barrier islands undermined shallow foundations and caused many buildings to collapse. Many areas had suffered beach and dune erosion during past coastal storm events, which made the buildings in those areas more vulnerable to flood and erosion impacts from Ivan.

Wind

Although structural system failures tend to be perceived by the public and the building industry as the dominant issue of concern, it is clear that for buildings built in accordance with the 2001 FBC or the 2000/2003 IBC, structural issues have, in general, been addressed by the codes. Now, the arena in which improvements can and must be made are those related to water intrusion and integrity of the building envelope. Protecting the integrity of the building envelope is important not only to minimize losses and damages to building contents, but also to prevent full internal pressurization and progressive failure of buildings.

Extensive damage to the building envelope with associated minor structural system damage was observed at many residential buildings even though Hurricane Ivan was not considered to be a design wind event when evaluating wind speeds and wind pressures from the 2001 FBC or the 2000/2003 IBC and IRC. However, in the areas around Gulf Shores, Orange Beach, and Pensacola Beach, existing building stock constructed to the 1979 to 1997 SBC can be said to have experienced a design wind event, and, thus, damage observed is related to the design parameters used at the times these codes were enforced.

Widespread building envelope damage was observed by the MAT throughout the affected area. Performance of building envelopes was generally poor and led to widespread damage to the interiors of residences, businesses, and critical/essential facilities.

Windborne debris damage was not widespread. ASCE 7 predicts that significant windborne debris damage will begin in the 120-mph range in inland areas and in the 110-mph range when buildings are within one mile of the coast. Since Ivan's gust speeds were generally below that level, it is expected that glazing damage during Ivan would be less common than in other more powerful storms such as Hurricane Charley. Given that the actual wind speeds were below current code level wind speeds, the occasional damage to the structural elements and the widespread damage to building envelopes can be characterized as wind-related damage caused by inadequate design, old construction methods, outdated design codes and methods, lack of maintenance, and/or poor construction/code enforcement. Wind damage to the contents of residential and commercial buildings, and critical/essential facilities due to these failures is preventable.

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 Alabama, 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 Ivan. The report and recommendations also will help FEMA assess the adequacy of its flood hazard mapping and floodplain management requirements and determine whether changes are needed or additional guidance required. The general recommendations are presented in Sections 8.1 and 8.2. They relate to policies and education/outreach that are needed to ensure that designers, contractors, and building officials understand the requirements for disaster-resistant construction in hurricane-prone regions. Proposed changes to codes and standards are presented in Section 8.3.

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 8.2 and the code and standard recommendations of Section 8.3, will 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 Alabama and Florida rebuild their lives, homes, and businesses, there are a number of ways they can minimize the effects of future hurricanes, including:

Flood-related

- Elevate all new construction (including substantially improved structures and replacement of substantially damaged structures) in coastal A Zones with the bottom of the lowest horizontal supporting member above the base flood level.
- Require freeboard for all structures in all flood hazard zones with the amount varying with building importance (see ASCE 7-05 and ASCE 24-05 for building importance classification and freeboard requirements) and anticipated exposure to wave effects.
- Require V-Zone design and construction for new construction in coastal A Zones subject to erosion, scour, velocity flow, and/or wave heights greater than 1.5 feet.
- Use a deep pile and/or column foundation anywhere on a barrier island, if erosion/or scour are possible.
- For sites near bay or sound shorelines, foundation selection should be based on several factors: erodibility of the soil; exposure to “damaging” waves (> 1.5 ft high); potential for velocity flow; potential for floodborne debris; and required resistance to lateral flood and wind forces.

- Use pier foundations only where soil characteristics and flood conditions permit. If there are any doubts as to the appropriate foundation to use near bay and sound shorelines, elevate the building at least one story above grade on piles or another deeply embedded open foundation, and leave the area below free of obstructions or enclose it with breakaway walls.
- Design foundations and structures to withstand loads from floodborne debris during a base flood event (100-year).
- For barrier island sites outside the V Zone, the ground level floor of a multi-story building (typically used for vehicle parking and building access) should either: 1) use a lowest floor slab or floor system that will not collapse and can support all design loads, if undermined, or 2) use a slab or floor system that will collapse and break into small pieces if undermined.
- Elevate heating, ventilation, and air conditioning equipment above the BFE, and preferably to the same elevation as the lowest floor of a building. The equipment should be supported to prevent damage from flooding and fastened to resist blow-off from high winds. The preferred approach is a cantilevered platform.
- Ensure that breakaway walls are designed and built to break away cleanly and do not cause additional damage to the building. Minimize the size of any enclosure to the amount necessary for parking and building access.
- Either elevate pools above the BFE on a pile foundation (and design the pool without side support from soil), or install a frangible (breakaway) pool at grade level and consider it expendable. Do not rely on a bulkhead to protect the pool during a severe storm.
- Subject to local and state regulations for coastal armoring, assume that only heavy walls will provide protection during a severe storm, and note that even those may be overtopped by surge and waves. Consider lightweight bulkheads as temporary structures that may provide protection during minor storms, but which will likely fail during a major storm.

Wind-related

- Design and construct facilities to at least the minimum design requirements in the 2003 IBC in Alabama and the 2001 FBC and the 2004 FBC (after it becomes effective in the fall of 2005) in Florida.

- When renovating or remodeling for structural or building 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 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:

- Re-evaluate the methodology to determine flood zones and flood elevations in coastal areas to address the inconsistencies between observed flood elevations (and damages) and BFEs (and anticipated damages).
- Re-evaluate the storm surge data and modeling procedures that served as the basis for the effective FIRMs.
- Use Hurricane Ivan tide levels, inundation limits, and areas subject to wave effects as proxies for reconstruction guidance until such time as new, up-to-date regulatory studies and maps can be prepared and adopted.
- Allocate resources to hardening, providing backup power and data storage to NOAA/NWS's surface weather monitoring systems, including the Automated Surface Observing System (ASOS) located in hurricane-prone regions.
- Continue 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

- 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 September 18, 2004, the Mitigation Division of the Department of Homeland Security's Federal Emergency Management Agency (FEMA) deployed a Mitigation Assessment Team (MAT) to the States of Alabama and Florida to assess damages caused by Hurricane Ivan. This report presents the MAT's observations, conclusions, and recommendations as a result of those field investigations.

Chapter 1 provides an introduction, a discussion of the event, historical information, and background on the MAT process. Chapter 2 discusses the floodplain management regulations and the codes and standards that affect construction in Alabama and Florida. Chapter 3 provides a general characterization of the observed flood and wind effects, and it documents observed hazard mitigation lessons learned and best practices. Chapter 4 details structural systems' performance in residential and commercial buildings as well as in critical and essential facilities. Chapter 5 presents an assessment of building envelope performance. Chapter 6 discusses damages and functional loss to critical and essential facilities. Finally, Chapters 7 and 8 present the conclusions and recommendations that are intended to help guide the reconstruction of hurricane-resistant communities in Alabama and Florida and construction in all hurricane-prone regions. Additional information related to the specific technical issues is provided in the appendices.

1.1 Hurricane Ivan – the Event

The National Hurricane Center (NHC) has issued its report on Hurricane Ivan.[1] The report traces the history of the hurricane and presents meteorological statistics, casualty and damage statistics, and a forecast and warning critique. In addition, the National Weather Service (NWS) office in Mobile, Alabama, has prepared its own report on the storm.[2] The NWS report includes hourly 0.5-degree radar reflectivity images taken from the NWS WSR-88D Doppler Weather Radar in Mobile, Alabama, prior to, during, and after landfall; observed peak wind gusts and times; observed storm surge data; and 48-hour rainfall totals.

[1] Stewart, Stacy R., "Tropical Cyclone Report Hurricane Ivan 2-26 September 2004," National Hurricane Center Report, 16 December 2004, Revised 6 January 2005.

[2] National Weather Service Mobile – Pensacola, "Powerful Hurricane Ivan Slams the US Central Gulf Coast as Upper Category-3 Storm," www.srh.noaa.gov/mob/ivan_page/Ivan-main.htm.

THE SIGNIFICANCE OF HURRICANE IVAN

Hurricane Ivan was the most severe hurricane to strike the eastern Alabama, western Florida coastline in many decades. The significance of Ivan and its effects are summarized below:

- Ivan approximated or slightly exceeded design flood conditions on many of the affected barrier islands, with the highest open coast flood levels near the area of landfall.
- On the bay and sound shorelines between Gulf Shores, Alabama, and Santa Rosa County, Florida, Ivan greatly exceeded a design flood event. Flood levels during the storm generally exceeded the Base (1-percent annual exceedance probability) Flood Elevations (BFEs) on many Flood Insurance Rate Maps (FIRMs) by several feet, calling into question the adequacy of the storm surge modeling used as the basis for the FIRMs and highlighting the importance of adding freeboard when constructing in coastal floodplains.
- Flood and erosion damages on barrier islands were generally consistent with expectations. Buildings closest to the shoreline sustained the most severe damage, and buildings in areas with the narrowest beaches and dunes before Ivan struck sustained more damage than buildings in areas with wide beaches and healthy dunes before the storm.
- On barrier islands, newer pile- and/or column-supported buildings elevated above the BFE generally performed well; however, they sustained non-structural damage to areas below the elevated floor. Some newer buildings elevated to the BFE sustained flood damage (structural and non-structural) above and below the BFE. Many older, post-FIRM buildings sustained significant structural damage due to piling failures (e.g., inadequate pile embedment, pile breakage, poor connections between the piles and the elevated building, etc.) or inadequate foundations, or because of insufficient elevation.
- On the barrier islands, several relatively new (less than 10-12 years old), three- to five-story multi-family buildings, constructed on shallow foundations in flood Zones B, C, or X, collapsed due to erosion and undermining. This is the first time that recent post-storm investigations have observed total failures of multi-family buildings due to flood effects.
- Flood damage along bay and sound shorelines was far beyond expectations. Even newer buildings constructed in compliance with minimum community foundation and elevation standards sustained severe damage due to waves, floodborne debris, and velocity flow. Flood (inundation) damage occurred in many areas outside the Special Flood Hazard Area (SFHA) shown on FIRMs. The only types of buildings that generally performed well in these areas were those built on piles or stemwall foundations with their lowest floor above Ivan's wave crest elevation.
- Ivan was less than a design wind event when expected loads are compared to the 2001 Florida Building Code (FBC) and the 2000/2003 International Building Code (IBC) and International Residential Code (IRC) load provisions. These codes use a design wind speed map developed for the 1998 edition of ASCE 7 where substantial increases in design wind speeds were introduced in this region.
- Ivan was a design wind event from the Gulf Shores area east through Orange Beach and Pensacola Beach and inland in some areas as far north as I-10 for structural frames of buildings built under Standard Building Code (SBC) 1979 through 1997 wind load provisions for structural systems. In addition, Ivan was a greater than design wind event for this same geographic area when estimated actual loads on roof corners and edges are compared to the SBC 1979 through 1997 wind load provisions for cladding elements.
- Wind damage to both commercial and residential buildings was widespread in the southern portions of Baldwin County, Alabama, and in the southern portions of Escambia and Santa Rosa Counties, Florida.
- In general, buildings functioning as critical and essential facilities did not perform significantly better than their commercial-use counterparts. As a result of poor building envelope performance, the operations and response at many critical and essential facilities were hampered or shut down and taken off-line after the hurricane. Most critical and essential facilities in the impacted area were housed in older buildings and most, if not all, apparently were not mitigated to resist known hurricane risks.
- Hurricane Ivan generated a greater number and value of flood claims than any other coastal flood event in the history of the National Flood Insurance Program (NFIP) – over 18,000 claims valued at over 1 billion dollars.
- Due to the severe destruction, the MAT was tasked to assess performance of buildings (residential, commercial, critical and essential facilities), floodplain management regulations and FIRMs, building codes, and construction practices.

When Hurricane Ivan made landfall on September 16, 2004, the NHC reported it as a major hurricane that produced sustained winds of 121 miles per hour (mph), torrential rains, coastal storm surge flooding of 10 to 16 feet above normal high tide, and large and battering waves along the Alabama and western Florida Panhandle coastline. The NWS reports that on September 15 through 16, Ivan spawned 23 tornadoes[3] in Florida and produced as much as 10 to 15 inches of rainfall in some areas. Widespread damage occurred, including the damage and/or destruction of buildings, infrastructure, and beach erosion.

After landfall, Hurricane Ivan gradually weakened over the next week, moving northeastward over the southeastern United States and eventually emerging off the Delmarva Peninsula as an extratropical low on September 19, 2004. The remnant circulation of Ivan then moved southwestward, passed over South Florida into the Gulf of Mexico, and became a tropical storm again on September 23. As a tropical storm, Ivan made its second landfall over southwestern Louisiana on September 24, and finally dissipated inland over East Texas later that day. Figure 1-1 shows Ivan's path associated with its initial landfall on September 16, 2004.

[3] The MAT did not investigate any sites impacted by tornadoes spawned by Hurricane Ivan.

Figure 1-1.
Path of Hurricane Ivan

Beyond the normal NWS Automated Surface Observing System (ASOS) (the nation's primary surface weather observing network stations in the area), data were collected at a number of military airports and at a number of sites where universities deployed portable meteorological instruments and towers in front of the advancing storm. The result is that there are a number of surface data observations available for Hurricane Ivan, particularly near the coast. These observations provide a good basis for assessing the performance of various wind field models in describing the geographical distribution of winds throughout the region impacted by Hurricane Ivan.

The flood and wind data and maps of probable maximum wind speeds included in this report reflect the best available estimates at the time of publication. With all hurricanes, there can be localized areas impacted by special features of the storm including convective cells that bring high winds down to the surface. Nevertheless, with the exception of one unofficial observation from a sailboat in Wolf Bay, the surface observations provide a portrait of a wind field that does not contain significant local variations and is generally consistent with the geographical distributions and magnitudes suggested by the leading wind field models. Furthermore, the leading models provide estimates of maximum peak overland surface wind speeds that are within a couple of mph of each other.

Hurricane Categories

Hurricanes are classified in different categories according to the Saffir-Simpson Hurricane Scale. Table 1-1 presents the categories of the Saffir-Simpson Hurricane Scale along with their respective wind speeds, presented as both 1-minute sustained wind speeds and as 3-second peak gust wind speeds. Hurricane Ivan is categorized as a Category 3 "major hurricane" by the NHC in its Tropical Cyclone Report. A "major hurricane" is defined as one that has estimated 1-minute sustained wind speeds (over open water) that exceed 111 mph. For Ivan, the NHC estimated sustained wind speeds at landfall of 121 mph. This is equivalent to the threshold velocity for a Category 3 storm on the Saffir-Simpson Hurricane Scale.

As the storm made landfall just west of Gulf Shores, Alabama, the eye diameter is estimated to have increased to between 46 and 58 miles with the strongest winds occurring in a narrow region near the southern Alabama-western Florida Panhandle border (NHC Tropical Cyclone Report). A number of surface observation sites provided data throughout the coastal region. The data indicate that most of the region impacted by the storm likely experienced Category 1 intensity winds with some areas near the Alabama-Florida border experiencing Category 2 intensity winds. None of the surface wind measurements for overland conditions correspond to Category 3 intensity winds. Category 3 intensity winds may have occurred in relatively small areas along the gulf/land and bay/land interfaces near the Alabama-Florida border. A more complete discussion of wind speed estimates based on surface wind measurements and computer modeling is provided in Section 1.1.2.

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	>156	>195	<919

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

1.1.1 Storm Surge Analysis and Discussion

Many of the barrier islands exposed to Hurricane Ivan are low lying and could not contain the storm surge associated with the storm. Coastal storm surge flooding crossed the barrier islands, undermining buildings and roads, and opening new island breaches. In addition to the storm surge, breaking waves eroded dunes and battered structures. The storm's arrival was concurrent with high tide, which increased storm surge flooding that was estimated at 10 to 16 feet above normal tide levels. Large and dangerous battering waves occurred near and to the east of where the center of the storm made landfall.

National Oceanographic and Atmospheric Administration (NOAA) Gauge 8729840, located on the Pensacola Municipal Pier (Escambia Bay) in Florida, failed during Hurricane Ivan, but interior watermarks in the gauge housing indicated a 10.2-foot National Geodetic Vertical Datum of 1929 (NGVD) maximum water elevation (U.S. Army Corps of Engineers [USACE], 2004). The 10.2-foot water level is the highest ever recorded at the gauge site in its 82-year existence and is thought to reflect storm surge effects only, given that the gauge site is on a pier extending into the bay and that the contribution of Hurricane Ivan wave setup on the water level there was probably small.

An assessment to determine the recurrence interval of Hurricane Ivan was performed based on similar methodology used after Hurricane Opal in 1995. However, although the impacted area was very large with storm surge elevations exceeding the mapped 100-year flood elevations along the open coast and throughout the bays and sounds, only the Pensacola tide gauge was available to use for the recurrence interval analysis. Using this gauge, the analysis determined the recurrence interval was approximately 150 years. Given the limited data, this approximate recurrence interval applies only to the area surrounding the pier. Recurrence intervals in other parts of the affected area could have been higher or lower. Also, local effects (including the over washing of the barrier islands, which was not accounted for in the initial storm surge analysis performed over 20 years ago) significantly alter the storm surge levels in different parts of the area's bays and sounds.

To assist in the long-term recovery and mitigation effort, FEMA performed a Coastal High Water Mark (CHWM) study throughout the impacted area in Alabama and Florida. The study area extended from Dauphin Island, along Gulf Shores, Alabama, eastward to Destin, Florida, and northward into the Florida Panhandle to encompass Perdido, Escambia, and Blackwater Bays. The observations were taken at discrete points distributed along the open coast, the seaward and landward side of barrier islands, within the bays, and on the shores of several embayments.

FEMA's CHWM Survey provided observed values of the maximum flood elevations throughout the area impacted by Hurricane Ivan.[4] Table 1-2 presents a comparison of the High Water Marks (HWMs) and BFEs at the MAT investigation sites.

[4] FEMA 2004. Hurricane Ivan Flood Recovery Maps, http://www.fema.gov/ivanmaps/

Table 1-2. Comparison of HWMs and BFEs for MAT Investigation Sites

MAT Investigation Site	Flood Source	HWMs* (feet**)	FIS Stillwater Elevations (feet**)	BFEs (feet**)
Alabama				
Gulf Shores	Gulf of Mexico	10-14	10.0***	12-13
Orange Beach/ Perdido Key	Gulf of Mexico	12-15	9.9***	12-13
Florida				
Gulf Beach Heights	Perdido Bay	6-7	4.3	5
Seaglades	Big Lagoon	14	8.0	8-12
Pensacola Naval Air Station	Pensacola Bay	10-13	8.0	8-12
Pensacola	Escambia Bay	10-14	5.9/7.2	6-9
South Gulf Breeze	Santa Rosa Sound	10-14	8.0	9-12
West Gulf Breeze	Pensacola Bay	10-12	8.0	7-12
Northeast Gulf Breeze	Escambia Bay	7	4.9	5
Oriole Beach	Santa Rosa Sound	11	8.0	8-12
Floridatown	Escambia Bay	13-16	7.9	11-12
Avalon Beach	Escambia Bay	12	7.9	9
Pensacola Beach	Gulf of Mexico	6-12	10.5****	11-16

* HWMs are approximate stillwater elevations and do not include wave heights.

** In Alabama, elevations are referenced to the North American Vertical Datum of 1988. In Florida, elevations are referenced to the NGVD.

*** Includes wave setup of 2.2 feet.

**** Includes wave setup of 2.5 feet.

The measured CHWMs along the open beaches of the Gulf of Mexico are above the 100-year elevations from immediately west of Gulf Shores, Alabama, to just east of Destin, Florida. The measured CHWMs include the effects of wave setup. Data taken only from building interiors was used to evaluate the extent of the zone thought to be above the 100-year values. This eliminated the possibility of inadvertently including wave height.

Surge elevation contours were mapped in the impacted areas of Baldwin, Escambia, Santa Rosa, and Okaloosa Counties. The contours are based upon the surveyed CHWM elevations (referenced to the North American Vertical Datum of 1988). The CHWM elevations were used to find patterns in the coastal storm surge as it pushed against the open coast and into the inland bays. The known path and landfall location of Hurricane Ivan, together with the knowledge of how storm surge propagates inland, allowed surge contours to be drawn across the areas where the CHWMs indicate a change in storm surge elevation. Because of the inherent uncertainty and the random and irregular spacing of CHWMs, the surge contours represent a generalized maximum storm surge elevation, and required professional judgment in their creation. Within certain surge contours, CHWMs may be higher or lower than the contours if they did not fit the overall pattern assessed from the CHWMs.

Wave effects were not considered in developing the storm surge contours. To estimate the wave heights at the shoreline, standard FEMA methodology may be used, where the depth of water at the shoreline is multiplied by 1.55 to obtain the height of the wave crest above the ground at that point.

Surge elevation contours in Baldwin County are shown in Figure 1-2. HWM elevations along the open coast of Baldwin County were generally 2-3 feet higher than the effective BFEs shown on the FIRM. However, the HWM elevations along some of the inland bays (Bayou St. John, Perdido Bay, and Wolf Bay) were found to differ from the BFEs by only +/- 1 foot. It should be noted that several HWM elevations could not be compared to effective BFEs because the areas are currently mapped as Zone X, without established elevations.

Figure 1-2.
Surge elevation contours in Baldwin County, Alabama

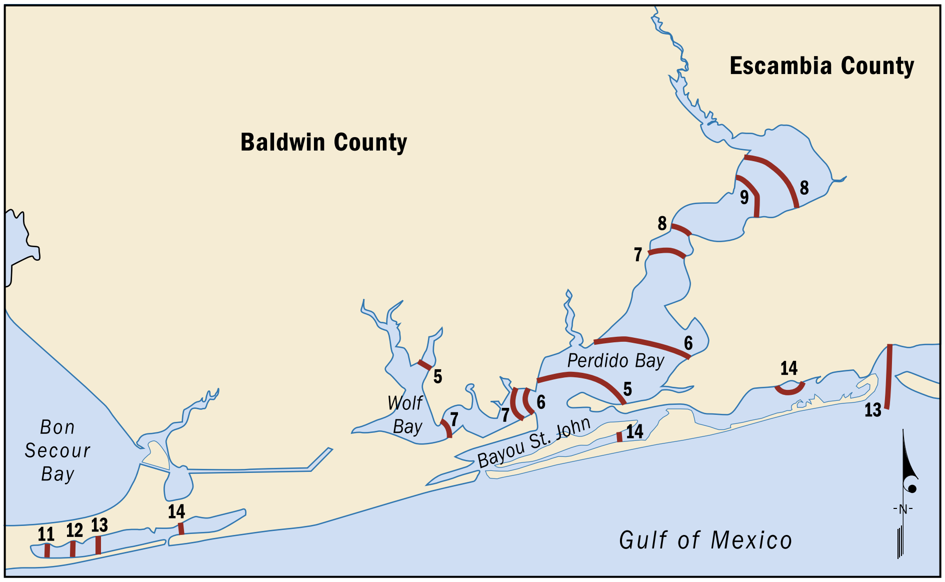


Figure 1-3 shows the surge elevation contours in Escambia County. Here, the HWM elevations in the inland bay areas varied greatly from the effective BFEs. Along Perdido Bay, the HWM elevations were found to be approximately 0-2 feet higher than the effective BFEs. Along Big Lagoon, HWMs were generally 6-8 feet higher than the BFEs. Along Pensacola Bay, they were about 4 feet higher, and along Escambia Bay, generally 5 feet higher. As with Baldwin County, it should be noted that several HWM elevations could not be compared to effective BFEs because the areas are currently mapped as Zone X, without established elevations.

Figure 1-3.
Surge elevation contours in Escambia County, Florida

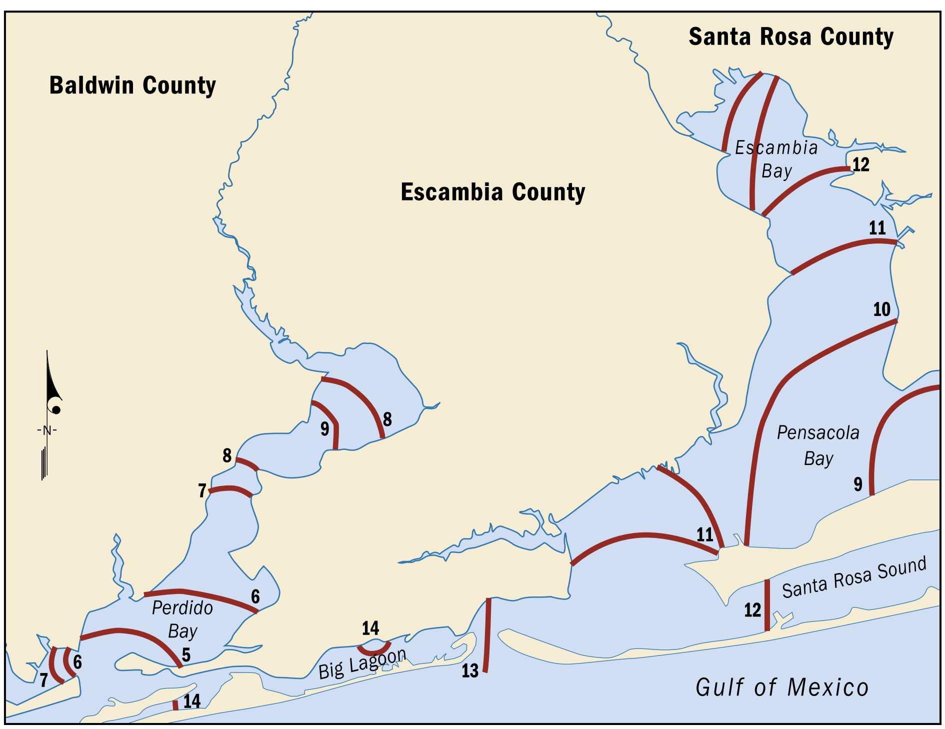


Figure 1-4 shows the surge elevation contours in Santa Rosa County. The HWM elevations in Santa Rosa County were generally found to be much higher than the effective BFEs in the inland bay areas. Along Pensacola Bay, the HWMs were generally 2-6 feet higher than the effective BFEs. However, there were also instances where the two elevations were equal, such as at Garcon Point along Pensacola Bay (both equal to 10 feet). Along Escambia Bay, the HWMs were found to be approximately 3-4 feet higher than the BFEs, and along East Bay, approximately 3-6 feet higher. Along the northern shoreline of Santa Rosa Sound, the HWM elevations differed from the BFEs by about +2 feet, while along Blackwater Bay, the HWMs were about 2-4 feet higher than the BFEs. As with the other impacted counties, several HWM elevations could not be compared to effective BFEs because the areas are currently mapped as Zone X, without established elevations.

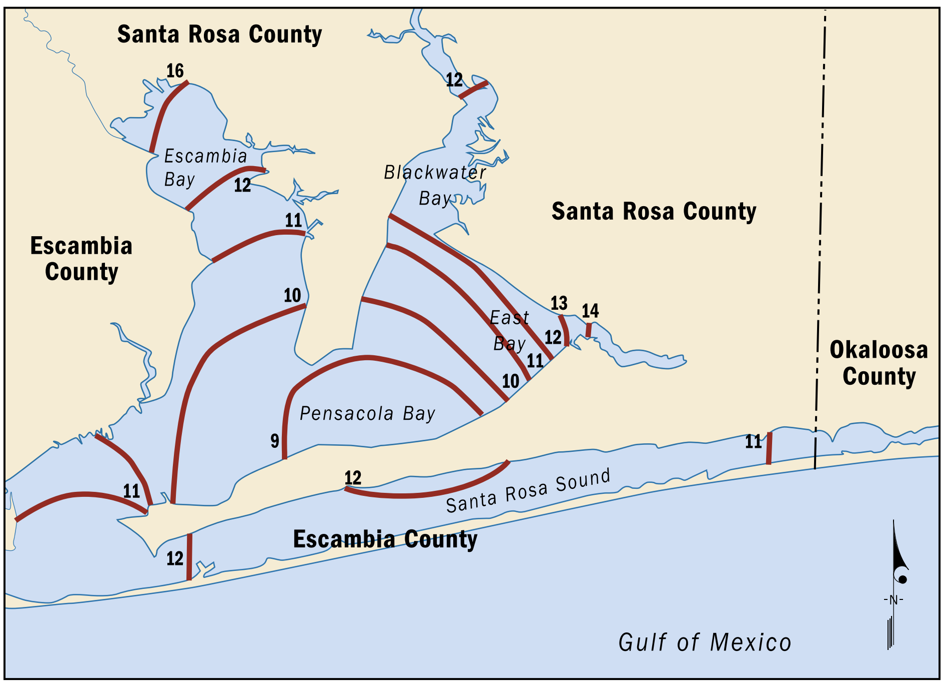


Figure 1-4.
Surge elevation contours in Santa Rosa County, Florida

Surge elevation contours for Okaloosa County are shown in Figure 1-5. HWM elevations along the open coast of Okaloosa County were generally equal to or lower than the effective BFEs shown on the FIRM. The HWM elevations along some of the inland bays, such as Boggy Bayou, were found to be 2-3 feet lower than the effective BFEs. Again, it should be noted that several HWM elevations could not be compared to effective BFEs because the areas are currently mapped as Zone X, without established elevations.

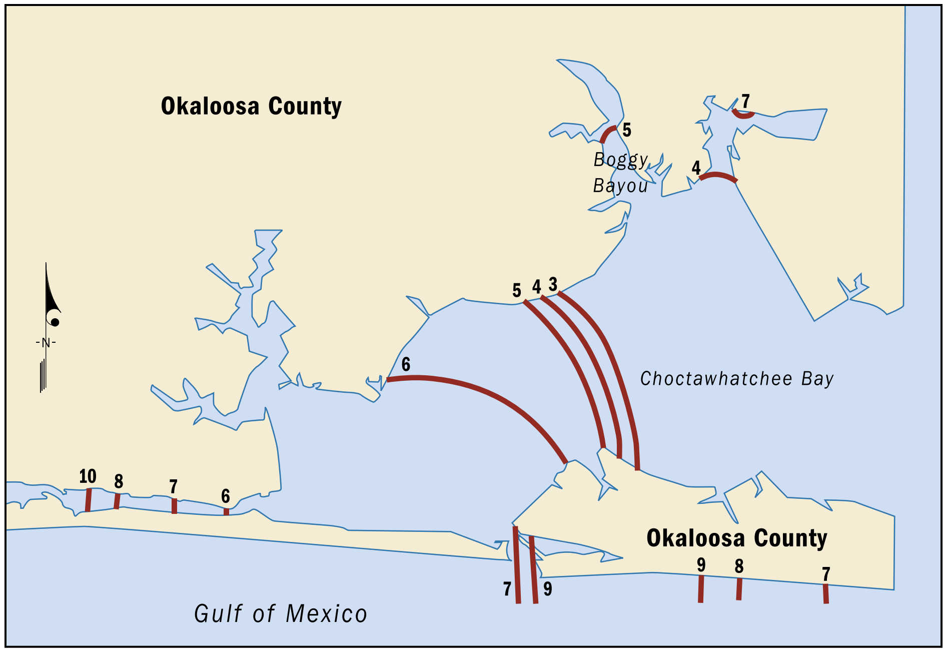


Figure 1-5. Surge elevation contours in Okaloosa County, Florida

The Hurricane Ivan CHWM data clearly show that the storm surge levels varied within the bays. This observation indicates that the 100-year level determined from the Pensacola Bay tide gauge applies to a limited area within the bay. Extreme storm surge conditions extended along a 90-mile length of the open coast reaching 5 miles west and 85 miles east of the storm track. As an initial assessment, it is reasonable to assume that conditions capable of producing hurricane storm surge elevations exceeding the 100-year recurrence magnitudes extended inland over this whole length of the coast.

The NOAA *Sea, Lake and Overland Surges from Hurricanes* (SLOSH) model prediction run output shows that the maximum surge conditions moved across the area as the storm tracked across the coast. Figure 1-6 shows the results of the SLOSH model for Hurricane Ivan. The hurricane crossed the coast in the general area of Gulf Shores and Orange Beach. Because it tracked north-northeast from there, Mobile Bay and most of the Alabama coast was exposed to the weaker "left-front" storm quadrant. In Alabama, the major storm surge struck Orange Beach, Gulf Shores, and the peninsula between Bon Secour Bay (the southeastern corner of Mobile Bay) and the open gulf. In Florida, the first major surge was along the open coast, at Perdido Key.

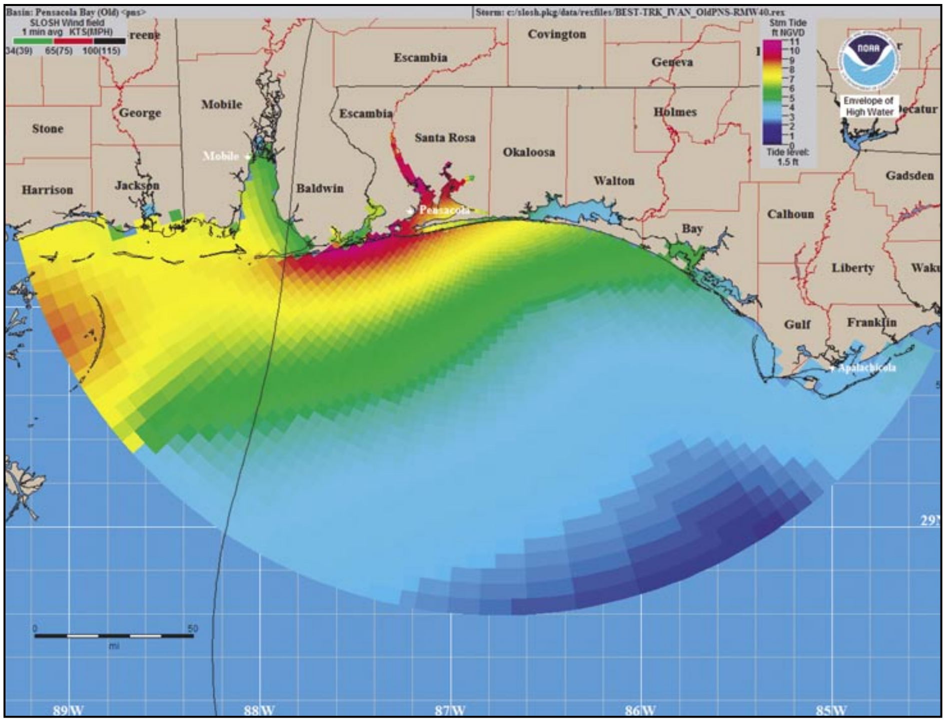


Figure 1-6.
The SLOSH model Envelope of High Water (EOHW) for Pensacola Bay, Florida

In general, the results of the SLOSH model correlated with the actual storm surge elevations from Ivan as compared by the MAT and NOAA. The results of FEMA's CHWM study are presented in Figures 1-7 through 1-10 for Alabama and Figures 1-11 through 1-17 for Florida. The points are shown to differentiate between surge, wave runup, and wave height data. Figure 1-7 shows the effect of the storm on Dauphin Island and the lower western part of Mobile County. Along the open coast, CHWM elevations reached 12 feet and ranged between 3 and 6.8 feet on the landward side of the island and the more protected areas.

Figure 1-7.
CHWM surveyed elevations for Dauphin Island area

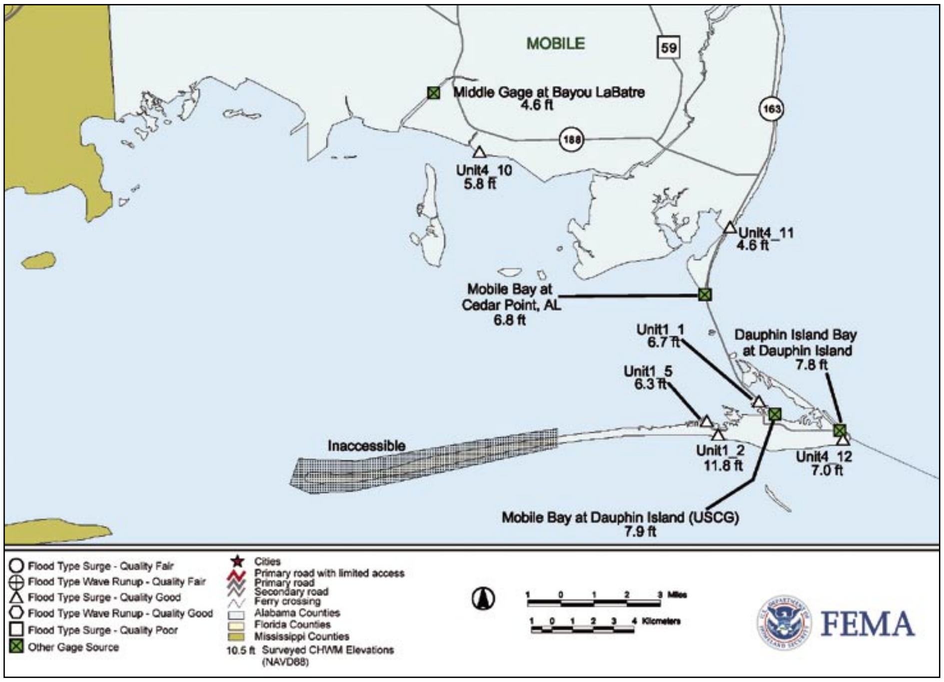
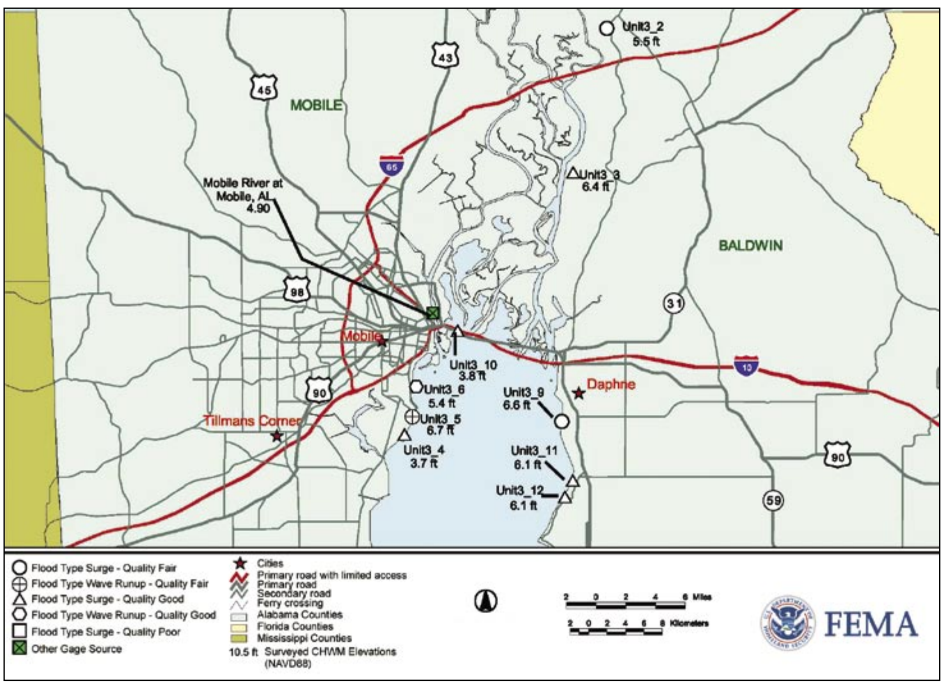


Figure 1-8.
CHWM surveyed elevations for Upper Mobile Bay area



Figures 1-9 and 1-10 show the CHWM elevations in Orange Beach, Ono Island, West Beach, and Fort Morgan. The surge height, determined from water marks in sheltered locations such as interior rooms, ranged between 12 and 14.5 feet along this portion of the open Alabama shore. Much of the beach system was overtopped or overwashed.

Little Lagoon filled with water, but the effects of wave setup may have been smaller than on the open coast, accounting for slightly lower CHWM elevations along its north shore.

The open gulf CHWM elevations decrease slightly near Perdido Pass, possibly because of the flow into Perdido Bay. Figure 1-10 shows that CHWM elevations in the lower Perdido Bay were 6 to 7 feet. Data from the Florida side of upper Perdido Bay (not shown) indicated that the water level increased towards the head of the bay with values in the range of 8.5 to 9 feet at its northern end. The surge was then amplified as it propagated up the lower Perdido River such that the U.S. Geological Survey (USGS) gauge at Barrineau Park indicated a level of 14 feet above the preceding river level. A similar effect appears to have affected the head of Wolf Bay as shown on Figure 1-10.

Figure 1-9 shows that the CHWM elevations were much lower along the eastern shore of Mobile Bay in Baldwin County compared to the open coast. Data on Figures 1-8 and 1-9 show that elevations on the order of 6.5 feet were characteristic of this eastern shore of Mobile Bay.

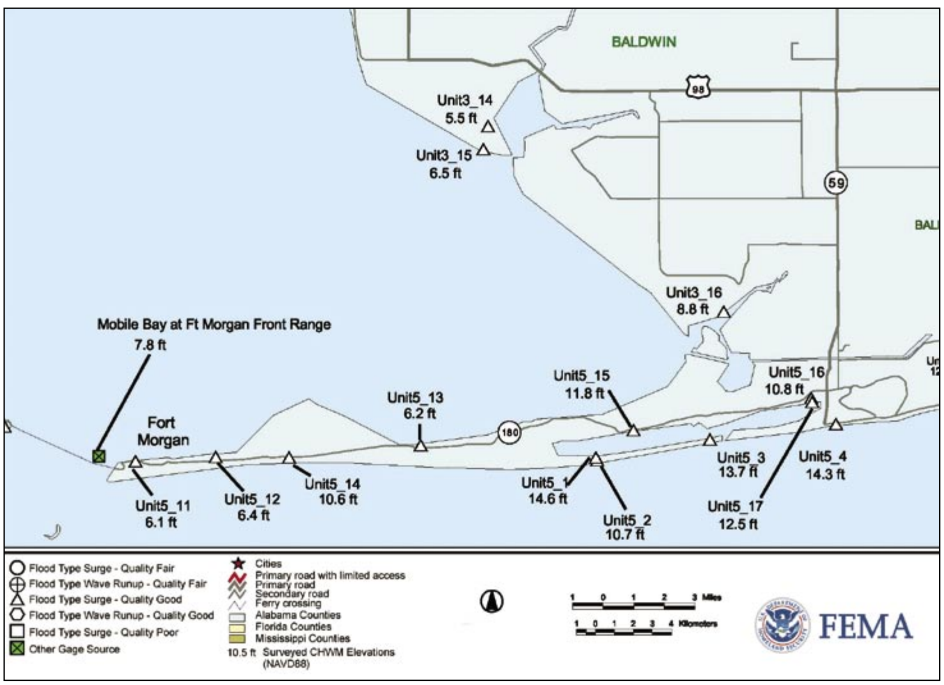
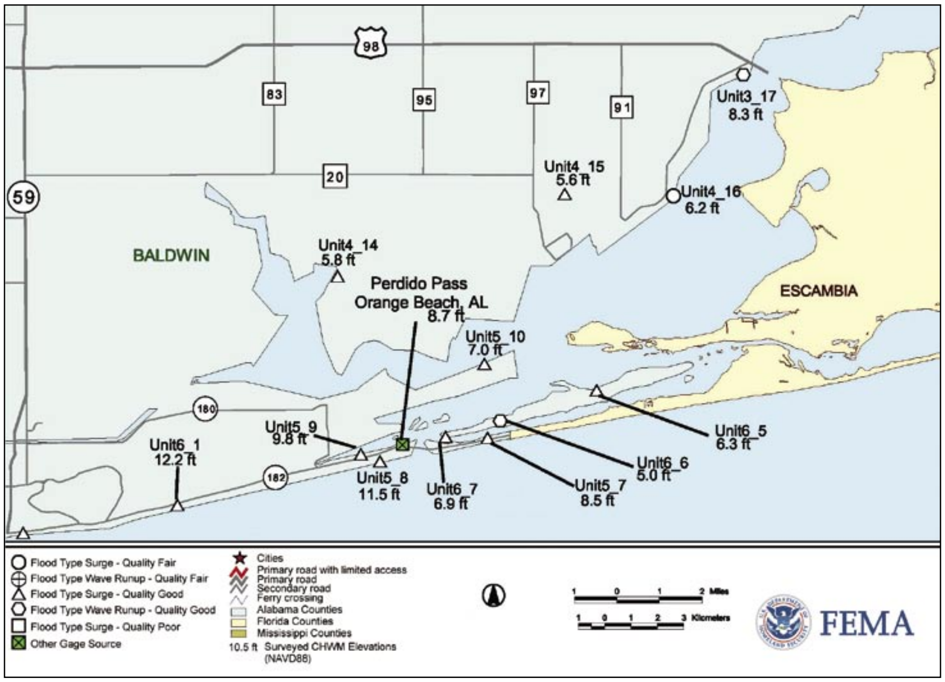


Figure 1-9.
CHWM surveyed elevations for West Beach/Fort Morgan area

Figure 1-10.
CHWM surveyed elevations for Orange Beach/Ono Island



The great majority of the CHWM data points collected for Florida represent watermarks from protected locations such as interior walls of coastal buildings. In some areas, the storm damage was so extensive that coastal roads were washed out or entirely buried with sand. These areas are shown as being inaccessible on the figures. Many of the gulf beaches in this area are within parks or National Seashores. These natural areas contained scant record of the coastal storm surge compared to the built-up areas.

The highest CHWM elevations in Florida occur in the Perdido Key area (see Figure 1-11). Much of this barrier island was overtopped. Such overtopping of the barrier island would allow a huge volume of water to enter Big Lagoon, and this could explain the very high CHWM elevations along the mainland coast (Figure 1-11). Figure 1-11 also shows that there was a noticeable difference in the CHWM elevation over the length of Perdido Bay. Both Ono Island and Innerarity Point have high ground well above the flood elevation. It appears that bay water was displaced towards the upper bay faster than it could be refilled from the gulf. This results in a differential in the CHWM elevations of about 3 feet over the 12-mile length of the open bay.

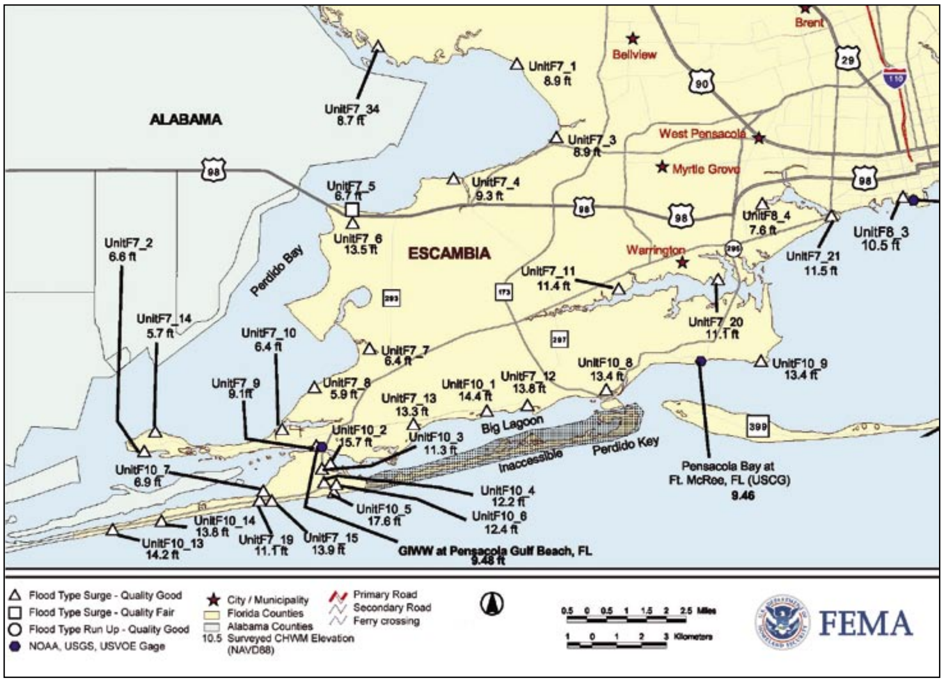


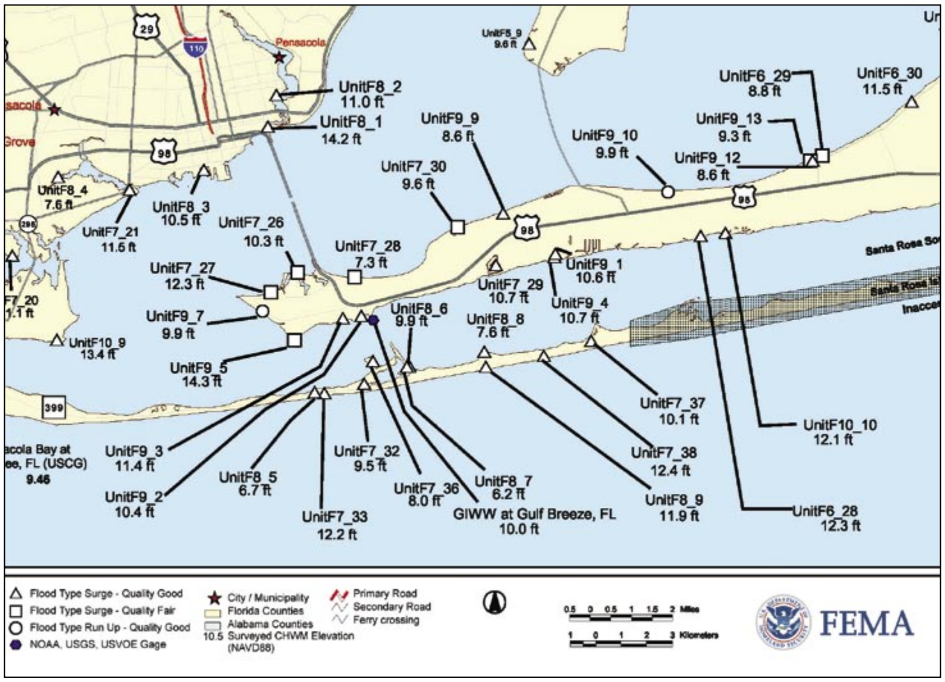
Figure 1-11. CHWM surveyed elevations for Innerarity Point and Perdido Key areas

Figure 1-12 shows the area between the entrance to Pensacola Bay and Garcon Point in the northwest corner. Much of the barrier island was subject to extensive damage by the surge. This includes overtopping and overwashing at many locations. The road was buried in many places, and access to the island was restricted for weeks. The surge along the Pensacola Beach Barrier Island may have been limited by the low height of the land. With nothing to back up against, the surge passed over the island into Santa Rosa Sound and lower Pensacola Bay. The differences in the CHWM elevations between the gulf and sound sides support this inferred surge behavior.

The Santa Rosa Peninsula, which lies behind the barrier island, has ground that is much higher than the maximum surge elevation. Figure 1-12 shows that the surge setup along the southern peninsula shoreline had elevations on the order of 11 and 12 feet. This is in contrast with values of 6 to 8 feet only 2 miles away across Santa Rosa Sound. These CHWM values also demonstrate that the volume of water within the Sound increased dramatically during the surge.

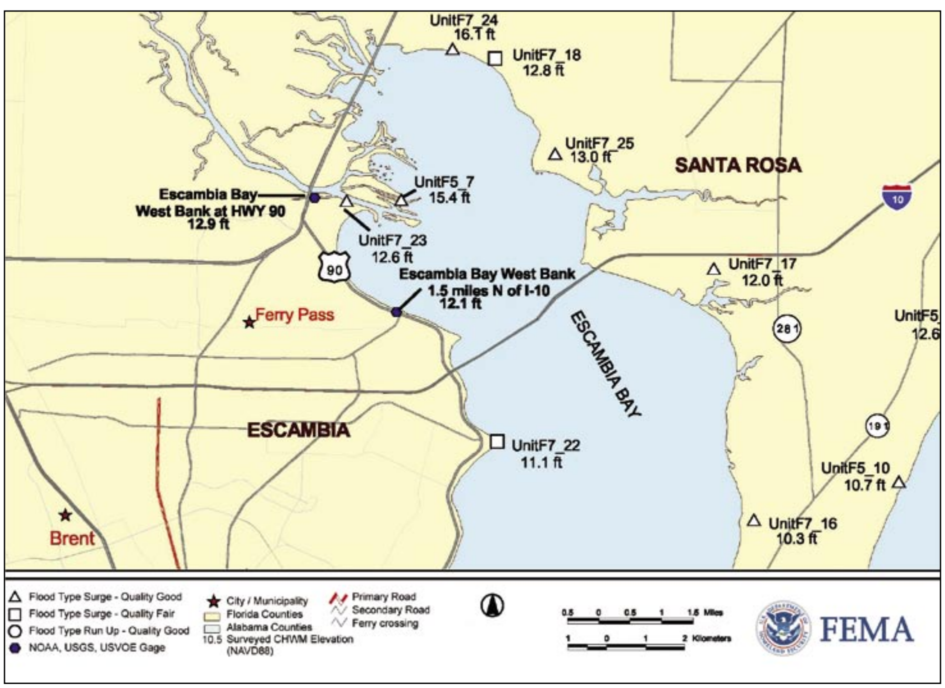
Figure 1-12 shows also that wind-driven water piled up along the south-facing shores of the Naval Air Station, the western suburb of Warrington, and the Port of Pensacola. This also brought high surge levels into Bayou Grande, Bayou Chico, and Bayou Texar. Maximum surge elevations throughout Pensacola Bay and the lower portions of Escambia and Blackwater Bays appear to have been on the order of 9.5 to 11 feet.

Figure 1-12.
CHWM surveyed elevations for Pensacola/ Gulf Breeze area



Figures 1-13 and 1-14 are centered on the Escambia and Blackwater arms of the estuary. In both cases there is a clear pattern of surge amplification towards the heads of these bays. The highest observed elevation in Escambia Bay was 16 feet in Floridatown at the north end of Escambia Bay. The Ward Basin is near the north end of Blackwater Bay just south of the I-10 highway. Here, the surge elevation reached close to 13 feet. In general, the CHWM elevations are a few feet higher along the shores of the arms of the estuary than in the main portion of Pensacola Bay.

Figure 1-13.
CHWM surveyed elevations for Upper Escambia Bay area



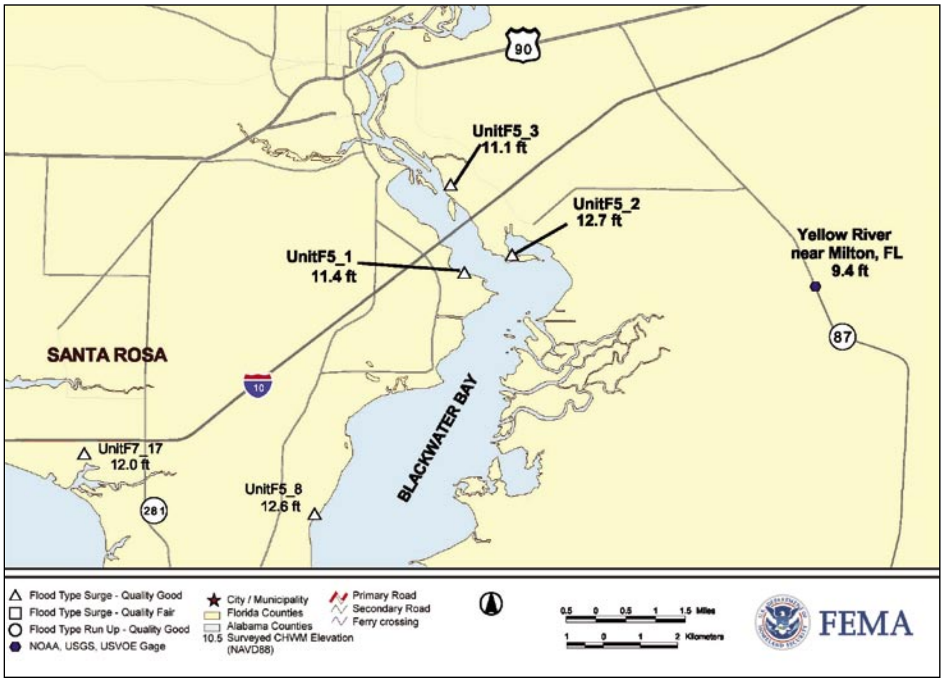


Figure 1-14. CHWM surveyed elevations for Blackwater Bay area

Figure 1-15 shows the eastern portion of Santa Rosa Sound near Navarre and the East Bay arm of the Pensacola Estuary. The CHWM elevations along the open gulf shore are consistent with the values further west. Considerable portions of this part of the island were overtopped or overwashed. Much of the barrier island was inaccessible due to road damage and burial.

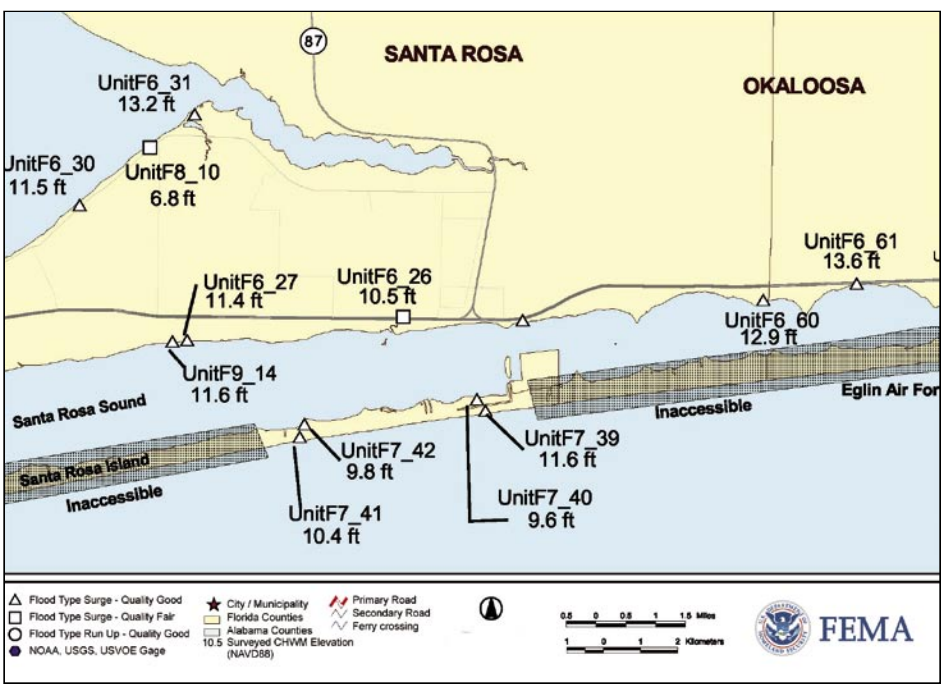


Figure 1-15. CHWM surveyed elevations for Holley Navarre area

The mainland shore of Santa Rosa Sound experienced a high surge that may have decreased slightly going east. However, this trend may be more apparent than real. It was noted that there appeared to be a correlation between the surge levels along the north shore of Santa Rosa Sound and the amount of shielding provided by the barrier island. Much of this island is part of Eglin Air Force Base and is undeveloped. The height of the dunes varies along the island, and there are patches of wooded areas. It was in the regions between the dunes and wooded areas where overtopping and overwashing occurred.

Figures 1-16 and 1-17 show data taken at the eastern end of Santa Rosa Sound and near Fort Walton Beach. Open gulf CHWMs approaching this 13-foot value have been located east of East Pass, which is the inlet into Choctawhatchee Bay, as well. This suggests that a coastal surge was generally at 12 feet or higher along more than 90 miles of the gulf shoreline between eastern Alabama and Destin, Florida. This open coast surge remained high much further to the east, but the land along the shore is high with varying relief so that the surge did not penetrate significantly behind the beach systems except at a few locations.

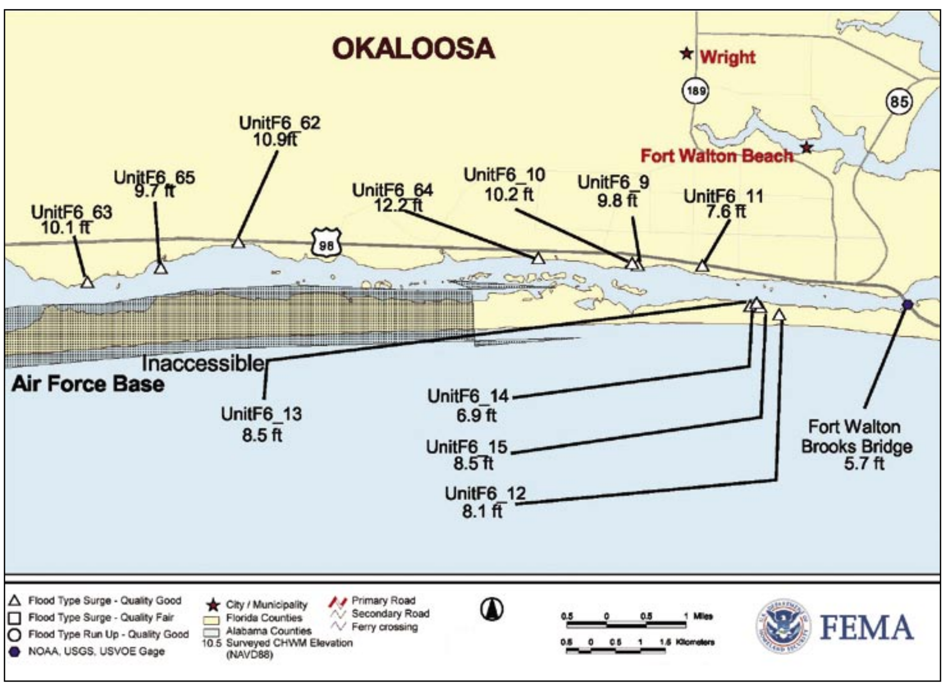


Figure 1-16. CHWM surveyed elevations for Fort Walton area

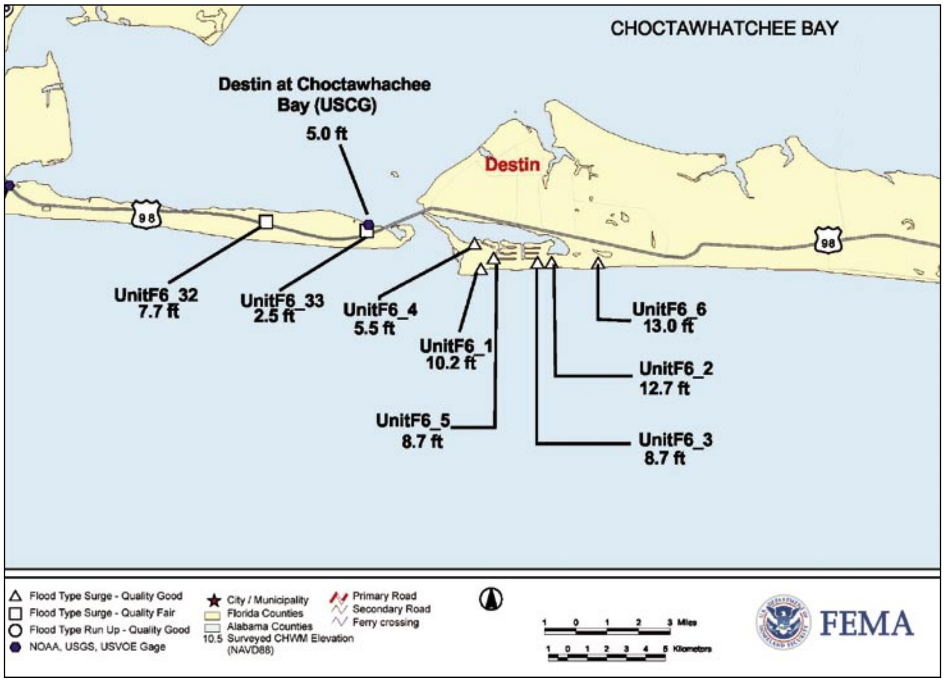


Figure 1-17. CHWM surveyed elevations for Destin area

Preliminary results of the CHWM study show that storm surge levels varied throughout the bays and that these elevations exceeded the 100-year surge elevations. Based on field observations and the CHWM study, the barrier islands were overtopped, which produced extremely high surge elevations in the back bays and, in some cases, elevations close to or nearly as high as the elevations on the open coast. The overtopping of the barrier islands was not accounted for in the surge modeling, which was performed over 20 years ago and used in the current Flood Insurance Studies (FISs). Numerous hurricanes have impacted the Alabama and Florida Panhandle coastline and severely eroded many of the high dunes that were modeled in the surge analysis. Because of the changes in the barrier islands, a new surge model would likely produce higher surge elevations, resulting in higher BFEs in the back bays.

The CHWM study had the following recommendations on how to use the CHWM information to assist in the recovery effort from Hurricane Ivan:

- Compare the Hurricane Ivan CHWMs to the flood elevation data on the effective or preliminary FIRMs. These comparisons can help determine where the updated flood hazard data was supported by the flooding or where new detailed studies should be performed to update the maps. They can help illustrate deficiencies of the existing maps.
- An evaluation is needed of the recurrence intervals of the surge conditions across the area. This will vary from place to place owing to distance from the storm track and local geographic effects. Preliminary evidence suggests that much of the area that experienced the most severe surge conditions was exposed to more than 100-year conditions.
- Compare the Ivan CHWMs to CHWMs from other significant flood events. This will identify areas of repetitive flooding that can assist in determining locations that would make good flood mitigation projects.
- Complete detailed engineering analyses to determine flood elevations in the areas where deficiencies of the existing FEMA maps have been identified, or in areas where property loss occurred and there were no previous studies.
- The locations and severity of the Ivan CHWMs can help identify areas of concern for future mitigation projects when funding for such projects becomes available.
- Use these CHWMs to evaluate the success of completed mitigation projects. The flood depths that occurred during Ivan can be used to estimate potential damage that could have occurred to buildings that have been bought out and removed as part of mitigation projects already completed. Documentation of the “damages avoided” can be used as success stories to further support the mitigation efforts.
- Use the CHWM data to calibrate and validate FEMA’s Hazards US – Natural Hazards Loss Estimating Methodology (HAZUS-MH) flood model.

1.1.2 Wind Analysis and Discussion

The NWS and the NHC reported that Hurricane Ivan made landfall just west of Gulf Shores, Alabama, on September 16, 2004, at 2:02 a.m. (Central Daylight Time). After crossing the barrier islands, Ivan turned north-northeastward across eastern Mobile Bay and weakened to a tropical storm as it crossed the central portion of Alabama.

Wind speeds at MAT investigation sites have been estimated based on a review of the wind speed measurements and the plots shown later in this section. The results listed in Table 1-3 correspond to the locations shown in Figure 1-23.

Table 1-3. Estimated Maximum 3-Second Gust Wind Speeds at 10-Meters for MAT Investigation Sites (variations for terrain are provided)

MAT Investigation Site	3-Second Gust Speed Estimate for Exposure C (Open Terrain)	3-Second Gust Speed Estimate for Exposure B (Suburban Terrain)
Alabama		
Gulf Shores	105 – 115 mph	90 – 100 mph
Orange Beach	105 – 120 mph	95 – 110 mph
Florida		
Perdido Key	110 – 125 mph	95 – 110 mph
West Gulf Beach Heights	105 – 120 mph	90 – 105 mph
Gulf Beach Heights	105 – 120 mph	90 – 105 mph
Seaglades	105 – 120 mph	90 – 105 mph
Pensacola Naval Air Station	105 – 115 mph	90 – 100 mph
West Pensacola	105 – 115 mph	90 – 100 mph
East Pensacola	105 – 115 mph	90 – 100 mph
West Gulf Breeze	105 – 115 mph	90 – 100 mph
Northeast Gulf Breeze	95 – 110 mph	80 – 95 mph
Oriole Beach	95 – 110 mph	85 – 95 mph
Floridatown	95 – 110 mph	80 – 95 mph
Avalon Beach	95 – 110 mph	80 – 95 mph
East Side of Escambia Bay Near Bridge to Gulf Breeze	95 – 110 mph	80 – 95 mph
Pensacola Beach	105 – 115 mph	90 – 105 mph

Figure 1-18 shows the approximate extent of tropical storm winds (39 to 73 mph, 1-minute sustained) and hurricane force winds (greater than 74 mph, 1-minute sustained) for Hurricane Ivan. These wind speed contours are based on a combination of actual wind readings and wind field models. The first wind field model is the H*wind program (Weather and Forecasting, September 1996) produced by the Atlantic

Oceanographic and Meteorological Laboratory's Hurricane Research Division (HRD). The second is the FEMA Hazards US – Natural Hazards Loss Estimating Methodology (HAZUS-MH) that was used by Applied Research Associates (ARA) with some adjustments. The maximum recorded Exposure C (open terrain) wind speeds for specific locations in Alabama and Florida are presented in Figure 1-19.

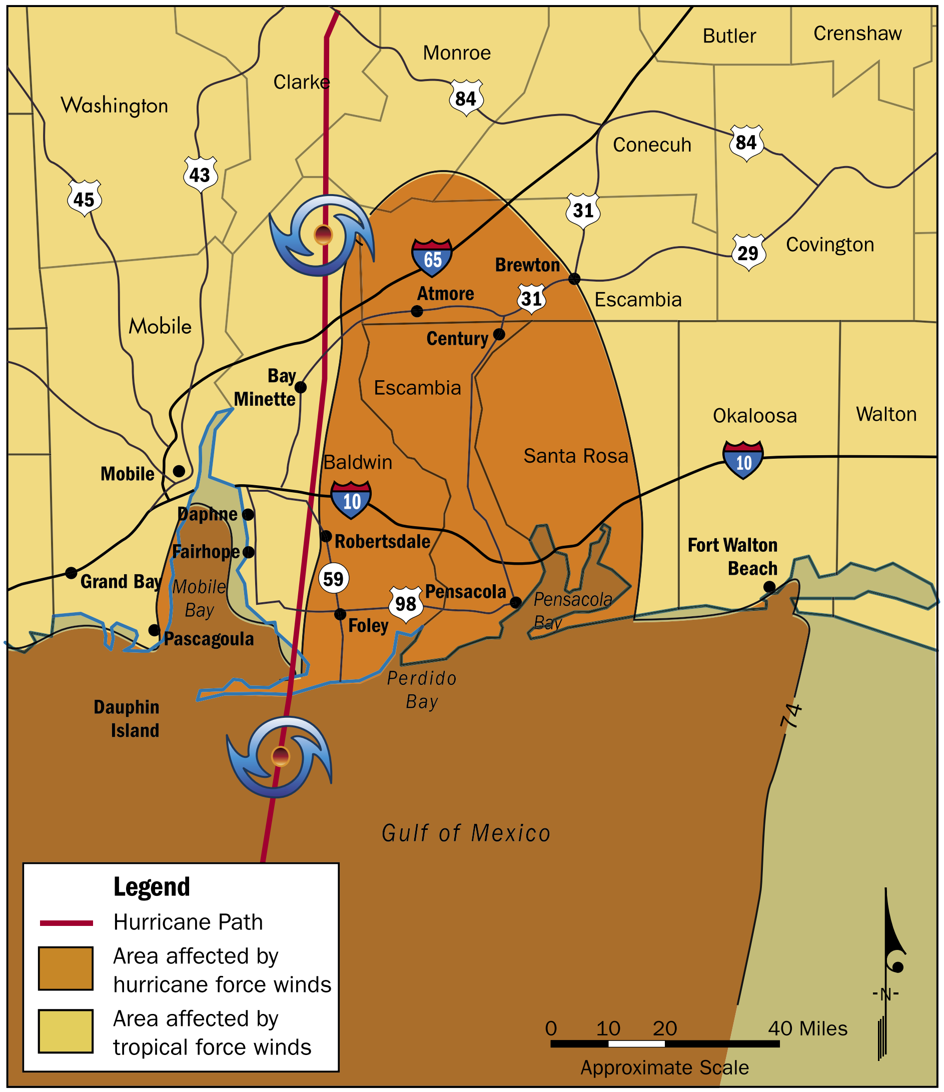


Figure 1-18.
Extent of hurricane and tropical storm force winds for Hurricane Ivan

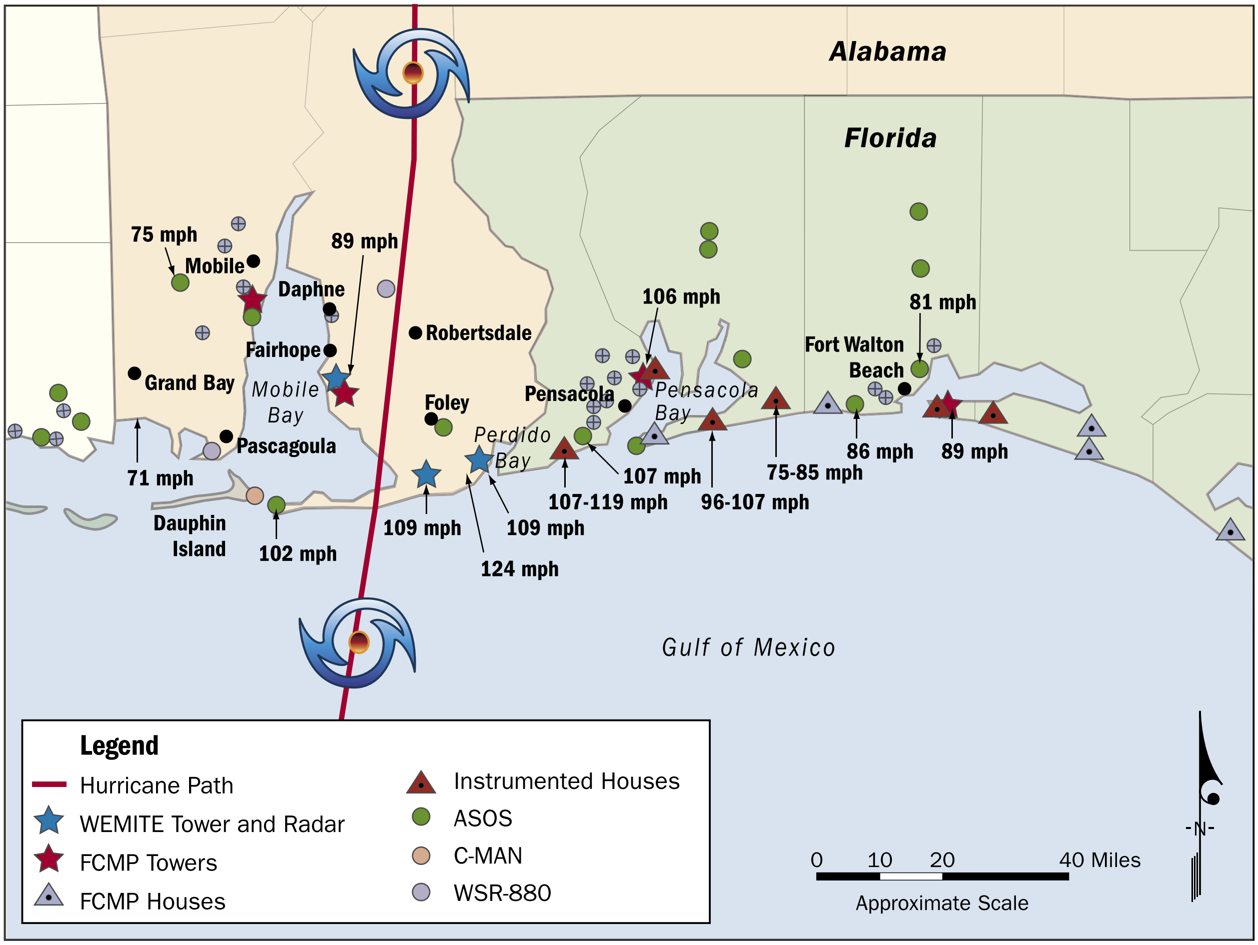


Figure 1-19.
Maximum recorded wind speeds from Hurricane Ivan normalized to 3-second peak gust at 10 meters, Exposure C (open terrain)

Despite the large number of wind speed recordings that were available throughout the area impacted by Hurricane Ivan, measurements were not available at all locations investigated by the MAT. Thus, damage investigators and weather scientists must estimate wind speeds using a variety of methods, the most reliable of which are scientifically based wind field models. The best known model for estimating wind speed variations available in the public domain is H*wind from NOAA's HRD[5]. Past experience with H*wind-based analyses suggests that the model provides reasonably accurate estimates of the maximum wind speeds seen over significant areas impacted by the storm.

[5] Powell, Mark D., Houston, Samuel H. and Reinhold, Timothy A., "Hurricane Andrew's Landfall in South Florida. Part I: Standardizing Measurements for Documentation of Surface Wind Fields," Weather and Forecasting, Vol. 11, No. 3, September 1996. Powell, Mark D., and Houston, Samuel H. "Hurricane Andrew's Landfall in South Florida. Part II: Surface Wind Fields and Potential Real-Time Applications" Weather and Forecasting, September 1996.

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 avre shown in Figure 1-20. A second modeling approach that usually produces reasonable estimates of maximum wind speeds and lateral distributions of winds involves use of wind field based models such as the one in FEMA's HAZUS-MH loss estimation methodology.[6] The wind field analysis conducted by ARA using this model is shown in Figure 1-21. The maximum wind speed estimates for Hurricane Ivan (when normalized) agree within about 3 mph between the H*wind and ARA analyses despite their independent approaches to making wind speed estimates. There are, however, larger differences between wind speeds at specific locations within the wind field. The estimated wind speed ranges for the various locations visited by the MAT are shown in Table 1-3.

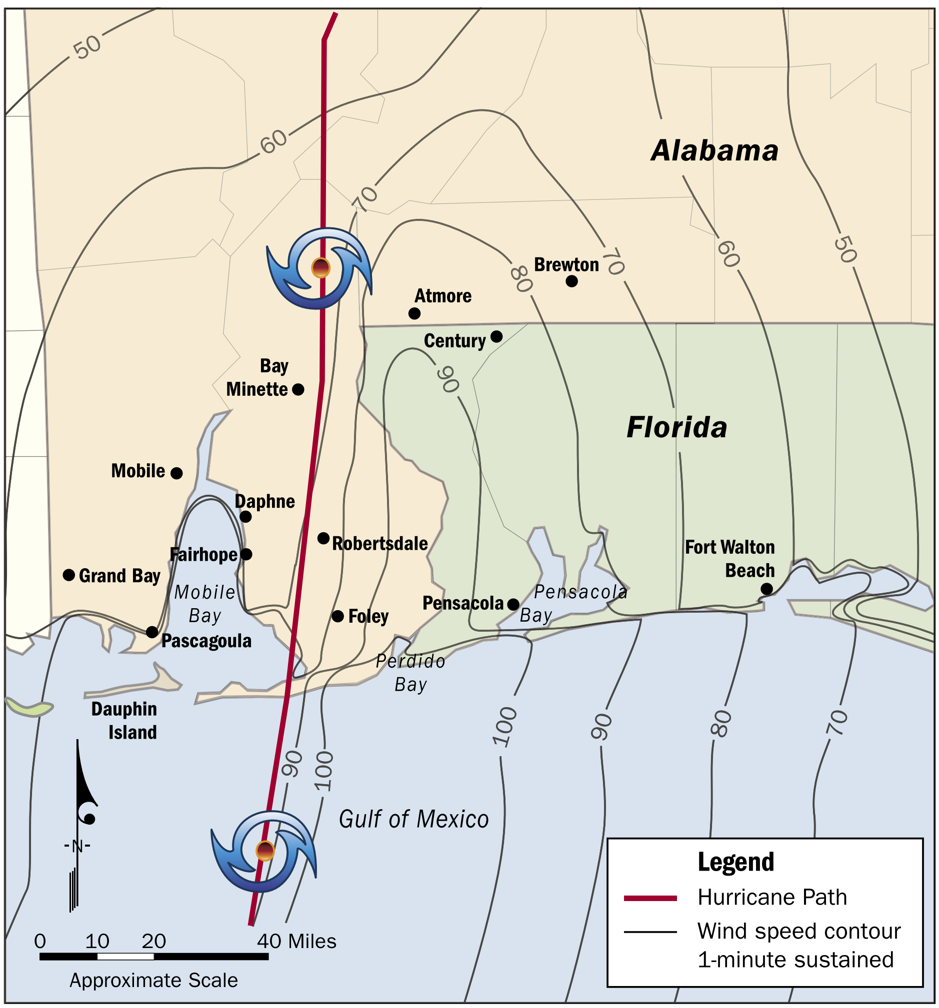


Figure 1-20.
Wind swath contour plot (1-minute sustained winds at 10 meter elevation) based on H*wind analysis

[6] Vickery, Peter J., Skerlj, Peter, Steckley, Andrew and Twisdale Lawrence A.,"Hurricane Wind Field Model for Use in Hurricane Simulations" Journal of Structural Engineering, ASCE, Oct. 2000, pp 1203-1221.

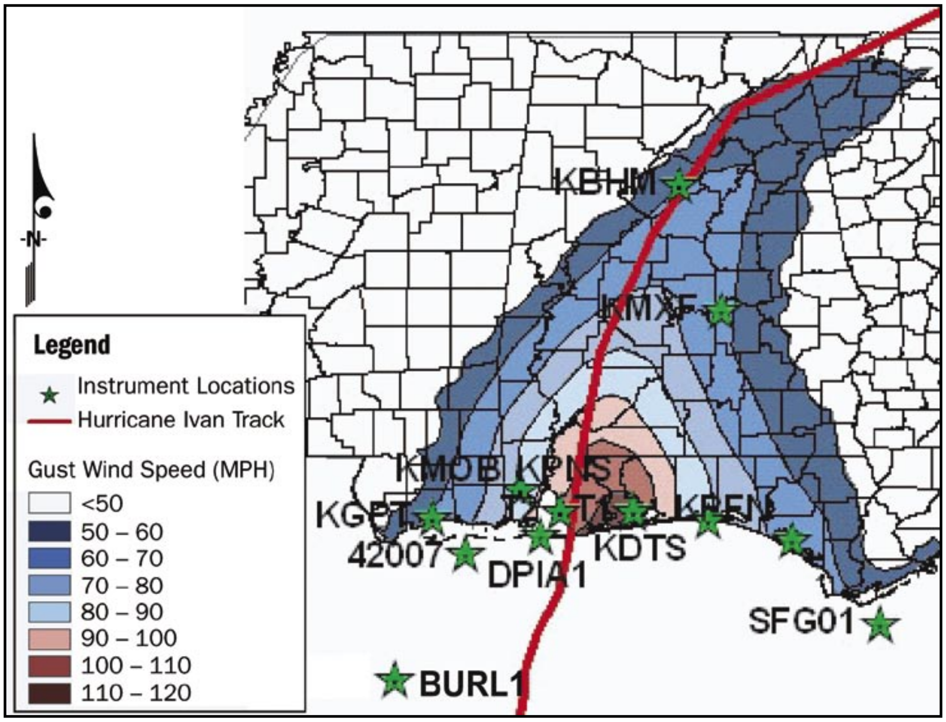


Figure 1-21.
Wind swath contour plot (3-second gust at 10-meter elevation) based on HAZUS-MH wind field methodology (ARA). The stars and letters indicate official stations reporting data for at least part of the storm.

A number of wind speed measurements were recorded at locations along the Alabama and Florida Panhandle coasts. Notable wind speeds recorded for Hurricane Ivan were obtained at the following official locations as shown in Table 1-4.

Table 1-4. Notable Wind Speeds Recorded for Hurricane Ivan

Recording Site	Location	Wind
Official Locations	**Alabama**	
	Grand Bay (AWIS)	71 mph (gust)*
	Mobile (NWS-KMOB)	75 mph
	Florida	
	Eglin Air Force Base (KVPS)	81 mph (gust)*
	Pensacola (NWS-KPNS)†	100 mph
	Pensacola Naval Air Station (KNPA)	107 mph (gust)*
	† Instrument stopped recording values after this reading and may have missed peak.	* Averaging time for gust measurements unknown. Estimated to be between 2 and 5 seconds.
Universities deploying portable 10-meter meteorological towers at various locations along the coast	**Alabama**	
	Fairhope (30.48ºN 87.87ºW) by Florida Coastal Monitoring Program Tower 2	89 mph
	Gulf Shores Airport (30.29ºN 87.67ºW) by University of Oklahoma DOW3	109 mph
	Florida	
	Pensacola Regional Airport (30.48ºN 87.19ºW) by Florida Coastal Monitoring Program Tower 1	106 mph
	Destin Airport by SBCCOM/CR5000 (30.4ºN 86.48ºW)	89 mph
Other notable measurements at non-standard heights and exposures from a number of sources	**Alabama**	
	Fairhope (30.5ºN 87.89ºW) by Texas Tech University WEMITE 2 – Obstacles for some upwind directions may have reduced the observed maximum values	73 mph
	Gulf Shores Airport (30.3ºN 87.66ºW) by Texas Tech University WEMITE 1 – (Actual values at 9.1 meter elevation of 102 mph [3-second gust])	104 mph
	Wolf Field MIPS (30.43ºN 87.54ºW) – (Actual values at 4 meter elevation of 87 mph [3-second gust])	109 mph
	Sailboat Odalisque in Wolf Bay – (Actual value at 22 meter elevation of 145 mph gust with about 2 miles of open water exposure for strong wind direction)	124 mph
	Florida	
	FCMP house ~ 1-mile east of Big Lagoon State Recreation Area – (Actual value of 91 mph [2-second gust] at 7 meters elevation in suburban area)	119 mph (107 mph for Exposure B)
	FCMP house ~ 8-miles east of Gulf Breeze – (Actual value of 82 mph [2-second gust] at 7 meters elevation in suburban area)	107 mph (96 mph for Exposure B)

Note: Wind speeds provided are 3-second peak gust wind speeds at 10 meters, Exposure C (open terrain) except where noted otherwise.

1.2 Historical Hurricanes (Frequency of Hurricanes and Tropical Storms in Eastern Coastal Alabama and Florida Panhandle

Gulf Shores and Dauphin Island, Alabama; and Fort Walton, Pensacola, and Destin, Florida, have been affected or directly hit by past hurricanes that made landfall in the vicinity of Hurricane Ivan's landfall. Historical information shows that four of these cities have been brushed or hit by a hurricane or tropical storm approximately once every 3 years; Gulf Shores has been brushed or hit approximately every 4 years. For a direct landfalling hurricane (within 40 miles), the statistics show the likelihood of such an event as once every 8.9 years for Fort Walton and Pensacola, approximately once every 12 years for Destin, and approximately once every 13 years for Gulf Shores and Dauphin Island. Figure 1-22 highlights some of these hurricanes and storms with paths similar to that of Hurricane Ivan; three of the hurricanes are described below.

Hurricane Frederic, 1979

Hurricane Frederic was the most severe hurricane to strike the Mobile, Alabama, area since 1926. It was a Category 3 hurricane, making landfall on Dauphin Island and passing to the west of Mobile. Storm tides of 8 to 12 feet above normal were reported from Pascagoula, Mississippi, to western Santa Rosa Island, Florida. Frederic was notable due to the extent and magnitude of damage to coastal construction, including the destruction of many barrier island homes that were elevated on pilings to the 100-year stillwater level as required by the NFIP at the time. The occurrence of Frederic was a driving force in modifying NFIP minimum construction standards to require elevation to the wave crest elevation rather than the stillwater level.

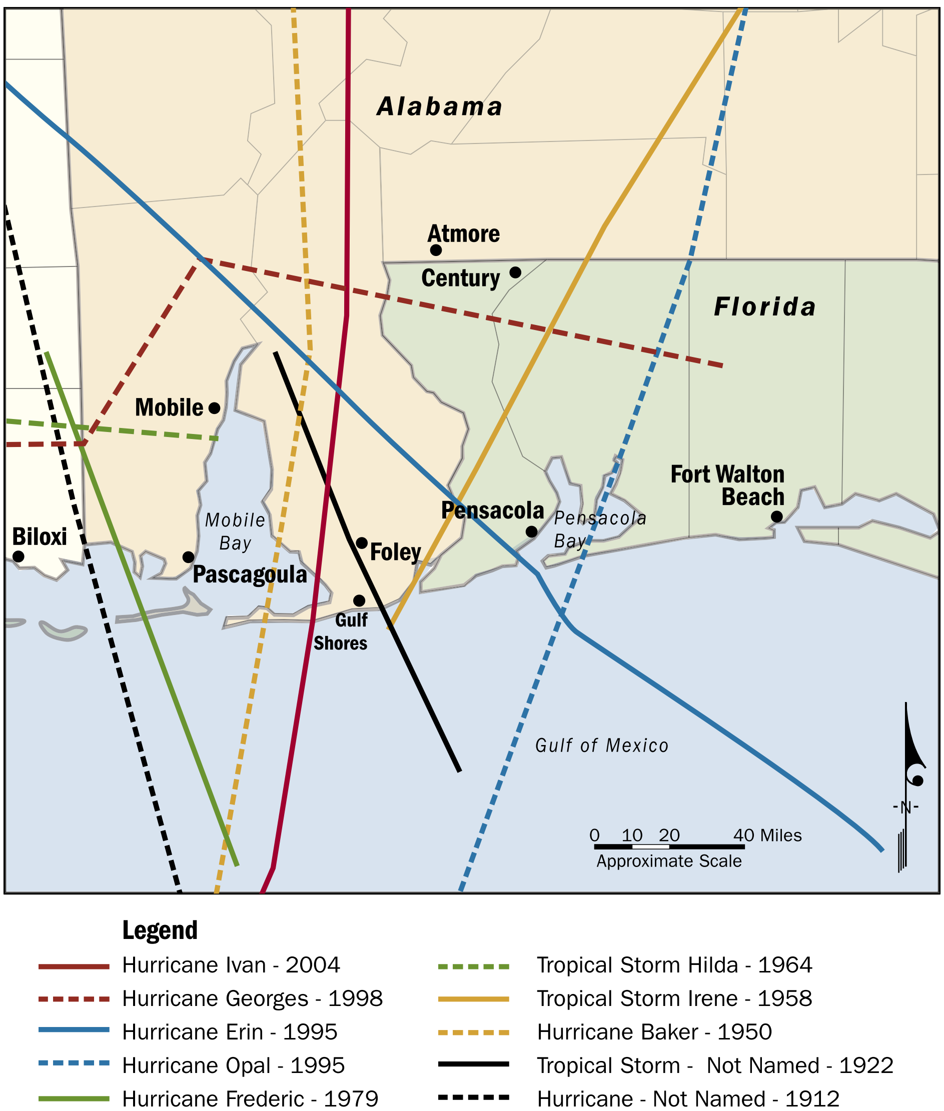
Hurricane Opal, 1995

Opal became a tropical storm near the north-central coast of the Yucatan Peninsula at the end of September 1995. After meandering over the southwest Gulf of Mexico, Opal became a hurricane and gradually accelerated toward the northeast gulf. Early on October 4th, Opal intensified explosively and, according to NHC reports, its maximum sustained winds reached 150 mph. However, the hurricane weakened when its center crossed the coast near Pensacola Beach, Florida. Fifty people died in Guatemala and Mexico, and 9 in the United States. The total damage approached $3.5 billion (year 2000 dollars) and included extensive flood damages.

Hurricane Georges, 1998

Hurricane Georges' 17-day journey resulted in seven landfalls, extending from the northeastern Caribbean to the coast of Mississippi, and 602 fatalities – mainly in the Dominican Republic and Haiti. Georges made landfall during mid-morning of September 25 in Key West, Florida, with maximum sustained winds of 104 mph, according to NHC reports. After moving away from Key West, Georges turned more to the northwest, then north-northwest, and gradually slowed down on September 26 and 27. The hurricane made landfall near Biloxi, Mississippi, on the morning of September 28 with estimated maximum sustained 1-minute winds of 104 mph. After landfall, the system meandered around southern Mississippi and was downgraded to a tropical storm on the afternoon of September 28. The total estimated damage from Georges is $5.9 billion (year 1998 dollars).

Figure 1-22. Historical hurricane and tropical storm paths



1.3 FEMA Mitigation Assessment Teams

Most people know of FEMA for its response to disasters and its assistance to the impacted people. Other important contributions of the agency are the science 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 minimizing the damages and economic impact on the communities where these events occur.

Since the mid-1980s, FEMA has sent MATs to Presidentially Declared Disaster areas to evaluate building performance during hurricanes. The MAT determines the adequacy of current building codes, other construction requirements, and building practices and materials. Based on estimates from preliminary information of the potential type and severity of damages in the affected area(s) and the magnitude of the expected hazards, FEMA determines the potential need to deploy one or more MATs to observe and assess damage to buildings and structures from wind, rains, and flooding associated with the storm. These teams are deployed only when FEMA believes the findings and recommendations derived from field observations will provide design and construction guidance that not only will 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.

1.3.1 Methodology

In response to a request for technical support from the FEMA Disaster Field Offices in Mobile, Alabama, and Orlando, Florida, FEMA's Mitigation Division deployed a MAT to Alabama and Florida to evaluate building performance during Hurricane Ivan and the adequacy of current building codes, other construction requirements, and building practices and materials. Hurricane Ivan approximated a design flood event on the barrier islands in an area with relatively recent development. This provided a good opportunity to assess the adequacy of NFIP floodplain management requirements as well as current construction practices in resisting storm surge damage. FEMA was particularly interested in evaluating damages to buildings in coastal AE Zones where coastal construction methods are not required.

Field investigations to assess building conditions in selected areas affected by the hurricane began on September 18 and concluded on October 3, 2004. The team conducted ground inspections across the width of the storm track from its landfall near Gulf Shores, Alabama, to Oriole Beach, Florida, as shown in Figure 1-23 below. Aerial inspections were conducted from Dauphin Island, Alabama, to the East Pass at Destin, Florida. The aerial inspections were made possible by the Office of the Federal Coordinator for Meteorological Services and Supporting Research (OFCM) which serves as the executive agent for the Working Group for Natural Disaster Reduction and Post-Storm Data Acquisition (WG/NDR/PSDA). FEMA is a member of the WG/NDR/PSDA.

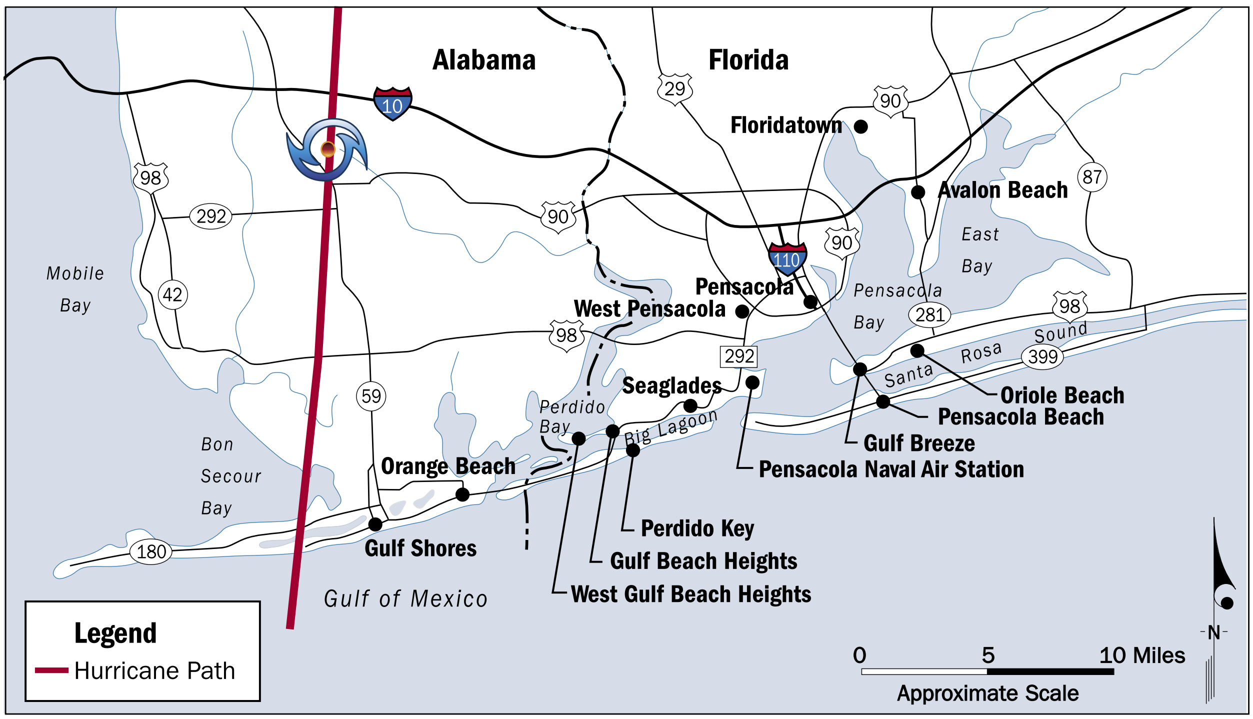


Figure 1-23. Some of the locations visited by the MAT

1.3.2 Team Composition

The MAT included engineers and other experts from FEMA Headquarters and the Regional Office and from the design and construction industry. Team members were drawn from FEMA's database of national experts. Their fields of expertise included structural, wind, and civil engineering; architecture; coastal science; and building codes.

2 Floodplain Management Regulations and Building Codes and Standards

Floodplain management regulations, and building codes and standards, are adopted and enforced to regulate construction in at-risk areas. The floodplain regulations applicable to the affected areas are discussed in Section 2.1. Section 2.2 discusses the building codes and standards used to regulate construction in Alabama and Florida. The building code requirements specific to floods are discussed in Subsections 2.2.1 (Alabama) and 2.2.2 (Florida). Subsections 2.2.3 and 2.2.4 discuss the Alabama and Florida building code requirements specific to wind, respectively.

2.1 Floodplain Management Regulations

All of the communities visited by the MAT participate in the NFIP and have adopted floodplain management regulations that meet or exceed minimum NFIP requirements. Up until 2000, these requirements generally were contained only in community floodplain management ordinances. Starting in 2000, however, flood-resistant provisions and floodplain management requirements began to be incorporated into model building codes (e.g., the International Building Code [IBC], the International Residential Code [IRC], and the National Fire Protection Association [NFPA] 5000).

Thus, if a community in Alabama has adopted a recent edition of these codes (without amending the code to remove the flood provisions), it will have two avenues for enforcing flood-resistant design and construction requirements – the floodplain management ordinance and the building code (see Figure 2-1). More details are contained in Sec. 2.2.1 of this report.

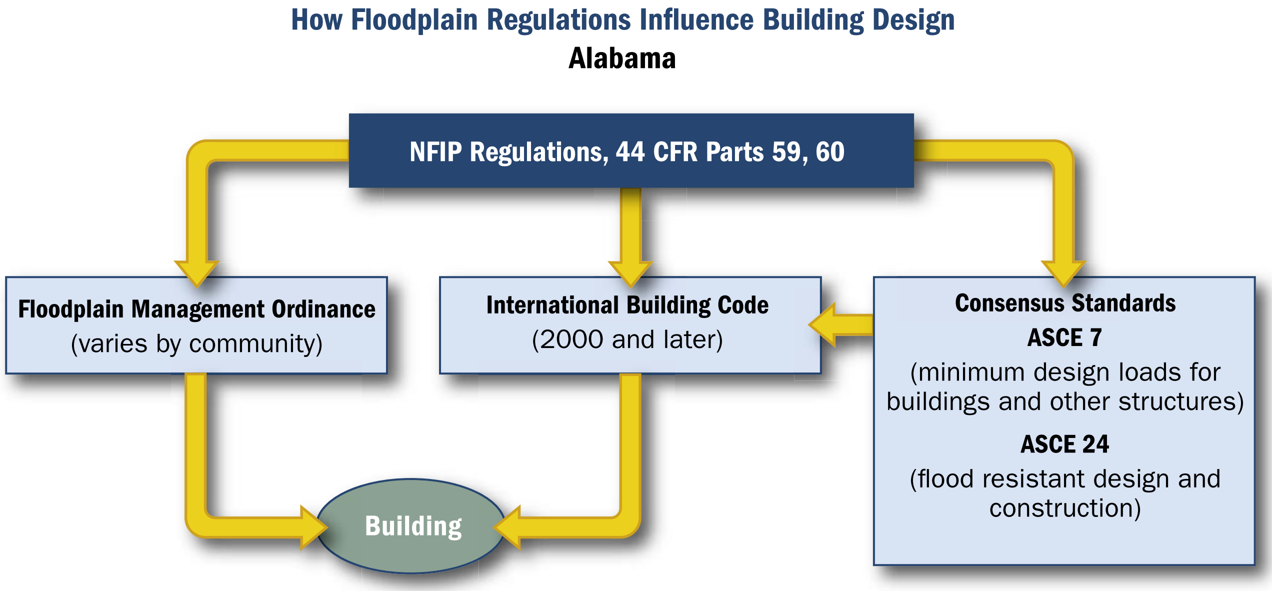


Figure 2-1. Floodplain Management Regulations and Building Design, Alabama

This is not the case in Florida, where the Florida Building Code (FBC) is in place. Chapter 31 of the FBC specifically defers floodplain management issues to the community floodplain management ordinance. However, a companion set of design requirements for coastal construction seaward of Florida's Coastal Construction Control Line (CCCL) has been placed in Chapter 31 of the FBC (see Figure 2-2). Many of the CCCL requirements are similar in nature to NFIP requirements (e.g., pile foundations, elevation above the 100-year wave crest elevation, etc.). More details are contained in Sec. 2.2.2 of this report.

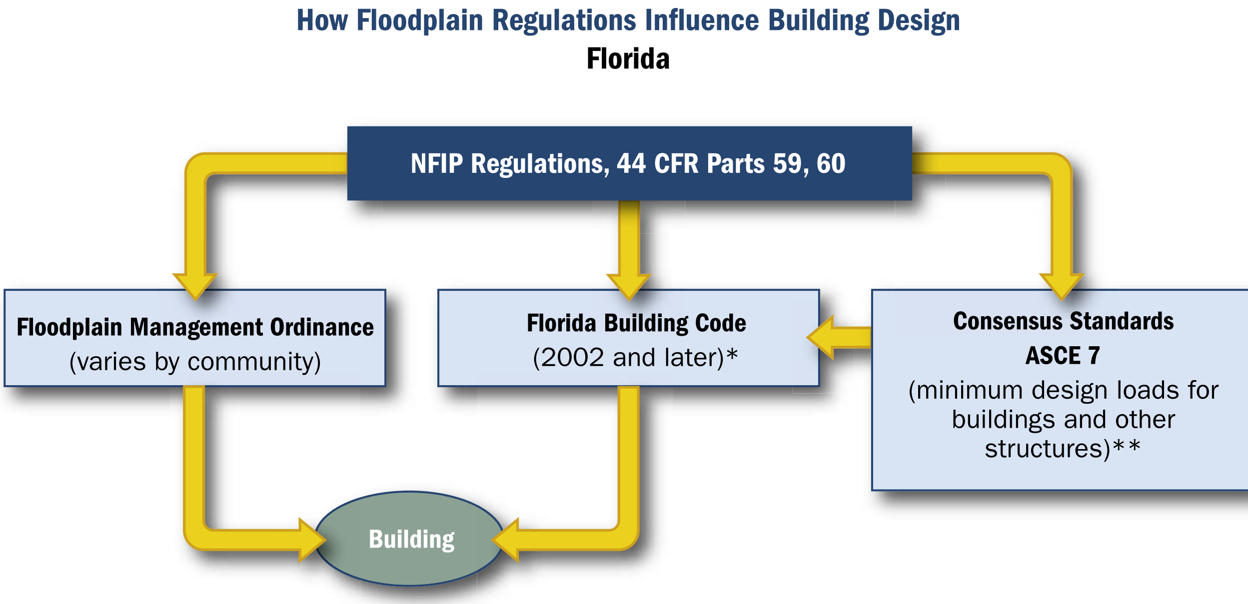


Figure 2-2. Floodplain Management Regulations and Building Design, Florida

* Ch. 31 defers to Floodplain Management Ordinance, contains CCCL requirements

** Flood loads only via load combination, FBC Ch. 16

2.1.1 Flood Studies, Flood Maps, and Floodplain Management Regulations

FEMA provides participating communities with a Flood Insurance Rate Map (FIRM) and Flood Insurance Study (FIS). Several areas of flood hazard are commonly identified on the FIRM. One of these areas is the Special Flood Hazard Area (SFHA), which is defined as the area that will be inundated by the flood event having a 1-percent chance of being equaled or exceeded in any given year. The 1-percent annual chance flood is also referred to as the base flood or 100-year flood. SFHAs labeled as Zone AE have been studied by detailed methods and show Base Flood Elevations (BFEs). SFHAs labeled as Zone VE are along coasts and are subject to additional hazards due to storm-induced velocity wave action. BFEs derived from detailed hydraulic analyses are shown within these zones. (Zone VE is used on new and revised maps in place of Zones V1-V30.) Mandatory flood insurance purchase requirements apply in all SFHAs.[1]

[1] Note: The term “Zone A” is used in this report to represent those flood hazard zones identified on the FIRMs as A1-30, AE, and AO, and “Zone V” is used to represent those flood hazard zones identified on the FIRMs as Zone V1-30 and VE. Where used in this report, these terms are not intended to describe approximate or unnumbered zones (i.e., zones without BFEs). Approximate and unnumbered zones will be identified specifically as such. Further, when the term “BFE” is used in conjunction with “Zone A” in this report, it should be taken to mean the BFE for Zones A1-30 and AE, and the depth number shown on the FIRM for Zone AO.

DESCRIPTION OF FLOOD ZONES

Zones X, B, and C. These zones identify areas outside of the SFHA. Zone B and shaded Zone X identify areas subject to inundation by the flood that has a 0.2-percent probability of being equaled or exceeded during any given year. This flood is often referred to as the 500-year flood. Zone C and unshaded Zone X identify areas above the level of the 500-year flood. The NFIP has no minimum design and construction requirements for buildings in Zones X, B, and C.

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

A Zone. The portion of the SFHA not mapped as a V Zone. Although FIRMs depict A Zones in both riverine and coastal floodplains (as Zones A, AE, A1-30, and AO), the flood hazards and flood forces acting on buildings in those different floodplains can be quite different. In coastal areas, A Zones are subject to wave heights less than 3 feet and wave runup depths less than 3 feet. Flood forces in A Zones in coastal areas are not as severe as in V Zones, but are still capable of damaging or destroying buildings on shallow foundations. For this reason, different design and construction standards are recommended (by the MAT and others) in coastal A Zones.

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

The zone designation and the BFE are critical factors in determining what requirements apply to a building and, as a result, how it is built. For example, the NFIP minimum requirements for buildings built in Zone VE (Coastal High Hazard Areas) are: 1) the building must be elevated on pile, post, pier, or column foundations, 2) the building must be adequately anchored to the foundation, 3) the building must have the bottom of the lowest horizontal structural member at or above the BFE, and 4) the building design and method of construction must be certified by a design professional. The area below the BFE must be free of obstructions; if enclosed, the enclosure must be made of lightweight wood lattice, insect screening, or breakaway walls.

In the Zone AE, the NFIP requires that the top of the lowest floor of a building must be at or above the BFE; however, there are no standards for foundations other than the general performance standard that the building be anchored to resist floatation, collapse, and lateral movement. In an A Zone, non-residential buildings can be flood-proofed with their walls made substantially impermeable to the passage of floodwater.

For buildings built in Zones B, C, and X (areas of moderate or minimal hazard from the principal source of flood in the area), there are no NFIP building requirements, even for buildings built on barrier islands, because these buildings are outside of the SFHA.

Many of the buildings on shallow foundations that failed in Hurricane Ivan were built in areas that were designated as Zone B, C, or X at the time of construction. These areas were exposed to V-Zone conditions during Hurricane Ivan as a result of long-term erosion or the erosion that occurred during the storm.

2.1.2 Higher Regulatory Standards

One of the goals of the MAT was to investigate building failures in mapped Zones AE, B, C, and X. The MAT determined that some of the communities visited have adopted more stringent design and construction requirements for these zones (e.g., Santa Rosa Island Authority), and that structural damage to newer buildings in these communities was generally less than in communities that have not adopted higher standards.

The MAT also observed a large number of buildings in all flood hazard zones (VE, AE, B, C, X) that were constructed (voluntarily) to higher than required elevations with pile foundations. These structures generally sustained far less flood damage than nearby structures constructed to the minimum NFIP requirements. This was especially true in Zone AE, where buildings were constructed several feet above the BFE on pilings, thus reinforcing the benefits of using V-Zone design and construction techniques in the coastal A Zone.[2]

2.1.3 Relating Observed Flood Damages to the FIRMs

FEMA's methodologies for mapping have evolved over the years due to improvements in our understanding of coastal processes and the development of new technologies. Over a 30-year period, there have been at least four generations of FIRMs in the area affected by Hurricane Ivan. As methodologies have evolved, BFEs have gone up or down, and Zones VE, Zones AE, and Zones X have expanded or contracted. The differences in damages between adjacent buildings are due to differences in how the buildings were constructed (i.e., building elevations), and some of this can be explained by the flood hazard zone and BFE that were in effect at the time the buildings were constructed.

> FEMA recently announced an update of the coastal flood hazard mapping guidelines. The guidelines will promote more accurate flood studies by incorporating consistent methodologies and improved technological processes. Guidelines are being developed first for the Pacific Coast, with the Atlantic and Gulf Coasts to follow.

The MAT determined that the area flooded by Ivan exceeded the SFHA shown on the effective FIRMs for many communities, from Gulf Shores, Alabama, to Okaloosa County, Florida, which is reflected in Table 1-2 and based on the current FIRMs and the High Water Marks

[2] As a working definition, consider the coastal A Zone to be that area near the shoreline with exposure to breaking wave heights between 1.5 and 3.0 feet. Another way to identify the coastal A Zone is to identify areas near the shoreline and exposed to waves, where base flood stillwater depths are between approximately 2 feet and 4 feet, or where the ground lies between 3 feet and 6 feet below the BFE.

(HWMs) as shown in Figures 1-7 through 1-17. The coastal FIRM changes over the years likely resulted in variations in lowest floor elevations and construction practices since most buildings tend to be constructed to the minimum regulatory requirements.

During its investigations, the MAT researched the flood hazard mapping for two locations in Baldwin County, Alabama; three locations in Escambia County, Florida; and one location in Santa Rosa County, Florida. The results of some of this research (for one location in Baldwin County and the location in Santa Rosa County) are provided in Sec. 2.1.3.1 and 2.1.3.2, respectively.

2.1.3.1 Baldwin County, Alabama

The effective FIRM and FIS for Baldwin County are in countywide format and are dated June 17, 2002. Table 2-1 shows the 2002 Baldwin County 100-year stillwater elevations and BFEs along the Gulf of Mexico shoreline near Orange Beach and Gulf Shores.

Table 2-1. Baldwin County Stillwater Elevations and BFEs (2002)

Flooding Source	FIS Stillwater Elevations (feet*)	BFEs (feet*)
Gulf of Mexico	9.3 – 10	10 - 15**

* Elevations are referenced to NAVD 1988
** Includes wave setup of 2.2 feet

The MAT conducted a series of comparisons to assess flood map changes that occurred with the various map revisions (see Figure 2-3 for a typical comparison). These changes are significant because they would have influenced building construction while the maps were in place. Three sets of maps were compared: the Baldwin County Flood Hazard Boundary Map (FHBM) from October 1983 (based on the NOAA tide gauge frequency study); the January 1985 FIRM that was based on the TTSURGE joint probability analyses; and the latest FIRM, dated June 2002.

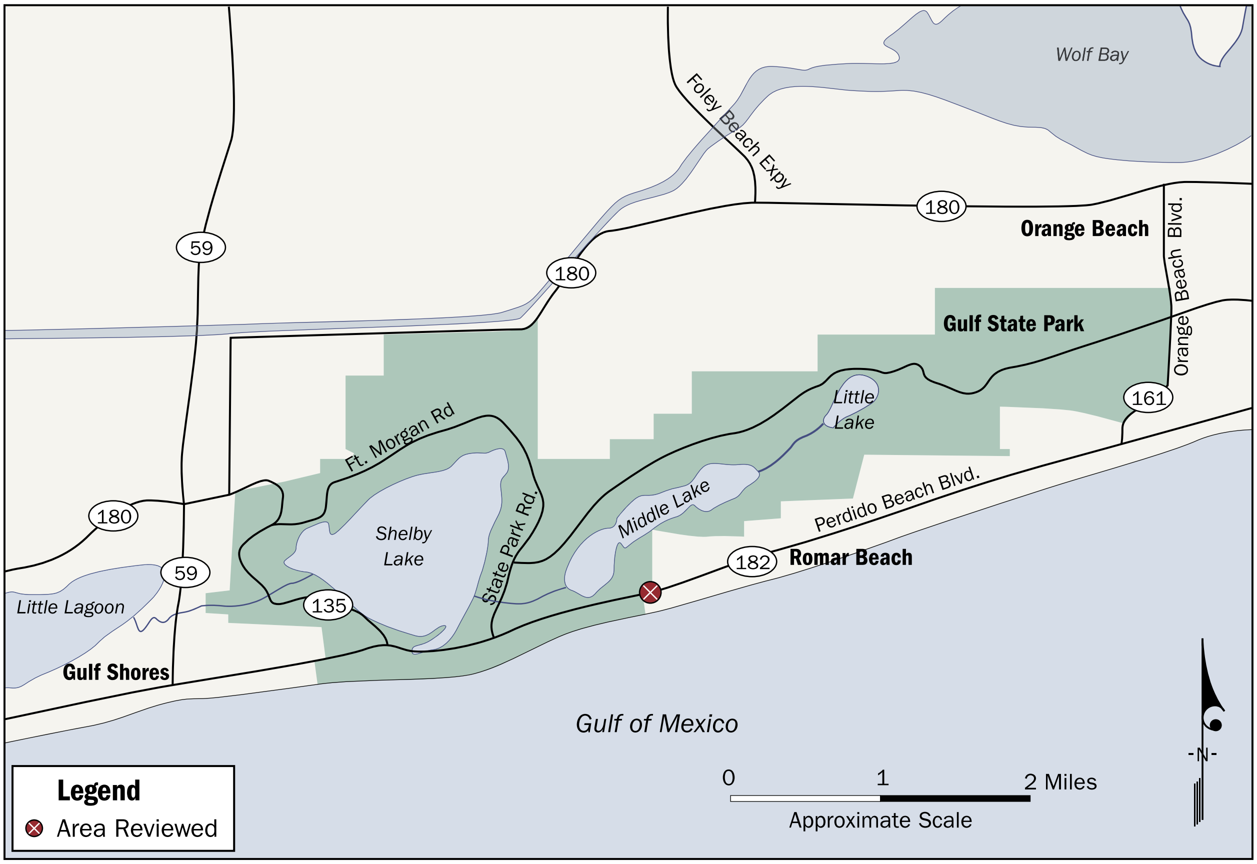
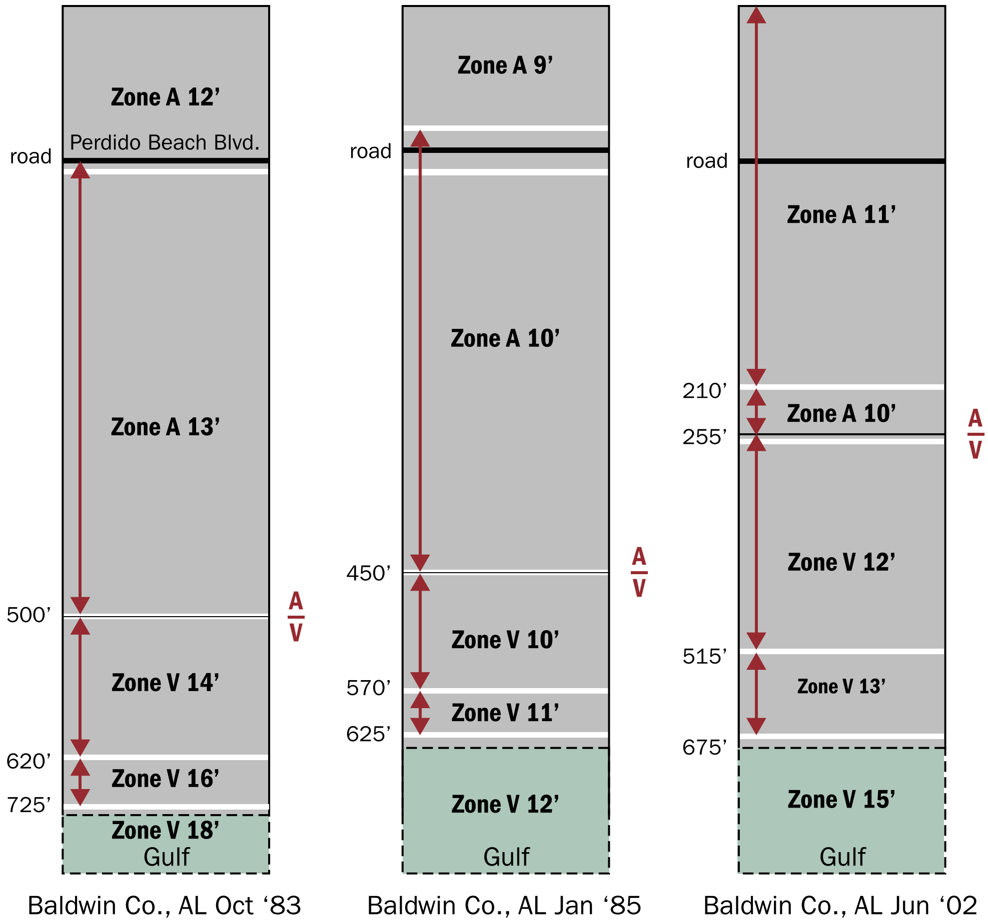


Figure 2-3. Baldwin County location near the State Park/Orange Beach boundary (see red dot) where the historical FIRMs (1983, 1985, 2002) were reviewed.

During the 2002 revision, wave setup of 2.2 feet was added along the open coast barrier islands, and the primary frontal dune was included as a V-Zone mapping criterion. Differences between the 2002 and the previous (1985) FIRM include: 1) BFEs on the barrier islands generally increased 2 to 3 feet and 2) the V-Zone width increased approximately 200 to 250 feet. The 2002 revisions outside the barrier islands were primarily to reflect updated topographic information (the BFEs did not change significantly in these areas).

One of the areas the MAT researched in Baldwin County is located at the west end of Orange Beach at the State Park boundary (see red dot in Figure 2-3). This area is located on FIRM panel 01003C0819 K of the current maps. The flood zone boundaries were measured from the centerline of Perdido Beach Boulevard on the 1983, 1985, and 2002 FIRMs at this location. Figure 2-4 illustrates the flood zone changes here, plus the decreasing and then increasing BFEs over time.

Figure 2-4. Comparison of FIRMs over time, at the State Park boundary, west end of Orange Beach (Orange Beach, Baldwin County, Alabama)



Figures 2-5, 2-6, and 2-7 illustrate the nature of flood and erosion damage at this location during Ivan. While the ages of the destroyed and surviving buildings are not known, most were likely built after Hurricane Frederic in 1979. A review of the damage and the FIRMs also indicates the following:

- Houses built to the 1985 BFEs and foundation requirements were generally at a disadvantage compared to those houses built to the 1983 and 2002 requirements.
- The surviving houses in Figure 2-5 were all built on pilings, even though it appears NFIP regulations did not require construction on pilings at those locations (the houses are within approximately 250 feet from the road, where all the FIRMs show Zone A).
- The surviving houses were all near the rear and middle of the beach where wave effects would have been reduced somewhat. None of the houses on the front row in this area survived.

- The surviving houses in Figure 2-5 were likely built with the lowest floor above the BFEs shown on the FIRMs. The CHWM figures in Chapter 1 show Ivan stillwater elevations of approximately 12 to 14 feet NAVD in the area, and wave heights could have been several feet higher yet (the highest BFE within 600 feet of the road was 14 feet NAVD between 1983 and 1985).

Figure 2-5.
Ivan damage at the west boundary of Orange Beach. Houses are missing from piles and piles are broken near the ground level. (See Figures 2-6 and 2-7 for ground photos.) (Orange Beach/State Park boundary)

Figure 2-6.
Ground photo of the same area as Figure 2-5. At this location, all houses seaward of the blue house (circled) were destroyed by Ivan. Some houses (arrow designates the left house in Figure 2-5) washed landward largely intact. Other houses were completely destroyed. The likely cause was pile breakage due to inadequate pile size and/or insufficient elevation of the houses, combined with large lateral (flood and wind) loads acting on the houses.

Figure 2-7.
Building on the right side of Figure 2-5 survived, although it sustained destruction of the lower enclosed area and suffered extensive internal damage due to wind (soffit loss, window breakage, rainfall penetration).

MAT examination of larger buildings in Orange Beach (see section 3.1.2) confirmed these general findings: elevation above the BFE on an adequate pile foundation was the key to buildings successfully resisting flood forces during Ivan.

2.1.3.2 Santa Rosa County, Florida

The effective FIRM and FIS for the unincorporated areas of Santa Rosa County, Florida, are dated July 17, 2002. The most recent coastal revision was first reflected on the January 19, 2000, FIS and FIRM. For this revision, updated coastal flooding analyses were prepared for the open coast shorelines of the Gulf of Mexico, Santa Rosa Sound, and Pensacola Bay up to U.S. Route 90. The revision incorporated primary frontal dune analysis, updated wave action, and provided a new shoreline and the effects of coastal erosion. Wave setup of 2.5 feet was added to the open coast stillwater elevation. The July 17, 2002, FIS and FIRM were produced to reflect changes in community boundaries; there was no revised flooding analysis provided as part of this revision.

Table 2-2 presents stillwater elevations from the Santa Rosa County FIS dated July 17, 2002.

Table 2-2. Santa Rosa County Stillwater Elevations

Flooding Source	FIS Stillwater Elevations (feet*)	BFEs (feet*)
Gulf of Mexico	10.5**	11-16
Pensacola Bay	4.9 – 5.7	5-8
Santa Rosa Sound	8.0	8-12

* Elevations are referenced to NGVD 1929.
** Includes wave setup of 2.5 feet.

The MAT conducted a detailed comparison to assess flood hazard zone changes over time in Santa Rosa County, Florida, along Bay Street in the Oriole Beach area (see Figure 2-8). The zero station for this comparison was taken at the centerline of the intersection of Bay Street and Harrison Avenue. The MAT used two sets of maps: the Santa Rosa County FIRM dated November 1985 and the FIRM dated January 2000, the latter of which reflects the same flood hazards shown on the current effective FIS dated July 17, 2002. Figure 2-9 shows how the flood zones and BFEs changed between the 1985 and 2000 FIRMs. The major changes are an increase in BFEs seaward of Bay Street of up to 3 feet and an inland expansion of the SFHA of approximately 1,500 feet (with BFEs of 8 and 9 feet in the newly mapped inland areas).

Figure 2-8.
Santa Rosa County locations where historical FIRMS were reviewed. The easternmost dot (just northwest of Bay Street and Harrison Avenue) shows the reviewed Santa Rosa County location, and the other dots reflect building locations discussed later in this section.

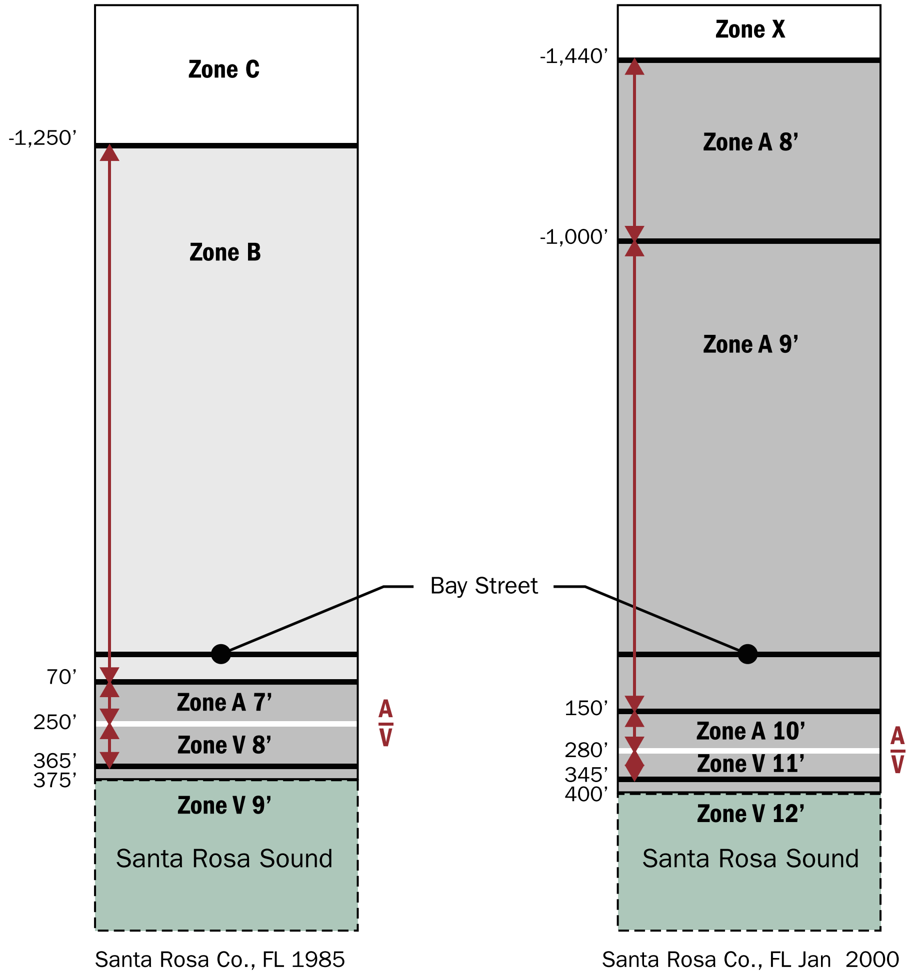


Figure 2-9. Santa Rosa County: Comparison of FIRMs at the centerline of the intersection of Bay Street and Harrison Avenue

Figure 2-10 shows some of the houses in the newly mapped area. These buildings are on ground estimated at +/- 7 feet NGVD, approximately 700 feet north of Bay Street (1,000 feet from Santa Rosa Sound) and within 1,000 feet of Harrison Avenue. The FIRMs in Figure 2-9 show the changes that have occurred in the vicinity. The houses were constructed in flood hazard Zone B, outside the SFHA shown on the 1985 FIRMs, but had 2 to 4 feet of water inside as a result of Hurricane Ivan. Some property owners said their lenders had not notified them when the flood maps changed, and they had not purchased flood insurance.

Many houses constructed along the west end of Bay Street (approximately 1 mile west of Harrison Avenue) were older, pre-FIRM houses, and were likely built on land with grade elevations of 5 to 6 feet NGVD. These houses were later mapped by the 1985 FIRM as Zone B or Zone AE with a BFE of 7 feet NGVD and by the 2000 FIRM as Zone AE with a BFE of 9 feet NGVD. Figure 2-11 shows a typical house along the west end of Bay Street that was damaged heavily during Ivan. The house was most likely in Zone B at the time of construction (but is currently mapped as Zone AE elevation 9 feet NGVD). The figure shows significant damage due to storm surge and wave and floating debris impacts, which are typical of V-Zone conditions. The HWM (stillwater) in this area was approximately 11 feet, as shown on Figure 1-12. Based on FEMA's current flood hazard mapping methodology, the 11-foot stillwater elevation and a ground elevation of approximately 6 feet would yield a wave crest elevation of approximately 13 to 14 feet NGVD during Ivan. The house shown in Figure 2-11 undoubtedly experienced V-Zone conditions during Ivan.

Figure 2-10.
Typical houses at Birdseye Circle, which had 2 to 4 feet of flooding inside the houses. This area was mapped as being outside the SFHA on the 1985 FIRM, which likely governed the construction standards that were followed when the house was built.

Figure 2-11.
Typical damage to houses along Bay Street that were impacted by surge and wave effects from Santa Rosa Sound. This house on the west end and south side of Bay Street was constructed with a slab-on-grade foundation. The house was either pre-FIRM or constructed in Zone B (1985 FIRM) and is currently mapped as Zone AE with a BFE of 9 feet. The house undoubtedly experienced V-Zone conditions. (Santa Rosa County)

Figure 2-12 is an aerial photograph showing houses along Bay Street (above the canal) that were impacted by storm surge, waves, and floodborne debris. These houses were likely constructed in Zone B, according to the 1985 FIRM; however, many were likely built prior to the 1985 FIRM. Although the surge and wave impacts from Hurricane Ivan in the area produced V-Zone conditions, the current FIRM shows these houses in Zone AE with a BFE of 9 feet.

Figure 2-12 also shows houses constructed along Santa Rosa Sound that experienced different levels of damages based on the elevations of their lowest floors. The white house on the bottom right was constructed above the BFE on a pile foundation and higher than other nearby houses, which were constructed on a slab or stem wall foundation. The lower houses were severely damaged by storm surge, waves, and debris impacts. The white house and other nearby pile-supported houses along this shoreline appear to have been constructed several feet above the BFE, which prevented significant flood damages; based on elevation certificates, two of the pile-supported houses in this area were constructed to an elevation of 15 feet, over 5 feet above the minimum elevation requirement.

Figure 2-12.
Aerial view of houses along Bay Street (above the canal) and Santa Rosa Sound that were heavily damaged by storm surge and wave impacts. The circled house is the same house shown in Figure 2-11. The house on the lower left is the same house shown in the background of Figure 2-13. Houses elevated above the BFE on pilings (see arrow) sustained far less flood damage than houses at lower elevations.

Figure 2-13.
The house in the foreground was constructed on piles and had minimal flood damage during Ivan, although it lost a pile support for the deck. The house in the background (see arrow) was constructed at much lower level and sustained significant flood damage throughout the first floor. The damaged house is also shown on the left side of Figure 2-12.

Figures 2-14 and 2-15 show a house on Santa Rosa Sound that was heavily damaged by waves and floodborne debris. The house was likely constructed when the area was mapped as Zone B, but the effective FIRM shows the house in Zone AE with a 10-foot BFE. Like the other nearby houses, this house undoubtedly experienced V-Zone conditions during Ivan. Had this house been elevated on a substantial pile foundation, as was the house west of the canal entrance (see arrow) or the white house in Figure 2-12, the flood damage would probably have been minimal.

Figure 2-14.
The house on the right (circled), which is at the west end of Del Mar Drive, south of Bay Street, along the Santa Rosa Sound, was heavily damaged by storm surge and wave and debris impacts. The same house is shown in Figure 2-15. The effective FIRM shows the house in a Zone AE with a BFE of 10 feet. Note minimal flood damage occurred to the newer, pile-elevated house west of the canal entrance (arrow).

Figure 2-15.
This house, located on Santa Rosa Sound and circled in Figure 2-14, was severely damaged by surge, wave, and debris impacts. The large timber that washed into the house reportedly originated across the Sound in Pensacola Beach

These examples point out several important points:

- The changes in flood hazard zones and BFEs over time likely contributed to the reduction of flood damage experienced by newer houses, but given a storm like Ivan with flood levels above the BFE, the new maps alone could not ensure building survival.
- Elevating newer houses on pilings several feet above the BFE was also central to the success of these buildings. Elevating the lowest floor above the BFE (freeboard) contributed greatly to the reduction in flood damage, especially in areas shown as Zone AE on the effective FIRM that experienced V-Zone conditions during Ivan.

2.2 Building Codes and Standards

Alabama adopts building codes on a statewide basis only for state-owned buildings, such as schools. Local jurisdictions determine the adoption of building codes for private buildings. All Alabama jurisdictions have traditionally adopted editions of the Standard Building Code (SBC) published by the Southern Building Code Congress International. The City and County of Mobile had adopted the 2000 International Building Code (IBC) on May 15, 2001 (City of Mobile) and in 2000 (County of Mobile).[3] The City of Orange Beach adopted the 2003 IBC in the summer of 2004. The City of Gulf Shores adopted the 2003 IBC as an emergency measure after Hurricane Ivan to improve the quality of the reconstruction. Most other affected Alabama communities such as those in unincorporated Baldwin County were still enforcing the 1997 or 1999 SBC at the time of Hurricane Ivan.

In the Florida Panhandle, the SBC – with local amendments – was used to regulate construction until early 2002. By March 2002, the FBC 2001 Edition had been adopted statewide. The FBC, administered by the Florida Building Commission, governs the design and construction of residential and non-residential (commercial, industrial, critical/essential, etc.) buildings in Florida. In December 2004, the Florida Building Commission completed the 2004 Edition of the FBC. The 2004 Edition replaces the 2001 Edition and will be adopted statewide by administrative rule in the fall of 2005.

2.2.1 Flood Requirements in Building Codes and Standards – Alabama

Flood-resistant construction requirements in coastal Alabama are located in the building codes (IBC, IRC), which themselves reference community floodplain management ordinances and consensus standards with flood requirements (i.e., Minimum Design Loads for Buildings and Other Structures published by the American Society of Civil Engineers 7 (ASCE 7) and Flood-Resistant Design and Construction (ASCE 24)). One additional program affects coastal construction in Alabama: the CCCL, which acts as a seaward limit for construction. Details for each are provided below.

[3] The International Code Council (ICC) was formed to bring together the three model code groups and their respective codes – ICBO (*Uniform Building Code*), BOCA (*National Building Code*), and SBCCI (*Standard Building Code*) - under a unifying code body in support of common code development. In 2000, the ICC developed a family of codes, including the *International Building Code* (IBC) and the *International Residential Code for One- and Two-Family Dwellings* (IRC).

2.2.1.1 Flood Provisions in the IBC (2003)

The IBC is applied to multi-family buildings (with a few exceptions, which are governed by the IRC), and to non-residential buildings. Most of the mandatory flood provisions are contained in ***Section 1612 (Flood Loads)***, but others also occur in the Code related to lowest floor elevation inspection, flood resistance materials, accessibility, ventilation, and elevators.

2.2.1.2 Flood Provisions in the IRC (2003)

The IRC applies to one- and two-family dwellings and to some townhouses. Most of the mandatory flood provisions are contained in ***Section R323 (Flood-Resistant Construction)***, but others also occur in the Code related to utilities, design, and floodplain construction.

2.2.1.3 Flood Requirements in ASCE 7

Design loads used by the IBC (2003) are taken from ASCE 7 (2002). The following sections of ASCE 7 deal with flood:

- Section 2.3 (Load Combinations, including different load combinations for V Zones and coastal A Zones)
- Section 5.3 (Flood Loads, which covers hydrostatic, hydrodynamic, and wave and impact loads; and which specifies load criteria for breakaway walls)

Flood design loads, per se, are not specified by the IRC (2003) since it is a prescriptive code. The IRC refers the designer to the local jurisdiction for flood requirements. The IRC makes use of environmental hazard maps (wind, seismic, snow, etc.), which are largely consistent with ASCE 7 hazard maps.

2.2.1.4 Flood Requirements in ASCE 24

ASCE 24 is a standard devoted entirely to flood-resistant design and construction. It is referenced by Section 1612 of the IBC (2003), which states: "The design and construction of buildings and structures in flood hazard areas, including areas subject to high velocity wave action, shall be in accordance with ASCE 24."

The IRC does not reference ASCE 24; thus, communities would have to reference ASCE 24 directly for its provisions to apply to small residential buildings. However, Section R323 of the IRC states that buildings in floodways shall be designed in accordance with the IBC, thereby mandating use of ASCE 24 for buildings in floodways.

The 1998 edition of ASCE 24 was the first edition produced and, by default, was the edition referenced by the 2003 IBC. However, a new edition of ASCE 24 (2005 edition) is forthcoming, and the 2005 edition has some significant changes to the earlier edition. The 2005 edition of ASCE 24 will be referenced by the 2006 edition of the IBC.

2.2.1.5 Coastal Construction Control Line (Alabama)

In addition to the NFIP and building code requirements, buildings constructed along the Gulf shoreline may also be subject to CCCL regulations (Alabama Administrative Code, Division 335-8) administered by the Alabama Department of Environmental Management (ADEM), Coastal Area Management Program, except in the City of Gulf Shores, which administers the CCCL within its jurisdiction. The CCCL was established in the mid-1980s and has not been revised since that time.

In Alabama, the CCCL is a line of prohibition, seaward of which no construction (including substantial improvement of an existing structure) or excavation is allowed. Any proposed building on a parcel intersected by the CCCL must obtain a permit from ADEM (or approval from Gulf Shores). CCCL variances may be obtained in some instances where the property owner can demonstrate that enforcement of the CCCL provisions would constitute a taking. CCCL coordinates and maps are available from ADEM and Gulf Shores.

When construction on a parcel intersected by the CCCL involves commercial or multi-family structures (e.g., a hotel, motel, or condominium), the permitting is more involved than for a single-family or duplex-type structure. Commercial and multi-family CCCL permits require an Environmental Impact and Natural Hazards Study that includes:

- A wave study that addresses the flood hazard and erosion potential using eroded beach profiles for pre- and post-developed conditions,
- Location and delineation of velocity zones, and
- Analysis of the project's potential to significantly increase the likelihood that damage will occur from floods, hurricanes, or storms.

Commercial and multi-family CCCL permits also require a Beach and Dune Enhancement Plan that includes provisions for dune walkovers, sand fencing, and vegetation and dune maintenance.

Bulkheads, retaining walls, or similar structures are not permitted on parcels intersected by the CCCL unless it can be demonstrated that: 1) the bulkhead or retaining wall is landward of the CCCL and it is necessary to protect and ensure the structural integrity of an existing or previously permitted structure, and 2) there are no other feasible non-structural alternatives.

2.2.2 Flood Requirements in Building Codes and Standards – Florida

Flood-resistant construction requirements in coastal Florida are located primarily in community floodplain management ordinances and in Chapter 31 of the FBC (for buildings seaward of the Florida CCCL).

2.2.2.1 Flood Provisions in the FBC (2004 Edition)

Major flood provisions contained in the 2004 Edition of the FBC address siting requirements for nursing homes, hospitals, educational facilities, and shelters as well as general flood-resistant design requirements. Section 1605.2.2 of the FBC states that flood loads shall be determined by the provisions of ASCE 7. There is no reference in the FBC to ASCE 24.

The Florida Building Code – Residential Volume (2004) is a new document that is also under development at this time. Like the FBC, Section R301.2.4 of the residential volume defers most matters related to flood-resistant construction to the community floodplain management ordinance.

2.2.2.2 Coastal Construction Control Line (Florida)

The CCCL is established by the Florida Department of Environmental Protection (FDEP) and describes the landward boundary of "that portion of the beach-dune system which is subject to severe fluctuations based on a 100-year storm surge, storm waves, or other predictable weather event" (Florida Statutes, Ch. 161). As a practical matter, the state defines the CCCL position as being one of the following:

- the landward limit of storm-induced erosion (where upland elevations are substantially greater than the 100-year still water level)
- the landward limit of a 3.0 foot wave propagating at the 100-year stillwater level (where upland elevations are low and profile inundation occurs)

- at the landward limit of overwash (in instances where the profile is not inundated but where wave overtopping and sediment deposition occur), or
- at the landward toe of the coastal barrier dune structure impacted by, but not destroyed by, erosion accompanying the 100-year stillwater level and storm waves.

The Florida CCCL is generally situated farther landward than the Alabama CCCL, and unlike the Alabama CCCL, the Florida CCCL is a line of jurisdiction (not prohibition), seaward of which a permit is required from the FDEP and seaward of which special provisions of Section 3109 of the FBC apply. The CCCL permit from FDEP addresses building siting and beach/dune protection issues, while Section 3109 of the FBC addresses building design and construction requirements. The Florida CCCL has been re-established and moved over the years, unlike the Alabama CCCL.

Building requirements seaward of the Florida CCCL are in many ways similar to NFIP V-Zone requirements: elevation above the 100-year wave crest on a pile foundation; design for simultaneous flood and wind loads, including the effects of storm-induced erosion; aside from the foundation, construction below the lowest floor must be frangible (i.e., breakaway); etc. However, the State has established its own 100-year wave crest elevations, which, in most cases, are higher than FEMA's BFEs along beachfront areas.

A comparison of NFIP flood hazard zones and the CCCL in Florida shows that the CCCL lies landward of the V-Zone boundary in some locations and seaward in others. In areas where the CCCL is seaward of the V-Zone boundary, the higher of the BFE and the state's wave crest elevation will govern (subject to local freeboard requirements).

In the areas where the CCCL is more landward than the V-Zone boundary, CCCL provisions will generally control design and construction in any A Zones seaward of the CCCL (again, subject to higher standards imposed by a community). There may be some inconsistencies, however, about which designers should consult building officials and floodplain managers (concerning, for example, whether flood openings are required in CCCL-mandated breakaway walls in mapped A Zones seaward of the CCCL).

2.2.3 Wind Requirements in Building Codes and Standards – Alabama

In Alabama, the 1997 and the 1999 SBC was the code in effect for most impacted counties. The exceptions are the City and County of Mobile; they adopted the 2000 IBC/IRC on May 15, 2001 (City of Mobile) and in 2000 (County of Mobile).

2.2.3.1 Comparing Design Wind Speeds

Current codes and standards (the FBC, the IBC, and ASCE 7) standardize the wind speed measure as the 3-second peak gust. This differs from the fastest-mile wind speed measure that was previously used by the SBC and ASCE 7 and the wind speed measure of 1-minute sustained that is used in the Saffir-Simpson Hurricane Scale presented in Chapter 1.

The IBC specifies higher wind speeds for coastal Alabama than any of the previous editions of the SBC. Baldwin County, Alabama, is approximately 75 miles long in the north-south direction perpendicular to the Gulf of Mexico coast line. Mobile County is similar at 65 miles long. Therefore, there is great variation in the design wind speeds from the coastal, southern end of the counties to the inland, northern end. At the time of Hurricane Frederic in 1979, the SBC design wind speeds were fastest-mile speeds varying from 110 mph at the coast to 90 mph inland, the equivalent of 3-second peak gust speeds are 130 mph at the coast to 105 mph inland. The 1985 SBC modified the required speeds to match those in American National Standards Institute (ANSI) A58.1 -1982, the predecessor to the ASCE *Minimum Load Standard for Buildings and Other Structures* (ASCE 7). For Baldwin and Mobile Counties, that range of speeds was 85 to 100 mph fastest-mile, or 100 to 120 mph measured as a 3-second peak gust. The wind speed map remained unchanged for all the subsequent editions of SBC, including the last edition in 1999. The maps used by the 2003 IBC are taken directly from ASCE 7-02. The 3-second peak gust wind speeds for Baldwin and Mobile Counties are 115 mph (north end) to 150 mph (at the coast) as shown in Figure 2-16. Table 2-3 contains a summary of the design wind speeds for the counties in Alabama visited by the MAT. Table 2-4 (in the next section) presents a summary of the design wind pressure on wall and roof areas for a typical residence in Gulf Shores. Exposure B is assumed for the IBC calculations. In instances where Exposure C design coefficients are applicable, the tabulated pressures would be approximately 30 percent higher than these values. SBC loads were based on Exposure B, but no differentiation was made for more open sites.

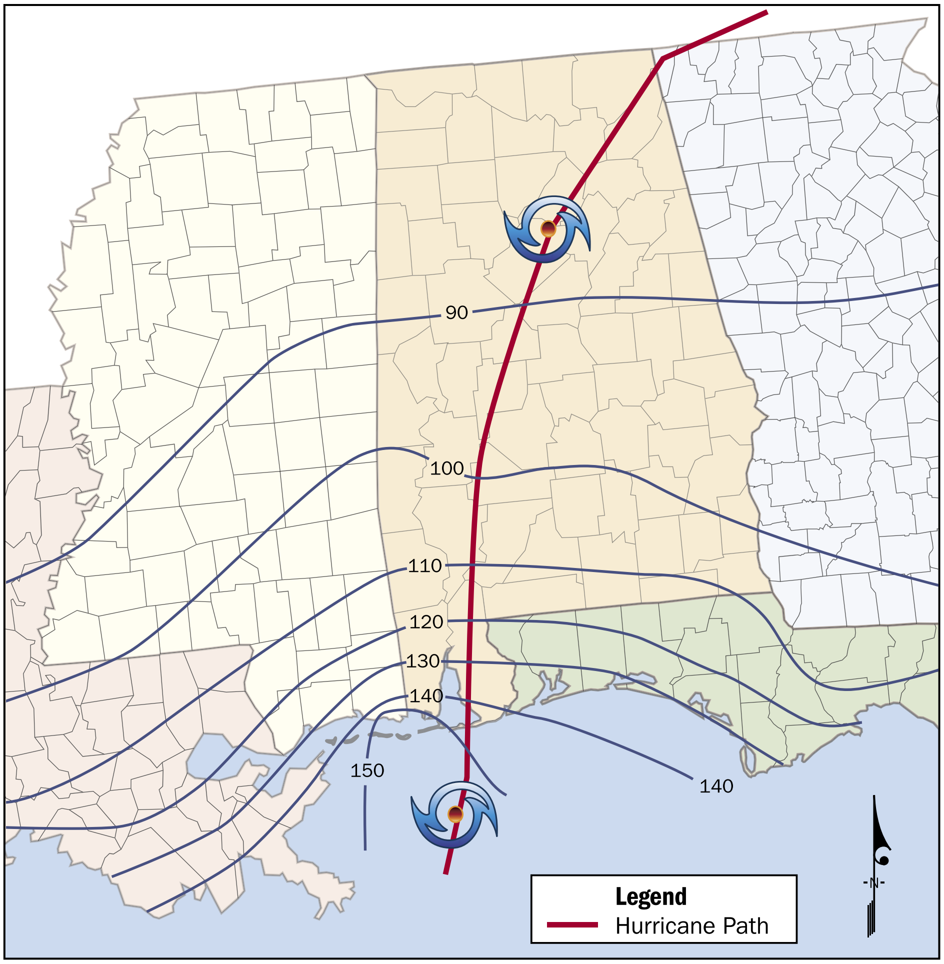


Figure 2-16.
Design Wind Speeds from IBC 2003 and ASCE 7-98 and 02

Table 2-3. Basic Design 3-Second Gust Wind Speeds (For Baldwin and Mobile Counties, Alabama)

County	Standard Building Code 1979 Edition*	Standard Building Code 1997 Edition*	International Building Code 2003 Edition and ASCE 7-98 and later
Baldwin	105-130 mph	100-115 mph	114-150 mph
Mobile	105-130 mph	100-115 mph	117-150 mph

* Code wind speeds reported as fastest-mile wind speeds in the SBC were converted to 3-second gust for comparison.

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.

2.2.3.2 Comparing Design Wind Pressures

The methodology required for calculating wind loads in the 2003 IBC is that prescribed in Chapter 6 of ASCE 7-02. Using ASCE 7 for determination of wind loads ensures designers are using state-of-the-art methodology in wind-load analysis to calculate wind loads. The ASCE 7-02 provisions provide the same loads as ASCE 7-98 for the cases discussed previously. In addition to the improved load computations provided by ASCE 7, the IBC also has requirements for windborne debris protection of glazing, and improved component and cladding requirements, particularly for roof coverings and accessories. It is evident that the design wind pressures have been increasing for components and cladding with each new code development over the last 25 years. This increase was due to observed failures and damage to buildings (similar to MAT observations in Gulf Shores and Orange Beach) at these exterior building systems when subjected to a design level wind event such as Hurricane Ivan.

For example, the required pressure for corner zones of roofs has increased more than 3 fold over that period. Corner zones did not even exist in the 1979 SBC. The 1979 SBC did not prescribe higher loads at roof perimeters or corners, or at wall corners. These increases are a reflection of the findings of both wind tunnel research full-scale measurements and post-storm investigations. The pressures have increased most dramatically on the parts of buildings that consistently experienced wind-induced damage. In addition, wind speeds in this region of the Gulf Coast increased as a result of new modeling of the hurricane threat.

Table 2-4. Typical Single-Family Residence in Gulf Shores, Alabama

Description	Standard Building Code 1979 Edition	Standard Building Code 1997 Edition	International Building Code 2003 Edition – Also ASCE 7-98 and later	Maximum Recorded Wind Speed for Hurricane Ivan using IBC Factors
Basic Wind Design Speed	110 mph	97 mph	145 mph	
Equivalent Wind Speed (3-second gust)	130 mph	115 mph	145 mph	124 mph
Wind Design Pressures on Exterior Walls	(psf)	(psf)	(psf)	(psf)
As Main Frame				
Edge	20/-18	21/-18	32/-28	24/-21
Middle	20/-18	15/-13	23/-20	17/-15
Net Edge	33	32	46	34
Net Middle	33	21	31	23
As C & C				
Middle	27/-27	25/-25	38/-42	28/-31
Corner	27/-27	25/-29	38/-51	28/-38
Wind Design Pressures on Roof (4 in 12 slope)	(psf)	(psf)	(psf)	(psf)
As Main Frame				
Windward Edge	-25	-26	-40	-30
Leeward Edge	-19	-19	-28	-21
Windward Middle	-25	-19	-28	-21
Leeward Middle	-19	-14	-22	-16
As C & C				
Middle	-23	15/-23	22/-35	16/-26
Corner	-23	15/-52	22/-73	16/-54

1 The pressure calculations under each code for both main frame and components and cladding 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 were 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.

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).

2.2.4 Wind Requirements in Building Codes and Standards – Florida

Both the SBC and the FBC 2001 specify higher wind speeds for areas that are closer to the ocean or gulf and lower wind speeds for the inland areas. However, the methodology required for calculating wind loads in the FBC is that prescribed in Chapter 6 of ASCE 7 (with exceptions). 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 designers use state-of-the-art methodology in wind load analysis to calculate wind loads. The use of ASCE 7 also provided Florida with an opportunity to align with the IBC and IRC (basis for the FBC 2004 Edition), both of which also incorporate the methodologies of ASCE 7 for load determination. However, it is important to note that the legislative statutes governing construction in Florida restrict use of ASCE 7 to the 1998 Edition and, thus, do not incorporate the updates included in the 2002 Edition of ASCE 7. The FBC 2001 Edition also instituted improved design requirements for components and cladding (such as roof coverings) and debris impact criteria that were not previously required by the SBC.

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

First, regarding wind loads, the Florida Legislature mandated several items. One such mandate relates to the wind load provisions of ASCE 7-98 as implemented by the IBC:

> (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 IBC, 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.*]

Next, the Florida Legislature modified the windborne debris regions of ASCE 7-98 as follows:

> (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 IBC, 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. 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 Legislature 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.]

However, it is important to note that 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 provided immediate construction successes during Hurricane Ivan. Most newer houses and commercial buildings near the coast designed and constructed to the design wind requirements in the FBC 2001 Edition performed well and sustained only minimal damage during this hurricane event. These results are in contrast to the damages observed in the older building stock, which often ranged from roof covering and cladding damage, to roof structural failures, to partial structural collapse of the primary load-bearing system.

Santa Rosa, Escambia, and Okaloosa Counties experienced the heaviest damage during Hurricane Ivan. Many of the existing buildings and structures in these counties were built under the 1997 edition of the SBC. In these counties, like other areas in the state, the FBC 2001 Edition is now the applicable building code; exceptions to debris impact requirements should be noted.

The SBC, FBC, IBC, and ASCE 7 codes and standards in hurricane-prone areas differ significantly in four areas:

1. The wind speed measure and the design wind speed
2. How and where pressures are calculated on a building
3. Requirements for debris impact protection
4. The FBC defines building exposure categories as Exposure B except for areas within 1,500 feet of the coast

These differences, which will affect the performance of buildings, are discussed in the following subsections, respectively.

2.2.4.1 Comparing Design Wind Speeds

Current codes and standards (the FBC, the IBC, and ASCE 7) standardized the wind speed measure as the 3-second peak gust. This differs from the fastest-mile wind speed measure that was previously used by the SBC and ASCE 7 and the wind speed measure of 1-minute sustained that is used in the Saffir-Simpson Hurricane Scale presented in Chapter 1. Figure 2-17 shows the FBC 2001 wind speed and windborne debris region map. Table 2-5 presents the design wind speeds (in 3-second gusts) for the heavily impacted counties from Hurricane Ivan using three different codes. The wind speeds shown in Table 2-5 are the nominal design, 3-second peak gust wind speeds at 33 feet above ground for Exposure C category (open terrain). The SBC used fastest-mile wind speeds; the FBC 2001 Edition uses the 3-second peak gust wind speed. To facilitate comparison with the FBC, the MAT converted fastest-mile wind speeds provided in the older editions of the SBC Code into 3-second peak gust wind speeds.

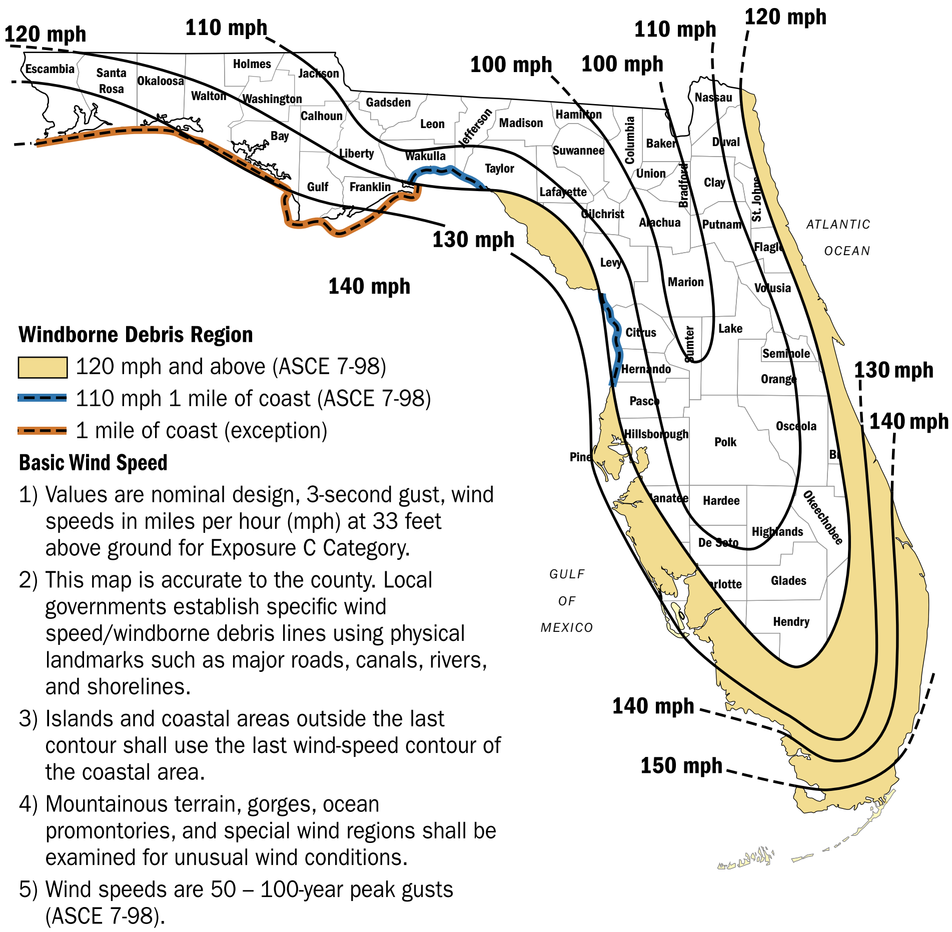


Figure 2-17. Wind speed and windborne debris region map (Courtesy of the Florida Building Commission, 2001)

Table 2-5. Basic Design 3-Second 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 and later Editions
Escambia	105-130 mph	105-112 mph	120-140 mph
Santa Rosa	105-130 mph	105-112 mph	120-140 mph
Okaloosa	105-130 mph	105-112 mph	116-134 mph

* Code wind speeds reported as fastest-mile wind speeds in the SBC were converted to 3-second gust for comparison.

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.

2.2.4.2 Comparing Calculated Wind Pressures

The wind pressures used for design of buildings in the Florida Panhandle have changed significantly from the design pressures from 25 years ago. The 2001 FBC uses the wind speed map from ASCE 7-98, as shown in Figure 2-16. This map prescribes a design wind speed of between 130 and 140 mph for the affected coastal areas. By comparison, Ivan's estimated wind speeds were almost 20 percent below the design wind speeds required by the current code.

From Table 2-6, the buildings in the Pensacola area constructed to the older SBC codes experienced a design level or near design level event. As such, pressures on the main structural systems were at or near design loads. An analysis of the wind pressures resulting from the actual speeds shows an even greater disparity between the code-prescribed design pressures and the pressures predicted from the actual recorded wind speeds for components and cladding systems. As seen in Table 2-6, the resulting pressures are 25 percent to 40 percent below the code pressures.

Table 2-6. Wind Pressures on a Single-Family Residence in Pensacola, Florida

Description	Standard Building Code 1979 Edition	Standard Building Code 1997 Edition	International Building Code 2001 Edition – Also ASCE 7-98 (and later editions)	Maximum Recorded Wind Speed in Florida from Hurricane Ivan using IBC Factors
Basic Wind Design Speed	105 mph	95 mph	135 mph	
Equivalent Wind Speed (3-second gust)	130 mph	110 mph	135 mph	119 mph
Wind Design Pressures on Exterior Walls	(psf)	(psf)	(psf)	(psf)
As Main Frame Edge Middle Net Edge Net Middle	 18/-16 18/-16 30 30	 20/-17 14/-13 31 20	 28/-25 20/-18 40 27	 22/-19 15/-14 31 21
As C & C Middle Corner	 25/-25 25/-25	 24/-24 24/-28	 33/-36 33/-34	 25/-28 25/-34
Wind Design Pressures on Roof (4 in 12 slope)	(psf)	(psf)	(psf)	(psf)
As Main Frame Windward Edge Leeward Edge Windward Middle Leeward Middle	 -23 -17 -25 -17	 -25 -18 -18 -14	 -35 -25 -25 -19	-27 -19 -19 -14
As C & C Middle Corner	 -21 -21	 14/-22 14/-50	 19/-30 19/-63	14/-24 14/-49

1 The pressure calculations under each code for both main frame and components and cladding 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 were 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.

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).

2.2.4.3 Comparing Debris Impact Requirements

The FBC instituted statewide debris impact requirements related to design wind speeds. Prior to the FBC, the South Florida Building Code (with county provisions) identified debris impact requirements affecting the design of buildings for portions of Florida. However, the SBC, which was enforced in the portions of the state not using the South Florida Building Code, did not have debris impact requirements, and, therefore, buildings constructed prior to the adoption of the 2001 FBC were not required to protect openings against windborne debris. For new construction, Section 1606.1.5 of the FBC 2001 Edition defines the windborne debris impact regions as:

1. Areas where the basic wind speed is 120 mph (53 meters per second [m/s]) 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.
2. Areas within one mile (1.6 kilometers) of the coastal mean high water line where the basic wind speed is 110 mph (49 m/s) or greater.

Figure 2-17, in combination with the definitions above, depicts the windborne debris impact regions. Different criteria for requiring protection of openings against damage from windborne debris apply for new buildings constructed to the 2001 FBC in coastal Florida counties affected by Hurricane Ivan. Whereas a building within the 120-mph wind contour (or higher) triggers compliance with the statewide criteria for protecting openings, in the Florida Panhandle, only new buildings constructed within one mile of the coast are required to have opening protection. The FBC provides clear guidance on design requirements in the windborne debris regions. Buildings in these regions are required to protect glazed openings (windows and doors) to ensure that the building envelope remains "enclosed." To achieve the requirement of an "enclosed building," shutters, laminated glass, or other opening protection systems are required to be installed. Protection measures are required to resist large or small debris (missiles) depending upon their height on the exterior of a building above grade. An exemption is provided for residential construction in the Florida statutes allowing unprotected glazing and openings if the building was designed and constructed as a partially enclosed building. A building designed to resist the effects of internal pressurization accounts for higher pressures that occur when wind enters a building or structure. This exemption implies that wind and rain may enter the building increasing internal wind pressure substantially, yet the structural design is sufficient to prevent failure of the main wind-force resisting system. This method of high-wind design may result in substantial interior damage from the wind and rain that enter the building since openings are not protected. Additional guidance on the windborne debris region and the debris impact requirements is provided in FBC Section 1606.1.4.

Given the potential for extreme wind and water damage to buildings and building contents when the envelope is breached (as confirmed by 2004 post-hurricane investigations), building codes have begun to restrict the use of the partially enclosed design option. The 2004 supplement to the IBC removes this option; thus, building openings must be protected or glazed with impact-resistant glazing. A similar change to the IRC has been approved in committee, and the next edition (2006) is expected to eliminate the partially enclosed design option for buildings governed by the IRC.

2.2.4.4 High-Wind Elements of the Code

The FBC 2001 Edition has special and stringent requirements for HVHZ areas. Sections 1611-1616 in the FBC define wind and debris requirements of HVHZs. Only Dade and Broward Counties are included in the HVHZ areas.

The HVHZs affect the design and construction of buildings by requiring higher design wind speeds for the entire building and by requiring the design of specific building components, attachments, and equipment for the design wind speed. The difference in design pressure is often substantial and results in a much stronger main structure and higher component design values for buildings. Many other requirements (e.g., mandatory 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 of the state. Buildings built according to HVHZ requirements have much more capacity to withstand hurricanes and provide additional protection of property.

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 Chapter 5.

3

General Characterization of Damage

Chapter 3 provides a general characterization of the damage that resulted from Hurricane Ivan. Section 3.1 discusses flood effects on one- and two-family housing and on multi-family housing. Section 3.2 discusses wind effects on one- and two-family housing, multi-family housing, commercial buildings, and critical and essential facilities. Finally, Section 3.3 presents several case studies demonstrating lessons learned and best practices.

3.1 Flood Effects

As discussed in Chapters 1 and 2, Hurricane Ivan brought high storm surge and waves causing severe damage to buildings along the Gulf Coast in Baldwin County, Alabama, and the western portions of the Florida Panhandle. Damages resulted from high flood elevations and impacts from waves and debris. The storm surge caused severe coastal erosion that caused failure of shallow foundations. The MAT observed that flood elevations in many areas exceeded the 100-year BFEs depicted on the FIRMs by 2 to 4 feet, which was also confirmed by FEMA's Flood Hazard Recovery Maps, which were produced in the aftermath of Hurricane Ivan and included surveyed high water marks, as discussed in Chapter 1. Wave damage, which was anticipated in V-Zone areas, was also observed in mapped A-Zone areas. In many areas, flood levels resulted in V-Zone type damages in mapped A Zones. Wave and waterborne debris impacts caused significant damage to buildings and to enclosures, slabs, decks, stairs, utilities, and other ancillary features. See Appendix E for a discussion of FEMA's Flood Hazard Recovery Maps.

Since many houses were constructed to the current minimal flood standards and in many cases were pre-FIRM construction, Hurricane Ivan's high storm surge and waves, which exceeded the BFEs, significantly destroyed buildings on the open coast of the barrier islands and throughout the back bays and sounds.

3.1.1 Flood Effects on One- and Two-Family Housing

Severe flood damages occurred to one- and two-family buildings throughout the study area, on the barrier islands, and, more significantly, throughout the back bays and sounds. Particularly hard hit areas were near the shorelines of Little Lagoon, Big Lagoon, Santa Rosa Sound, Pensacola Bay, and Escambia Bay.

Most one- and two-family buildings on the barrier islands were built using V-Zone construction methods with pile foundations. Newer buildings constructed on pile foundations with proper embedment depth generally performed well, although many buildings experienced damages to lower area enclosures, nonstructural slabs, access stairways, and utilities. Older buildings (as well as a few newer buildings) that were built on piles with insufficient cross-section or embedment suffered destruction or severe damage.

In areas along the bays and sounds, Ivan's flood elevations frequently exceeded the BFE by 2 to 4 feet or more, which led to significant inundation, and wave and floodborne debris damage to buildings, even those constructed in compliance with community floodplain management requirements.

Many of the hardest hit areas were mapped as A Zone, but buildings experienced V-Zone conditions, with severe damage occurring to buildings elevated to the BFE on slab, pier, and crawlspace foundations. Buildings constructed outside the SFHA in areas mapped as Zones B, C, or X were often subject to A-Zone flood conditions during Ivan. As a general rule, wherever wave crest elevations and floodborne debris strikes occurred above the lowest floor elevation, the buildings, regardless of foundation type, were destroyed or severely damaged. The severity of wave and debris damage near bay and sound shorelines is one of the most noteworthy characteristics of Hurricane Ivan.

The buildings that resisted Ivan's flood forces most successfully were elevated several feet above the BFE on pile foundations. Buildings elevated on stem wall foundations in Zones A, B, C, and X also performed reasonably well, where the top of the foundation was above the limits of wave action and floating debris, and where the footing depth was sufficient to resist scour.

Figures 3-1 through 3-5 illustrate typical flood damages to one- and two-family buildings.

Figure 3-1.
Buildings constructed on deep pile foundations performed well; however, significant damage occurred to lower-level enclosed areas and to stairways, utilities, and non-structural parking slabs below the elevated portion of the building.

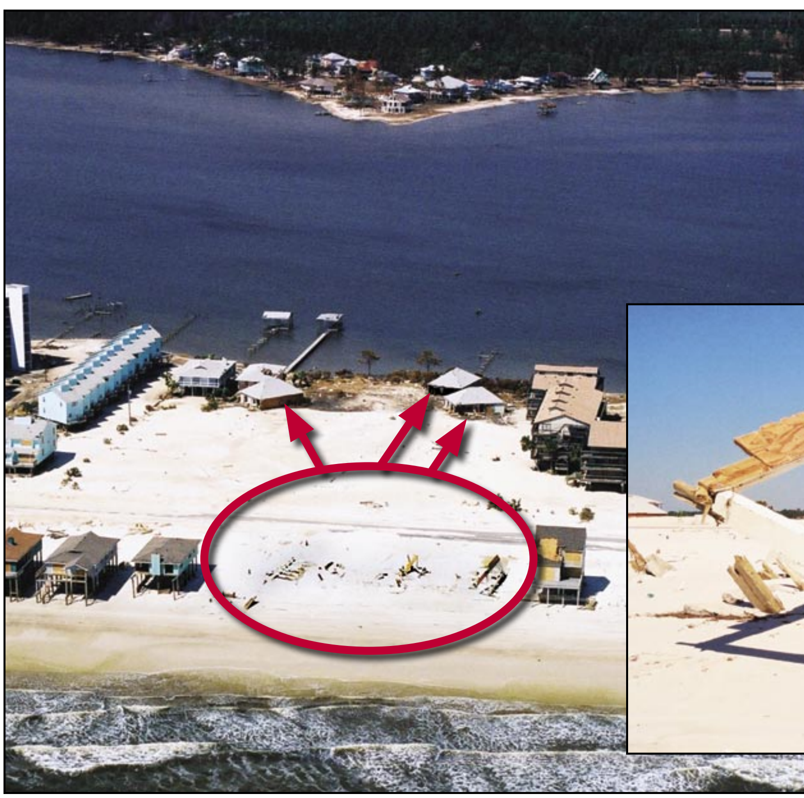


Figure 3-2.
Insufficient pile embedment caused displacement of houses (Gulf Shores, West Beach)

In many back bay and sound areas, the flood elevations exceeded the 100-year BFEs and this led to significant damage to buildings, especially those that were constructed to lower elevations. Severe damage was caused by wave and debris impacts. Most of the buildings on the bays and sounds were pre-FIRM buildings built below the current BFE or post-FIRM buildings built at BFE. When floodwaters exceeded their lowest floor elevations, these buildings were damaged by waves and debris impacts. The severity of the damage varied depending on the elevation of the lowest floor.

Many houses that were several rows back from the shoreline (in Zones A, B, C, and X) were somewhat protected, but they sustained considerable flood damage due to inundation levels above the lowest floor. In many cases, debris from docks and seaward of the rows of houses was carried inland by surge and waves, battering other houses and causing significant damage.

Figure 3-3.
This building, which was less than 2 years old, was constructed on piers at the current BFE of 9 feet. It was severely damaged by high storm surge, and wave and debris impacts. (Big Lagoon)

Even in areas where buildings were designed and elevated for high wave impacts, buildings suffered severe waterborne debris, surge, and wave damage when flood levels exceeded FIRM elevations by several feet, as shown in Figure 3-4.

Figure 3-4.
Damage to NFIP-compliant elevated structure in a V Zone (north end of Escambia Bay-Floridatown)

Figure 3-5.
Buildings constructed on piles and elevated several feet above the BFE sustained less flood damage than adjacent buildings at lower elevations. (Big Lagoon)

Pre- and post-FIRM residential buildings on slab-on-grade, crawlspace, or stem wall foundations in Zone AE near the back-bay or sound shorelines experienced substantial damage and/or complete destruction when flood elevations significantly exceeded mapped levels. Representative damages are shown in Figures 3-6, 3-7, and 3-8 where houses exposed to flood conditions from Little Lagoon and Big Lagoon (the water bodies behind Gulf Shores and eastern Perdido Key) experienced severe surge, wave, and debris damage when flood levels exceeded the BFE by 2-4 feet. Note that Figure 3-5 shows a pile-elevated building near the building shown in Figure 3-8.

Figure 3-6. Surge, wave, and debris damage (Little Lagoon)

Figure 3-7.
Older buildings below the current BFE sustained severe flood damage throughout the back bays. (Little Lagoon)

Figure 3-8.
This new building was constructed to the BFE, but was wiped off its foundation (slab atop stem walls) by Ivan. The destruction was likely due to storm surge, wave action, and floodborne debris, although wind could have contributed to the breakup of the building (note pine tree leaning over slab). (Big Lagoon)

Severe damage was caused by flood and wave impact to decks, stairs, utilities, and enclosed areas beneath elevated buildings, as shown in Figure 3-9. Floodborne debris impacts caused severe damage to buildings that were elevated to the BFEs, as shown in Figures 3-10 and 3-11.

Figure 3-9.
Utilities, parking slabs, and enclosed areas under an elevated building were severely damaged by the high flood elevations and wave action. (Gulf Shores)

Figure 3-10.
Large timbers washed from developments on Santa Rosa Island, across Santa Rosa Sound, and into several homes. (Santa Rosa Sound – Oriole Beach)

Figure 3-11.
Significant floodborne debris contributed to the severe damage of at-grade enclosed area beneath an elevated building. (Big Lagoon)

Figure 3-12. Significant floodborne debris contributed to the severe damage of buildings throughout the back bays and sounds in areas mapped as Zone AE. (Oriole Beach – Santa Rosa Sound)

3.1.2 Flood Effects on Multi-Family Housing

The nature and extent of flood damage to multi-family buildings varied considerably, depending on: 1) the location, foundation, and lowest floor elevation of the building, 2) the local flood conditions during Ivan, and 3) the degree of engineering attention received during design. Note that in some areas, building age was a poor predictor of building performance; the MAT observed some older multi-family buildings that performed well, and some newer multi-family buildings that were destroyed by Ivan's flood and erosion effects.

Obviously, building success or failure during Ivan was also dependent on how well the flood hazard maps in effect at the time of construction represented site conditions at the time of Ivan. Beach and dune erosion over time undoubtedly contributed to the damage or destruction suffered by barrier island multi-family buildings on shallow foundations in Zones B, C, or X. In addition, the accuracy of BFEs, flood hazard zones, and SFHA boundaries contributed to the damage suffered by multi-family buildings (on both barrier islands and back bays) that were constructed to minimum standards only.

Multi-family buildings that received a high degree of engineering attention (fully engineered structures) and had deep foundations appeared to withstand Ivan's flood and erosion effects, with the exception of lowest floor living units that were below Ivan's wave crest elevation. Fully engineered, multi-family buildings with parking areas at ground level and elevated floors built using VE-Zone construction methods above the BFE generally sustained the least amount of flood and erosion damage.

Many multi-story buildings (e.g., multi-family and commercial) along the Gulf shoreline suffered extensive surge, debris, and erosion damage to their lowest floor levels, pool decks, and bulkheads. The most extreme cases were complete building collapse due to undermining of shallow foundations (see Figure 3-13).

Figure 3-13. Collapse of 5-story, multi-family buildings on shallow foundations (Orange Beach)

Less extreme – but still severe – damage was observed at many multi-story condominium buildings along the Gulf shoreline of Orange Beach and Perdido Key. The lowest floors containing living units, lobbies, and common areas were often destroyed by storm surge and waves, as a result of floor collapse or destruction of exterior walls, or a combination of the two (see Figures 3-14 to 3-15).

Figure 3-14. Pile foundations performed well, but non-structural floor slabs collapsed and low-elevation living units were destroyed. (Orange Beach)

Figure 3-15. Building supported on pile foundation (foreground) survived while building on shallow foundation (background) collapsed. (Orange Beach)

A separate rapid-response study of Orange Beach multi-story structures was undertaken to determine the extent and characteristics of lowest floor living unit damages (see Appendix F). The study examined 41 multi-story buildings, not including the collapsed buildings, such as those shown in Figure 3-13. Thirty-nine of the 41 buildings had a total of 233 living units at the lowest floor level.

Dates of construction and flood regulations in effect at the times of construction (i.e., flood hazard zones and BFEs) were not available at the time of the study; thus, compliance with those regulations could not be verified. However, although it appears the majority of the buildings were constructed in Zones B, C, or A, they were constructed on pile foundations. Lowest floor elevations (top of floor and bottom of lowest horizontal supporting members) were measured as part of the study, and this information was compared against the FIRMs in effect between 1983 and 2004, during which the majority of the construction was thought to have taken place.

The study found that approximately 80 percent of the lowest floor living units were destroyed by flood and/or erosion effects, despite the fact that most of the buildings were constructed on pile foundations with the top of the lowest floor at or above the BFEs that have been in effect over the past two decades. The buildings that sustained the least structural damage due to waves and erosion were constructed to VE-Zone standards with their lowest horizontal structural member several feet above the BFE.

The study also found that the most common damage state was with the lowest floor intact and the non-structural walls destroyed (see Figures 3-16 and 3-17; this occurred in 21 of the 39 buildings, in 101 of the 233 lowest floor living units). The next most common damage state was lowest floor and walls destroyed (this occurred in 15 of the 39 buildings, in 58 of the 233 lowest floor living units). Fully intact conditions (no damage to the lowest floor or lowest floor living units) occurred at only 6 of the 39 buildings, and 28 of the 233 lowest floor living units.

Figure 3-16. Foundation and structural floor slab survived but lowest floor non-structural exterior walls were destroyed by surge and waves (Orange Beach)

Figure 3-17. Destruction of low-elevation living units by surge and waves, while second floor units survived intact (Orange Beach)

3.2 Wind Effects

As documented in Chapter 1, the maximum recorded 3-second peak gust wind speed in Hurricane Ivan was 117 mph in the Perdido Key area. The maximum wind speeds in Gulf Shores and Pensacola Beach were recorded to be 109 mph. The wind speeds recorded were well below the design wind speeds for this area under current building codes, but were just below the design wind speeds used for many years under the SBC. Both the IBC and FBC use the wind speed map from ASCE 7, as shown in Figure 2-16. This map prescribes a design wind speed of between 140 and 150 mph for the affected coastal areas. This means that the estimated actual wind speeds were almost 20 percent below the design wind speeds required by the current codes.

An analysis of the wind pressures resulting from the actual speeds indicates a disparity between the current code-prescribed design pressures and the pressures predicted from the estimated actual wind speeds. As seen in Chapter 2, the resulting pressures are 25 percent to 40 percent below the current code-prescribed pressures. However, it was notable that the magnitude of the calculated wind pressures based on the estimated wind speed is very similar to the wind pressures and loads calculated using the SBC codes that were in effect from 1985 until the present for the main structural systems. Comparing the pressures calculated for a code event under the SBC codes with the pressures calculated based on the estimated wind speed suggests that structural systems such as wall and roof framing received design level pressures while components and cladding systems such as roof decking, windows, doors, and wall cladding appeared to have been exposed to higher than design level pressures. With the code in effect for 20 years, it is reasonable to expect that a large percentage of buildings in the impacted area had been constructed under that code, and, thus, the damage discussed is consistent with the lower (older) design pressures that were exceeded.

3.2.1 Summary of Damage Types

Since the wind loads in Hurricane Ivan were significantly below the current design level and approximately equal to design levels of the past twenty years, one might expect that the buildings in the affected area would have minimal wind damage, but that was not the case. The damage observed appeared to be disproportionate to the wind speeds. The MAT observed the following:

- Wind damage to wall cladding was widespread throughout all building types and sizes. Damage to exterior insulation finish systems (EIFS) and vinyl siding was common.

- Roof coverings of all types were frequently heavily damaged.
- Rooftop equipment was frequently damaged or completely detached as a result of the wind.
- Soffit damage was also observed throughout the entire wind field of the storm.
- Building envelope damage to older buildings was more common than to newer buildings; however, there were still many incidences of substantial damage even to new buildings.

Wind-related structural damage was less widespread than the building envelope damage, but was not uncommon. The MAT observed the following:

- The most common structural damage was loss of light-framed roof structures, primarily in the form of roof sheathing attachment failure, and subsequent damage to framing such as trusses or rafters.
- Another common failure mode was wood framed gable end walls.
- Many pre-engineered metal buildings experienced heavy damage to both the building envelope and to the secondary framing members.
- Cantilevered gas station canopies failed frequently throughout the damage zone.

Older buildings typically experienced more damage than buildings constructed since the adoption of 2001 FBC and 2003 IBC for the following reasons:

- Older building codes' methods did not always result in resistance to high design wind pressures on critical building areas such as corner and wall areas (notable points of failure initiation).
- Even if an older building code was in place, the enforcement of the code may have been ineffective.
- Older buildings may have suffered from degradation of strength due to corrosion, termites, dry rot, poor maintenance, or a variety of other factors.
- Construction methods and materials commonly used at the time the older buildings were built may now be considered inappropriate for a high-wind area.

Some effects of these observations include the following:

- Design wind loads that are too low (due to older methods that have been revised by current codes), which result in members and connections that are too weak for the winds likely to be encountered at the site

- Fasteners for roof sheathing that are too small or are spaced too far apart
- Undersized or missing strapping to anchor the roof structure to the walls
- Lack of a continuous load at the connection between the walls and the foundations
- Structural design that did not account for unprotected windows and doors, which, when broken or damaged, lead to structural failures due to rapid increases in internal pressure
- Unprotected openings and glazing, which, when broken or damaged, lead to interior damage from wind-driven rain
- Collapse of large doors, leading to damage resulting from increased internal pressure and damage from wind-driven rain
- Corrosion of ties or fasteners used to attach cladding to the structure
- Corrosion of anchors or connectors that attach the building to the foundations or tie structural elements together

The MAT repeatedly observed cases where buildings constructed within the past few years survived the storm relatively unscathed, while older buildings next door or directly across the street sustained significant damage due to rainwater intrusion through damaged roof coverings, damaged soffits, and/or broken windows and doors.

3.2.2 Wind Effects on One- and Two-Family Housing

Hurricane Ivan affected a large stock of one- and two-family housing. In Gulf Shores alone there were over 1,400 homes in the barrier island damage zone. The other communities from Gulf Shores to Navarre Beach suffered varying degrees of wind-related damage to houses. The most widespread type of wind damage to homes was building envelope damage. Roof covering damage was the most common type of building envelope damage. All types of roof coverings were affected. Structural wind damage was mainly in the form of light-framed roof framing failures as shown in Figure 3-18. Insufficient attachment of roof sheathing panels to the framing beneath was the most common problem. Gable end wall failures were frequently observed, as were failed connections between the roof and wall members.

Figure 3-18.
Typical wind damage showing loss of roof sheathing and damage to structural roof framing (Ono Island)

3.2.3 Wind Effects on Multi-Family Housing

Wind damage to multi-family housing varied considerably with construction type. Low-rise, wood-framed condominium buildings suffered the same types of damage as their one- and two-family counterparts, as shown in Figures 3-19 and 3-20. Higher story buildings, typically built of cast-in-place concrete, suffered no wind damage to the primary structural frame. The observed damage was to the building envelope and, in some cases, to structural framing members, such as roof trusses. The common types of high-rise cladding damage were to stucco and EIFS, a popular wall material in the region as shown in Figure 3-21, and to all types of roof coverings.

Figure 3-19.
Typical roof sheathing and covering loss (Pensacola Beach)

Figure 3-20.
Typical gable end wall failure and loss of roof sheathing and wall (Perdido Key)

Figure 3-21.
Typical high rise cladding failure (Perdido Key)

3.2.4 Wind Effects on Commercial Buildings

Although the MAT did not focus on commercial buildings, the Team observed several while in the area. The wind damage was consistent with the damage observed in multi-family buildings in that it varied with construction type. Cladding damage was widespread, particularly to EIFS and all types of roof coverings, as seen in Figures 3-21, 3-22, and 3-23. Many pre-engineered metal buildings suffered significant damage to the building envelope and to secondary structural members such as girts and purlins, as seen in Figure 3-24. Steel joist and metal deck roof structures generally fared well. Wood-framed roof structures performed much as they did on residential buildings.

Figure 3-22. Commercial building roof covering failure (Pensacola Beach)

Figure 3-23. Commercial building wall cladding and secondary structure failure (Gulf Shores)

Figure 3-24.
Pre-engineered metal building damage (Orange Beach)

3.2.5 Wind Effects on Critical/Essential Facilities

The MAT focused on the damage and loss of function observed at many critical and essential facilities such as hospitals, schools, and shelters. Damage and resulting loss of function was most often the result of building envelope damage, as seen in Figures 3-25 and 3-26. Rooftop equipment damage was widespread. Little structural wind damage was observed.

Figure 3-25.
Metal wall panel damage to middle school (Gulf Breeze)

Figure 3-26.
Roof covering and roof deck damage to middle school (Pensacola)

3.3 Lessons Learned and Best Practices

Given the hurricane history of the area, several buildings previously visited before Ivan were visited again after Ivan. The MAT team also observed many other situations where prudent siting and construction improved the building performance during Hurricane Ivan. Several of these buildings are described below.

Condominium – Gulf Shores, Alabama

One of the best known examples is a U-shaped condominium in Gulf Shores. The original building was elevated on solid walls and was destroyed by surge and wave effects during Hurricane Frederic in 1979 (see Figure 3-27, upper photo). The building was reconstructed after Frederic on an open foundation (concrete columns atop pile caps and deep pilings). Even though the foundation survived Hurricane Ivan (Figure 3-27, lower photo), the MAT team observed significant wind damage and corrosion. Closer inspection (Figure 3-28) revealed the concrete columns elevating the building had been deteriorating for some time (i.e., chloride penetration into the concrete, corrosion of the reinforcing steel, and spalling of the concrete cover), and prior efforts to patch the columns were evident. This points out the need for constructing near the coast with sound, durable materials and high-quality workmanship.

Figure 3-27.
After this building was destroyed by Hurricane Frederic in 1979 (upper photo), it was re-constructed on concrete columns, pile caps, and deep piles. The foundation survived Hurricane Ivan; however, the building experienced significant wind damage (lower photo). (Gulf Shores)

Figure 3-28.
Severe corrosion of reinforcing steel and spalling of the concrete columns supporting the post-Frederic building shown in Figure 3-27. Note evidence of prior attempts to repair the columns.

Condominium Complex – Pensacola Beach, Florida

Another example of reconstruction using flood-resistant techniques is shown in Figures 3-29 through 3-33. In 1995, Hurricane Opal destroyed one of four low-elevation, masonry and wood-frame buildings comprising a condominium complex at Pensacola Beach (Figure 3-29). The destroyed building was replaced by an elevated building supported on concrete pilings above the BFE, in accordance with the local government's (Santa Rosa Island Authority) freeboard requirements (Figure 3-30). Waves, surge, and wind during Hurricane Ivan severely damaged the remaining three original buildings (Figure 3-31 and 3-32). The newer pile-supported building performed well from a flood perspective (but sustained some wind damage to the roof covering). Ground level breakaway walls, decks, and parking slabs were damaged under the new building, but the foundation and main structure successfully resisted flood and wave effects (Figure 3-33). The ability of the new building to successfully avoid structural damage due to flood forces demonstrates the importance of elevation on a deep pile foundation with breakaway construction below the elevated building.

Figure 3-29.
Hurricane Opal (1995) flood damage to one of the four original buildings

Figure 3-30.
1998 photograph showing the post-Opal replacement (pile supported) building (background) and one of the three remaining older buildings (foreground)

Figure 3-31.
Post-Ivan aerial photograph showing severe flood damage to two of the three older buildings, with newer, pile-supported building intact (left side)

Figure 3-32.
Ivan flood and wind damage to older building (post-Opal building visible at far left)

Figure 3-33.
Hurricane Ivan, non-structural enclosure and deck damage below newer building

Condominiums – Perdido Key, Florida

The MAT observed 4 condominiums in close proximity to each other on Perdido Key. They are shown in their pre-Ivan condition in Figure 3-34, and after Ivan in Figure 3-35. The lower pairs of buildings in each figure were newer, having been rebuilt after their predecessors (built on shallow foundations) collapsed during Hurricane Georges (1998). The upper pair of buildings (also on shallow foundations) survived Georges but collapsed during Ivan.

The lessons learned in Hurricane Georges served the owners of the bottom pair of buildings well during Ivan. These buildings were re-constructed following Georges with deep-pile foundation systems, and the foundations performed well during Ivan. The building on the left lost the ground floor parking slab as seen in Figure 3-36, and suffered substantial roof covering loss due to wind. The building on the right had a structural parking slab, which was undermined by Ivan but undamaged. The building had only minor cladding damage due to the wind.

Figure 3-34.
Four Orange Beach condominiums before Hurricane Ivan. The lower pair of buildings was newer, having been constructed after the predecessors were destroyed by Hurricane Georges (1998) (USGS)

Figure 3-35.
The four condominiums in Figure 3-34 after Hurricane Ivan. The newer buildings on pile foundations survived, while the older buildings on shallow foundations collapsed. However, the newer building on the lower left experienced significant interior water damage due to roof loss. (USGS)

Figure 3-36.
Deep foundation exposed by erosion, and collapse of undermined parking slab, as shown in the photo on the right.

Residential Buildings

Figures 3-37 and 3-38 show two residences near Big Lagoon after Ivan: an elevated building constructed to a newer code and an adjacent non-elevated building constructed to an older code. The difference in the performance of each building is apparent. The newer building sustained only non-structural flood damage at grade level, with no apparent wind damage to the roof or building envelope (the building performed as expected). The older building was severely damaged by flood and wind forces. This comparison demonstrates the importance of building elevation and wind-resistant design.

Figure 3-37. Elevated building constructed to newer code that survived Hurricane Ivan (Big Lagoon)

Figure 3-38. Older, non-elevated building (near building in Figure 3-37) severely damaged in Hurricane Ivan (Big Lagoon)

As discussed throughout this report, elevating a house on piles to the minimum standards and preferably several feet higher can prevent significant damage. Figure 3-39 shows an older house with a slab-on-grade foundation that was not elevated to the current BFE and that sustained considerable damage from Hurricane Ivan's high storm surge and debris impacts. Figures 3-40 and 3-41 show two houses located in the same general area as the house shown in figure 3-39, but, because they were elevated on piles to higher standards, they sustained minimal flood damage.

Figure 3-39.
House on La Paz Street that was not elevated to the current BFEs, and, therefore, was severely damaged by the high coastal flooding and wave impacts

Figure 3-40.
House on La Paz Street that was elevated on piles, which prevented severe damage from coastal flooding

Figure 3-41.
House on La Paz that was elevated on piles, which prevented major flood damage

Following Hurricane Ivan, Alabama homeowners with houses constructed to standards exceeding the adopted building code were rewarded with significantly less damage. The higher building standards, contained in the IRC and IBC, require far stronger framing, connections, walls and roofs that will withstand winds up to 140 mph. The homeowner of the surviving house shown in Figure 3-42 constructed the house on Orange Beach to the new code, before the town adopted the IRC and IBC in June 2004. As a result, the house had virtually no damage, although numerous houses nearby had significant damage or were destroyed. Figure 3-42 demonstrates the contrast between a house destroyed by wind and flood forces and a house that survived because it was built to the new code.

Figure 3-42.
The surviving house was built to incorporate the provisions of the new building code (IRC, IBC) even before it was adopted. (Orange Beach)

4

Structural Systems Performance

The dominant causes of structural failure observed by the MAT included surge, waves, flood-borne debris, and wind. Structural damage due to erosion was also common on the barrier islands. These types of damage occurred to residential buildings (single- and multi-family housing), commercial buildings, and critical and essential facilities.

Flood impacts are discussed in Section 4.1. Subsections 4.1.1 and 4.1.2 discuss the flood impacts on single-family and multi-family residential buildings, respectively. Subsection 4.1.3 discusses flood impacts to miscellaneous structures associated with residential buildings, such as bulkheads, non-structural slabs, breakaway walls, and utilities. Section 4.1.4 discusses impacts of debris borne by floodwaters. Flood impacts on commercial buildings were similar to those on residential buildings; thus, commercial buildings are not discussed separately. Wind impacts are discussed in Section 4.2.

4.1 Flood

4.1.1 Single-Family Residential Buildings

Single-family buildings throughout the western sections of the Florida Panhandle and the coastal areas of Baldwin County, Alabama, incurred significant damage caused by high floodwaters with wave action and debris impacts. In general, the damage resulted less from foundation failures (although these were observed) than from the high flood elevations (which exceeded the BFEs) and from the impacts of wave action and debris. In coastal back bay areas designated as flood Zones AE, severe damage was caused by wave action and debris generated from docks and damaged buildings, including debris originating on the barrier islands that washed across the sounds and bays.

Many structures constructed on pile foundations performed well, especially those buildings built several feet above the minimum flood elevation standards. Structural failures resulting from flooding generally correlate with the first floor elevation of the building, although some failures also resulted from erosion and improper connections between structural components. In general, the lower the elevation of the first floor of a building, the more the building was damaged. In coastal areas where the lowest floor elevation was lower than the wave crest elevation, the building was not only inundated by flooding, but also extremely susceptible to additional lateral and impact loads from wave action, floodborne debris, and velocity flow.

4.1.1.1 Pile Foundations

Pile foundations were the most common foundation type for residential buildings on the barrier islands and were also common for newer construction on the bay and sound shorelines. Generally, buildings constructed on pile foundation systems performed well, especially those constructed with the lowest floor several feet above the BFE. Exceptions were buildings with shallow pile embedment on the barrier islands which experienced significant erosion and pile-supported buildings anywhere the wave crests exceeded the elevation of the lowest floor.

Barrier Islands

Figures 4-1 through 4-3 show barrier island houses that experienced destruction of enclosures below the houses. Structurally, these houses performed well, but the breakaway walls, non-structural parking slabs, and the contents below the lowest floor were generally destroyed. This type of damage is anticipated when floodwaters and waves rise above the parking slab and batter the breakaway walls forming a below BFE-enclosure. Figure 4-4 shows another problem observed by the MAT – survival of residential buildings on pile foundations, but damage or destruction of pile-supported decks. Deck failure was sometimes due to deck foundation failure (piles supporting decks often are smaller and shorter than the building foundation) and sometimes to wind failure (uplift). In some instances, loss of decks led to envelope or structural damage to the houses.

In instances where pile-elevated buildings had their lowest floor at or just below the wave crest elevation during Ivan, damage to the floor system was observed. Figure 4-5 shows a typical example, where the piles and shore-perpendicular floor beams performed as intended, but where the wave crests struck the shore-parallel floor joists. The lateral forces exceeded the capacity of the joist connections, and the joists were pushed landward. The collapse of the joists was usually accompanied by damage to the floor and the building interior.

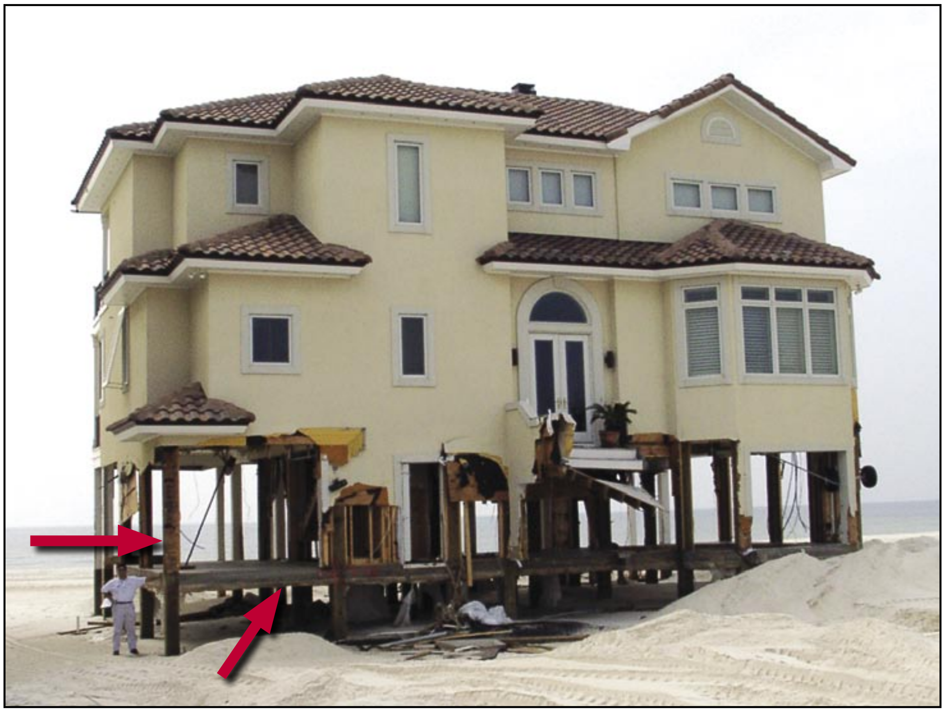


Figure 4-1.
House on a pile foundation that performed well. It experienced 5 feet of erosion that resulted in failure of a non-structural slab. Breakaway walls in lower level also failed as expected. (Gulf Shores)

Figure 4-2.
House on pile foundation, adjacent to breach in the barrier island, that experienced erosion and significant non-structural damage below the lowest floor (Gulf Shores).

Figure 4-3.
These pile-elevated houses in an area mapped as Zone VE at Pensacola Beach successfully resisted flood forces. Loss of breakaway enclosures and garage doors below the lowest floors occurred, as expected. (FL DEP Photo)

Figure 4-4.
Row of newer houses on pile foundations that experienced significant damages below the lowest floor, but overall the pile foundation systems performed well. Improper pile embedment for decks remains a concern as shown in the two houses in the center; one house shows the deck is sagging, and the other deck was destroyed. (Gulf Shores)

Figure 4-5.
Floor joists were pushed landward when the wave crest elevation was above the floor beam. (Gulf Shores)

Erosion can have a significant impact on the performance of pile foundations that are not embedded deeply enough in the soil. Many newer buildings with deep pile foundations performed well; however, there were numerous older buildings that lacked sufficient pile embedment to account for the loss of soil due to erosion and scour. In these instances, permanent deformation or failure of the foundation resulted. Figures 4-6 through 4-9 show several examples of failure of the pile foundations – either under buildings or under decks – that lacked sufficient embedment depth and structural capacity to resist Ivan's flood and wind forces.

Figure 4-6.
Significant erosion caused the non-structural parking slab to fail, and insufficient pile embedment caused the structure to lean. The high storm surge and waves caused destruction of the enclosure below the lowest floor. (Orange Beach)

Figure 4-7.
Erosion contributed to loss of the porch, failure of the retaining wall and non-structural parking slab, and destruction of the enclosure below the first floor. The main structure remained standing, but appears to have sustained some envelope damage when the porch failed. (Orange Beach)

Figure 4-8.
The pile foundations in the foreground failed. These houses were washed away (see Figures 3-2 and 4-9).

Figure 4-9.
These houses floated off their pile foundations (shown in Figures 4-8 and 3-2), probably a result of inadequate pile embedment.

Bay and Sound Shorelines

Pile-foundation performance along inland bays and sounds varied depending on the flood level, the pile diameter, and pile-to-beam connections. Most of the pile-elevated houses observed by the MAT along bay and sound shorelines were probably constructed in Zones A, B, or C; V Zones mapped along the bay and sound shorelines were relatively narrow, and relatively few houses were actually constructed in V Zones. However, many of the areas mapped as Zone A sustained V-Zone conditions during Ivan, and those areas mapped as Zone V usually sustained flood conditions far worse than those indicated by the FIRM. Where floor elevations were below the wave crest elevation, buildings were damaged or destroyed; where small diameter piles were struck by waves and large debris, they failed; where connections at the tops of the piles were inadequate, they failed.

As with the barrier islands, most of the pile foundations along bay and sound shorelines performed well where the lowest floor was elevated several feet above the BFE. In other cases, where pile-elevated houses were at or near the BFE, they often were heavily damaged by waves and debris (see Figures 4-10 and 4-11), sometimes torn completely from the pile foundations (see Figures 4-12 and 4-13).

Figure 4-10.
House constructed on a pile foundation in a V Zone along Escambia Bay. The house was apparently built in compliance with V-Zone requirements (BFE of 12 feet NGVD), but still experienced wave impacts on the elevated first floor of the building. (Floridatown)

Figure 4-11.
Damage to pile-supported house on a bay shoreline, when flooding and waves exceeded the lowest floor elevation (Gulf Breeze, Pensacola Bay)

Figure 4-12.
House at left (circle) was torn from its pile foundation. New houses under construction (arrows, see Figure 4-31 also) survived Ivan (Big Lagoon).

The destroyed house on the left side of Figure 4-12 was in the Grande Lagoon neighborhood, approximately ¾ mile across Big Lagoon from the barrier island, Perdido Key. Perdido Key was completely overwashed by Ivan, and stillwater flood levels in the vicinity of Grande Lagoon were approximately 13 to 14 ft NGVD (see Figure 1-11), with wave crest elevations higher. Flood hazard zones and BFEs shown on the FIRMs for this area ranged from VE, elevation 11 feet NGVD, to AE, elevation 9 feet NGVD. Figure 4-13 shows the same house (circled) with several nearby, pile-elevated houses that were also destroyed. It should be noted that some older but intact houses in the neighborhood were observed to have poor connections between the floor beams and the elevated houses. Wind might also have contributed to the structural failures seen in Figures 4-12 and 4-13.

Figure 4-13.
Same destroyed house as in Figure 4-12 (circled). Note adjacent pile-elevated houses near shoreline, also destroyed (Big Lagoon).

Another nearby neighborhood also illustrates the value of a sound pile foundation along bay and sound shorelines. Figure 4-14 shows an older pile-elevated house near the east end of Seaglade Drive, approximately one mile east of the Grande Lagoon neighborhood and exposed to similar flood conditions during Ivan. This house is in an area mapped as Zone AE, elevation 9 feet NGVD. The enclosure at ground level was destroyed, but, otherwise, the house sustained little flood damage.

Figure 4-14.
House constructed on piles several feet higher than the BFE. Floodwater, waves, and debris caused damages to the ground level enclosed area of the house, but not to the elevated portion. (Big Lagoon)

Figure 4-15 shows the region just to the west of the house in Figure 4-14. Older unreinforced masonry houses on slab foundations (arrows) were destroyed, but other houses elevated on piles above the BFE (circled) survived. MAT team members observed many debris scars 5-to-7 feet above the base of trees in the area, giving an indication of flood depths during Ivan. Debris scars were also evident on the underside of the joist sheathing of the house circled on the right side of Figure 4-15. The house was elevated one full story to allow for under-house parking. The dashed line in Figure 4-15 shows the landward limit of floodborne debris in the area; Figure 4-16 shows some of the debris.

Figure 4-15.
Area just to the west of the house shown in Figure 4-14. Pile-elevated houses above the BFE (circled) survived, while older houses on slab foundations were destroyed. Dashed line indicates landward limit of debris that washed through the area.

Figure 4-16.
Ground view of some of the debris shown in Figure 4-15.

Another location visited by the MAT along the north shoreline of Big Lagoon, was the Sinton Drive area, approximately 1.5 miles east of Seaglade Drive. Flood damages in the Sinton Drive area were consistent with those observed at Grande Lagoon and Seaglade Drive: survival of pile-elevated houses several feet above the BFE (see Figure 4-17), damage to houses elevated at or near the BFE (see Figure 4-18), and destruction of older houses at or near grade. The flood hazard zone and BFE for the house in Figure 4-17 are AE, elevation 8 feet NGVD, but this area experienced V-Zone conditions, i.e., water levels close to 14 feet NGVD with waves and floodborne debris.

Figure 4-17.
This house located near Sinton Drive successfully resisted flood forces since it was elevated higher than the BFE on piles (note the wind damage: loss of vinyl siding, soffit and roof covering). Lower, adjacent houses (see Figure 4-18) were destroyed.
(Big Lagoon)

Figure 4-18.
This photo shows the destroyed building adjacent to the house in Figure 4-17. It was destroyed (knocked off the masonry pier foundation) by some combination of storm surge, wave and debris impacts, and wind.
(Big Lagoon)

4.1.1.2 Slab on Grade

Buildings constructed with slab-on-grade foundations were widely observed throughout the affected area, and generally fell into two classes: 1) pre-FIRM houses inside and outside the SFHA, and 2) post-FIRM houses outside the SFHA. Many of these buildings sustained significant damage or were destroyed. In numerous cases, the high level of damage was associated with water levels several feet above the slab, accompanied by waves and floodborne debris (see Figures 4-19 through 4-22). Inundation-only damage was observed in flooded houses far from the shoreline (see Figure 4-23). Slab failure due to erosion was frequently evident on the barrier islands, but less so on the bay and sound shorelines.

Figure 4-19.
The pre-FIRM building constructed on a slab foundation (foreground) was completely destroyed, yet the adjacent building constructed on piles at a higher elevation remained intact and suffered relatively little damage. (Big Lagoon)

Figure 4-20.
Destruction of slab-on-grade house (circled) in the Grande Lagoon neighborhood. Adjacent houses elevated on piles above the BFE sustained destruction of ground level enclosures and some wind damage, but survived. (Big Lagoon)

Figure 4-21.
The unreinforced masonry pre-FIRM building in the foreground was swept off its slab foundation during Ivan. On the adjacent building, the lowest floor was gutted and the walls ripped out by wave and debris impacts.
(Oriole Beach)

Figure 4-22.
This slab-on-grade building located on the back side of the barrier island but directly on the sound was heavily damaged by wave action.
(Pensacola Beach)

Figure 4-23.
The slab-on-grade building located near the back side of the barrier island was protected from wave action by other houses, but had 4 to 5 feet of water inside. (Pensacola Beach)

4.1.1.3 Stem Walls

Overall, the MAT observed that stem wall foundations performed well against the storm surge, and wave and debris impacts near bay and sound shorelines. However, the MAT observed several buildings where the stem wall foundations survived, but the buildings atop the foundations were destroyed (see Figure 3-8) or heavily damaged (see Figures 4-24 and 4-25). In one instance, a stem wall foundation was used to elevate a house (under construction) above the BFE, and damage to the unfinished house was relatively minor – porch columns and one exterior wall were damaged, apparently by waves or debris slightly exceeding the top of the foundation (see Figure 4-26).

In all cases observed by the MAT, scour around the stem wall foundations was limited, and foundation failures did not occur; however, this type of foundation would be expected to be vulnerable to scour and erosion on barrier islands or on higher relief, sloping bay shorelines.

Figure 4-24.
House constructed in a Zone AE on a stem wall foundation, which survived, although high floodwaters with debris and wave action caused major damage (Big Lagoon)

Figure 4-25.
Stem wall foundation where floodwater exceeded required flood elevation by approximately 4 feet (Garcon Point, Escambia Bay)

Figure 4-26.
This stem foundation elevated the house above the BFE and performed well. The house, which was under construction at the time of Ivan, sustained minor flood damage to the walls and the columns under the porch. (Tiger Point, Santa Rosa Sound)

4.1.1.4 Piers

Many pier foundations were observed to perform poorly, although many of these foundations were used for older, pre-FIRM structures and were minimally reinforced or unreinforced. Figures 4-27 and 4-28 show examples of pier foundation failures at older structures. Figure 3-3 shows a newly constructed house on piers that was severely damaged by waves and debris that exceeded the height of the lowest floor although the piers themselves remained intact.

Pier foundations are typically constructed on shallow footings, which are prone to failure due to erosion and scour. Tall pier foundations are also prone to failure from overturning when flood loads are applied to the building. Pile foundations generally perform better than pier foundations, especially when constructed in sandy material, which is vulnerable to erosion and scour (see Figure 4-29). Pile foundations provide much more flexibility and cost efficiencies to account for increases in elevation of the finished floor of the structure and for additional embedment to allow for any erosion and scour that will likely occur on sandy beaches.

Figure 4-27.
Unreinforced pier foundations failed due to scour at the footing and flood levels exceeding the floor elevation (Oriole Beach).

Figure 4-28.
Center pier failed causing the elevated floor to collapse. Other adjacent buildings were elevated on pilings and solid foundation walls; the piers performed better than the solid walls, but not as well as the pilings (Santa Rosa Sound)

Figure 4-29.
Tall, lightly reinforced masonry piers failed due to lateral loads from surge and wave action. The pile supported houses under construction in the background are the same ones indicated (by arrows) in Figure 4-12. (Big Lagoon)

Manufactured houses placed on unreinforced, dry-stacked block piers were observed to shift in some cases due to the storm surge and wave action effects. Figures 4-30 through 4-32 provide several examples of piers shifting under manufactured houses. These types of piers are not suitable for coastal areas.

Figure 4-30.
Manufactured home park where houses experienced storm surge, scour, and foundation collapse (Orange Beach)

Figure 4-31.
Unreinforced, dry-stacked block piers slid off of footings. (Orange Beach)

Figure 4-32.
Dry-stacked pier failure (Orange Beach)

4.1.2 Multi-Family Residential Buildings

With a few exceptions, newer multi-family structures on the barrier islands generally withstood Ivan's flood and erosion effects quite well, with the exception of lower floors of some buildings that were heavily damaged when Ivan's waves exceeded local BFEs and when erosion undermined nonstructural slabs. Many multi-family buildings, however, sustained wind damage at less than design wind speeds (see Section 4.2).

One class of multi-family buildings sustained significant flood damage: those buildings constructed on shallow foundations on the barrier islands. Ivan caused up to eight feet or more of vertical sand loss in some beachfront areas, and several buildings not constructed with deep foundations collapsed. This was the first time that MAT members had seen catastrophic failures of multi-family buildings due to erosion. In some areas (e.g., Pensacola Beach, central Gulf Shores), undermining failures of some buildings on shallow foundations were probably prevented by recent beach nourishment projects.

The observed damages are discussed below by foundation types: shallow foundation and pile supported. Damages to bulkheads and pools are discussed in 4.1.3.1.

4.1.2.1 Shallow Foundations

Hurricane Ivan produced significant storm surge and high waves that caused widespread and severe erosion along the barrier islands of Baldwin County, Alabama, and the northwestern Florida Panhandle. In general, sand loss up to 8-10 feet high was observed, and 100 feet or more of dune loss was observed in some areas. Due to the severe sand loss, buildings constructed on shallow foundations experienced significant failure and collapse. Many of these buildings were constructed in flood Zones B or C, in which the NFIP has no specific foundation requirements. However, the FBC requires buildings constructed seaward of the CCCL to be constructed on pile foundations. In Alabama, where coastal construction requirements are not as strict as Florida's CCCL, severe building damage occurred as a result of erosion to soils supporting shallow foundations and surrounding shallowly embedded pile foundations. Figures 4-33 and 4-34 show a post-1997 building that was constructed on a shallow foundation in a Zone B. This building experienced total collapse during Hurricane Ivan. Figure 4-35 shows a similar collapsed building and the success of the adjacent buildings constructed on piles and columns.

Figure 4-33.
Total collapse of 5-story building on a shallow foundation (Orange Beach)

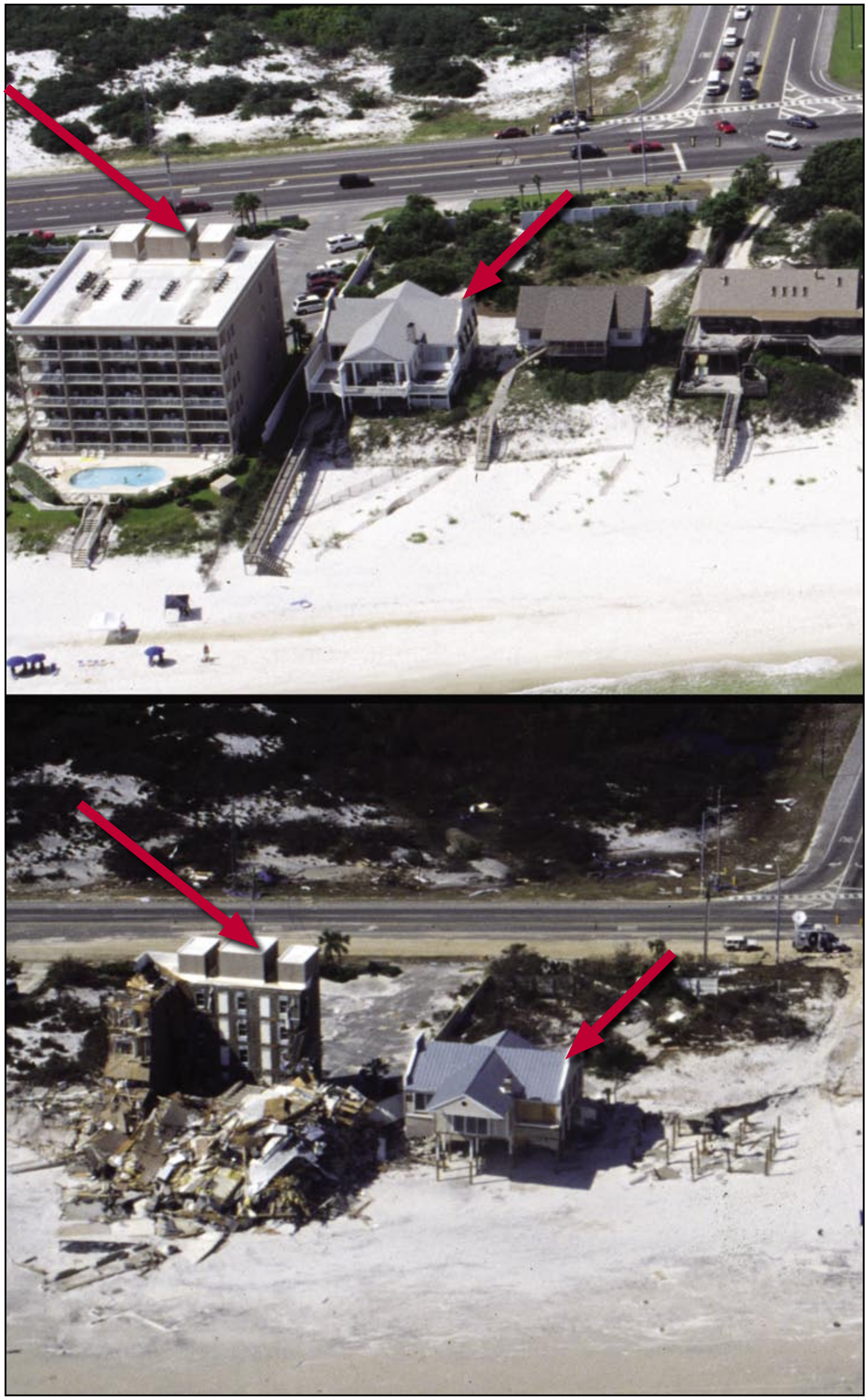
Figure 4-34.
Close-up of building shown in Figure 4-33 (Orange Beach)

Figure 4-35. Shallow foundation failure. Note success of pile support structures in the background. (Orange Beach - Perdido Key)

Figure 4-36 shows before and after Hurricane Ivan photos of a 5-story building that was constructed on a shallow foundation in flood Zone C in the late 1990s. The lowest floor elevation was 19 feet NGVD, several feet above the highest BFE shown nearby on the 1992 FIRM in effect when the building was constructed. However, the supporting soil was undermined during Ivan and the seaward two-thirds of the building collapsed. Review of the permitting file shows initial calculations indicated erosion would occur beneath the seaward edge of the foundation during a base flood event. Sand was added to the dune to compensate for the potential undermining, but it was obviously a poor decision to rely on a shallow foundation and a crude erosion calculation. Figure 4-37 shows another multi-family building on a shallow foundation damaged by Hurricane Ivan. In this case, the storm undermined just the front of the building, causing it to settle, and damaging all eight stories.

Figure 4-38 shows ground and aerial views of older buildings at Pensacola Beach, elevated on masonry walls and columns atop shallow footings. The seaward row of buildings survived Hurricane Opal in 1995 but did not survive Ivan in 2004, due in large part to the severity of Ivan. This scene will be repeated less and less in the future since new construction on Pensacola Beach is restricted to pile foundations by the local unit of government, the Santa Rosa Island Authority (SRIA). SRIA has mandated V-Zone design and construction standards and required 1 to 3 feet of freeboard across the entire barrier island community (V Zones and A Zones) since before Hurricane Opal. After Ivan, SRIA is modifying their ordinance to require 3 feet of freeboard everywhere.

Figure 4-36.
Collapse of a 5-story building constructed on a shallow foundation. Arrows identify buildings before and after Ivan. (Orange Beach) Photo courtesy of USGS



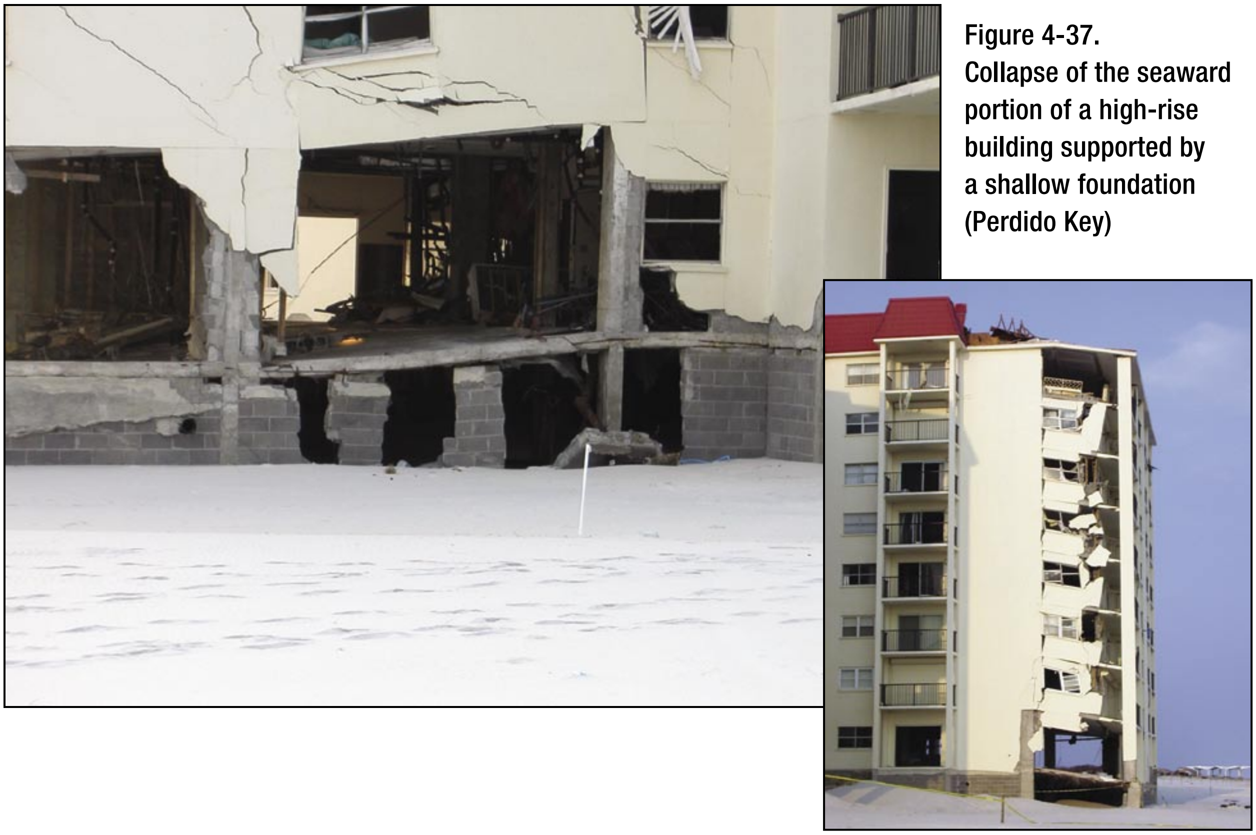


Figure 4-37.
Collapse of the seaward portion of a high-rise building supported by a shallow foundation (Perdido Key)

Figure 4-38.
Older buildings constructed on masonry columns and walls atop shallow footings (Pensacola Beach).

Although many multi-family structures were not affected by erosion during Ivan, many were affected by high winds, storm surge, waves, and floating debris. Figure 4-39 shows a building located on the north side of Pensacola Beach, near the Santa Rosa Sound shoreline. NFIP records indicate flood claims have been paid for units in the building on four occasions: September 1998 (Hurricane Georges), October 1995 (Hurricane Opal), August 1995 (Hurricane Erin), and September 1979 (Hurricane Frederic).

Figure 4-39.
This building has been flooded by Hurricane Ivan and four prior storms. (Pensacola Beach)

Figures 4-40 and 4-41 show another pre-FIRM multi-family building on a slab foundation that was heavily damaged by storm surge, waves, and debris, this one on the north side of Santa Rosa Sound.

Figure 4-40.
Multi-family building on a bay shoreline, heavily damaged by surge, waves, and floating debris (Oriole Beach, Santa Rosa Sound)

Figure 4-41.
Aerial view of building in Figure 4-40 (circled)

4.1.2.2 Pile Foundations

Pile foundations in multi-family structures generally performed very well, although the high storm surge elevations caused considerable damage to ground level enclosures and to some lowest floor living units, especially to those Orange Beach buildings constructed in flood hazard Zones B, C, or X, where BFEs had not been established. The use of pile foundations for multi-family buildings avoided the severe damage and collapse observed at buildings with shallow foundations but, by itself, was not sufficient to prevent loss of lowest floor living units. Full compliance with VE-Zone construction standards (e.g., use of a structural floor system and elevation of the lowest horizontal structural member above the wave crest elevation) was also necessary to prevent damage to those living units (see Figures 4-42 through 4-44). In some instances, buildings were sited far enough from the shoreline that erosion was not an issue, but Ivan's surge and wave action was still sufficient to damage the lower story.

Figure 4-42. Multi-story buildings on piles, impacted by storm surge, waves, and erosion, which damaged many lower area walls and floors (Orange Beach)

Figure 4-43. Although the pile foundation and structural elements survived, damage to lowest floor exterior walls, interior partitions, and floor slabs occurred during Ivan. (Orange Beach)

Figure 4-44.
Pile foundations alone are not enough; elevation of the lowest floor is also critical. The building on the left shows minimal damage, while the building on the right with the lower-level living units experienced significant non-structural damage. (Orange Beach)

A separate study of Orange Beach multi-story structures was undertaken to determine the extent and characteristics of lowest floor living unit damages (see Appendix F). The study examined 41 multi-story structures, not including the collapsed structures. Thirty-nine of the 41 buildings had a total of 233 living units at the lowest floor level. The buildings were constructed over the years in flood hazard zones B, C, AE, and VE, using high-rise construction techniques typical for their respective zones.

Approximately 80 percent of the lowest floor living units were destroyed by flood and/or erosion effects. Although most of the tops of the lowest floors were at or above the highest BFEs appearing on any of the FIRMs in the past 20 years, much damage was still sustained by the buildings, due to lowest floor collapse and/or stillwater levels during Ivan that exceeded BFEs by up to 2 feet (see Table 1-2 and Figure 1-8), with wave crest elevations higher yet.

Figures 4-45 and 4-46 show a pile and column supported building at Pensacola Beach that sustained little flood damage, despite severe scour around its foundation, since use of the grade level area was limited to parking and building access.

Figure 4-45.
This condominium on a deep foundation is located on the back side of the barrier island, north of Ft. Pickens Road. This building was severely damaged by wind, along with some utility damage in the lower level, and severe scour around the concrete pile caps. Since it was constructed on deep foundations and there were limited enclosures below the first floor, damage caused by storm surge was limited. (Pensacola Beach)

Figure 4-46.
Aerial view of the building shown in Figure 4-45 (FL DEP photo) (Pensacola Beach)

Figures 4-47 through 4-49 show examples of other flood and erosion damages that affected multi-family buildings on the barrier islands. Figure 4-47 shows a Perdido Key lower floor living unit that was flooded and buried in sand; no structural damage occurred to the building as a result, but the lower unit walls, fixtures, and contents were destroyed. Figure 4-48 shows several Orange Beach multi-family structures whose bulkheads, pools, decks, and lower floor spaces were damaged or destroyed. Figure 4-49 again illustrates the relative damages associated with deep and shallow foundations during Ivan; the 5-story building in the center (shallow foundation) collapsed, while the buildings on either side (deep foundations) sustained flood damage to the ground level enclosures and parking areas only.

Figure 4-47. Building with flood and wave damage to the lowest floor living units. Some units had up to two feet of sand deposited inside. (Perdido Key)

Figure 4-48. Most of the first floor units in these buildings were severely damaged (see Figures 4-53 and 4-54). (Orange Beach)

Figure 4-49.
Pile-supported buildings performed much better than buildings constructed on shallow foundations as shown in the building in the center, which collapsed. (Orange Beach)

4.1.3 Miscellaneous Structures

This section discusses observed damages and successes for various elements related to single and multi-family residential structures, including bulkheads, non-structural slabs, breakaway walls, and utilities.

4.1.3.1 Bulkheads

Bulkheads were used around many single-family and multi-family structures along the open coast in Gulf Shores and Orange Beach, Alabama. These structures were not observed as frequently along beaches in Florida due to state-mandated restrictions on coastal armoring. Their general purpose is to retain soil and provide protection from erosion. They are often used to contain sand that supports pool decks and non-structural parking slabs beneath buildings. In most cases, these walls were observed to have been damaged or destroyed by Ivan.

High storm surge, waves, and erosion resulted in frequent damages to bulkheads, pools, and pool decks. Figure 4-50 shows a typical pool failure. Lightweight bulkheads (particularly those constructed of vinyl and timber) sustained significant damage during Ivan (see Figures 4-51 and 4-52). Some concrete bulkheads failed, but the more substantial ones remained intact. However, even intact concrete bulkheads were sometimes overtopped and suffered erosion on the landward side (see Figures 4-53 and 4-54).

Figure 4-50.
Typical pool failure
(Pensacola Beach)

Figure 4-51.
Retaining wall failure
(Gulf Shores)

Figure 4-52.
Failure of vinyl bulkhead with concrete cap (Orange Beach)

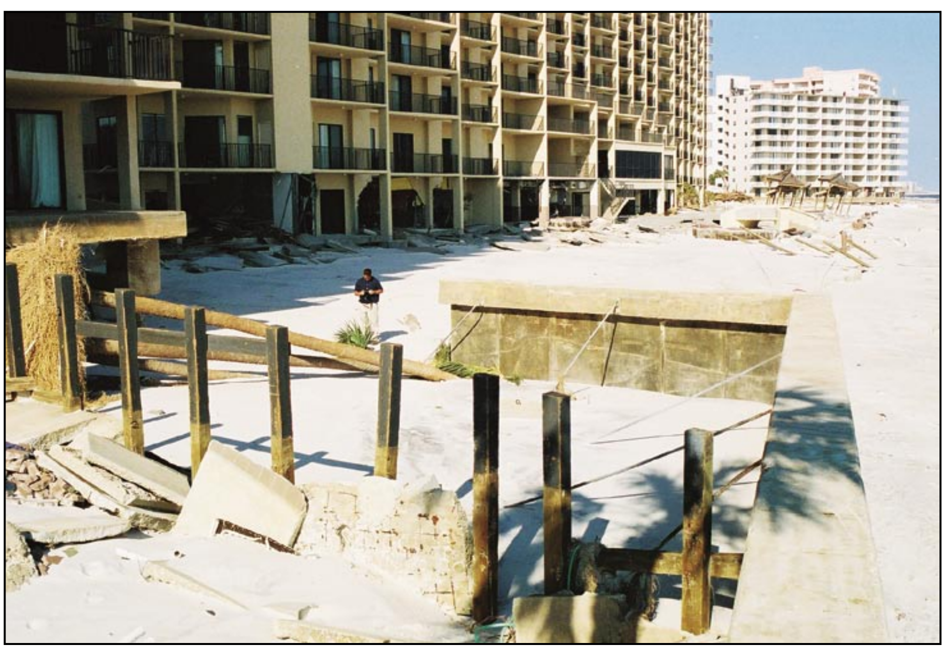


Figure 4-53.
Bulkhead remained intact, but short return wall allowed erosion behind the wall (Orange Beach)

Figure 4-54.
Bulkhead shown in Figure 4-53 remained in-place, but surge and wave overtopping, coupled with erosion at the short return wall, led to deck and retaining wall failure. (Orange Beach)

4.1.3.2 Non-Structural Slabs

Many pile-elevated single-family and multi-family buildings were constructed with non-structural parking slabs that relied on the underlying soil for support. When the underlying soil was washed away by Ivan, the slabs were undermined and almost always collapsed, as expected (some remained in place because they were tied to the pilings). Figures 4-55 through 4-58 show typical examples of the performance of these non-structural slabs.

Figure 4-55.
Sand below slab completely eroded away, causing the total failure of slab, but grade beams remained intact. (Gulf Shores)

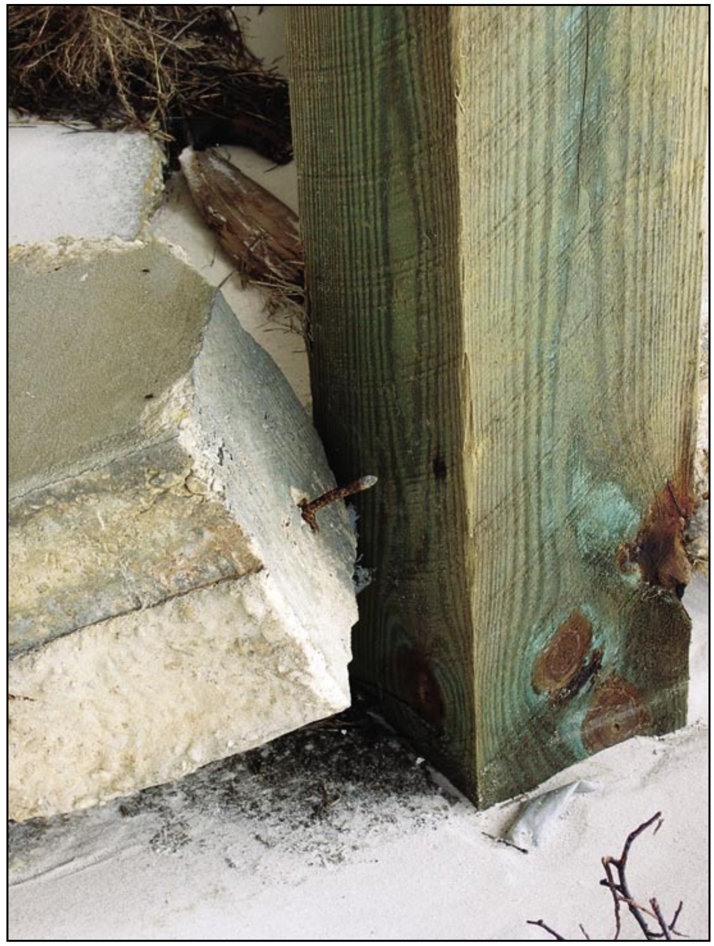


Figure 4-56.
Concrete slab partially separated from the pile even though it had been connected with a nail. These slabs should break free cleanly so they do not transfer flood loads to the foundation. (Gulf Shores)

Figure 4-57.
Typical non-structural concrete slab failure. Horizontal line indicates previous location of soil level and slab.
(Orange Beach)

Figure 4-58.
This slab failed but did not break into small pieces due to the reinforcing steel. The incomplete slab failure might have transferred flood forces to the foundation and contributed to the pile failure (piles in background were partially pulled out of the ground and are leaning). (Orange Beach)

4.1.3.3 Breakaway Walls

Walls used for enclosures below the BFE in areas designated as Zone VE must be designed to break away under the base flood. Breakaway walls are required in such instances so as to limit the transfer of wave and debris loads to the pile-elevated building foundation. The MAT observed the vast majority of breakaway walls functioned as intended (see Figure 4-59). However, in some instances the MAT observed some problems with breakaway wall design and construction. For example:

- Some breakaway walls did not break away cleanly, causing damage to wall finishes above the breakaway panels (see Figure 4-60).
- In some cases, utilities were connected to the walls, thereby preventing a clean wall failure (see Figure 4-61).
- In some cases, breakaway walls were installed across pilings instead of between pilings (see Figure 4-62).

Figure 4-59.
Failure of breakaway walls as designed (Gulf Shores)

Figure 4-60.
Poor detailing of the joint between the breakaway wall and the wall above contributed to loss of wall covering above the floor beam. (Pensacola Beach).

Figure 4-61.
Failure of interior partition to break away cleanly due to the attachment of utilities (Gulf Shores)

Figure 4-62.
Breakaway walls were nailed over the piles and floor beam, preventing a clean break. (Gulf Shores)

4.1.3.4 Utilities

The MAT observed significant damages to utilities at residential structures. The damages occurred due to the locations of utility components, their support, and their attachment. Figures 4-63 through 4-71 illustrate typical utility performance concerns observed by the MAT, all of which are discussed in FEMA 348, *Protecting Building Utilities from Flood Damage* and FEMA 55, *Coastal Construction Manual: Principles and Practices of Planning, Siting, Designing, Constructing, and Maintaining Residential Buildings in Coastal Areas.*

Figure 4-63.
Loss of condenser platform support. A cantilevered condenser support is recommended (see Figure 8-3). (Pensacola Beach)

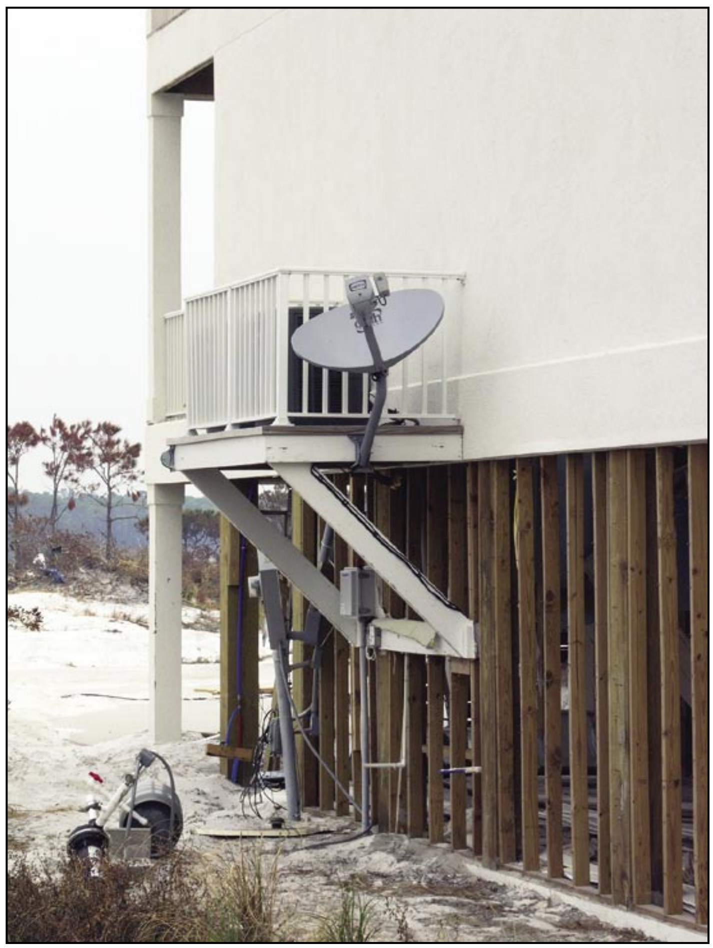


Figure 4-64.
Diagonal condenser platform members are susceptible to wave and waterborne debris damage. Cantilevered condenser platforms are preferable (see Figure 8-3). (Gulf Shores)

Figure 4-65.
Elevator system severely damaged by surge, waves, and debris (Gulf Shores)

Figure 4-66.
Loss of platform supports and air conditioning unit due to erosion and flood forces (Gulf Shores)

Figure 4-67.
House under construction at the time of Ivan (Big Lagoon). Note the condenser platform foundation survived the flood forces (masonry-column-supported house in the foreground was destroyed).

Figure 4-68.
Erosion and flood damage to multi-family electrical transformer and interior mechanical room (Perdido Key)

Figure 4-69.
Debris and sand in low-elevation mechanical room (Perdido Key)

Figure 4-70.
Damage to the electrical panel, but utility lines were located appropriately (beside an interior pile) (Pensacola Beach)

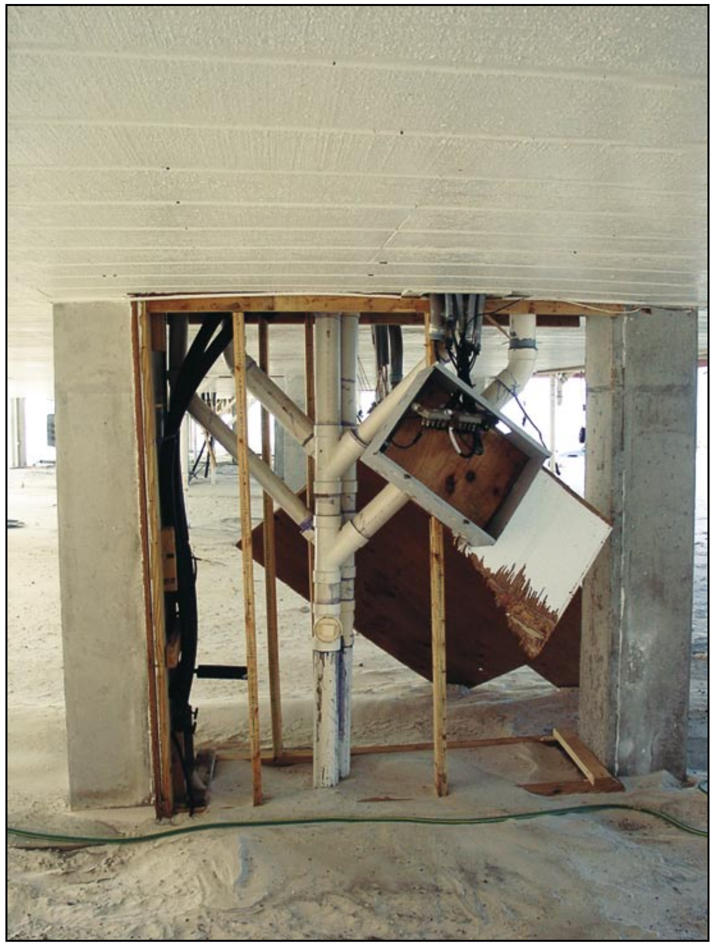


Figure 4-71.
Drain lines constructed between interior piles (which helped to protect them from flood forces), although electrical box was connected to plywood panel and was destroyed (Pensacola Beach)

4.1.3.5 Stairs

As coastal residences get more expensive and elaborate, the access stairs are getting larger and more substantial. In most cases, this does not present a problem; however, in some cases the stair structures could act as obstructions and could potentially transfer flood loads or cause wave deflection onto elevated structures. Figures 4-72 and 4-73, respectively, show examples of stairs that are and are not likely to act as obstructions.

Figure 4-72.
Massive stairs that will obstruct flows could deflect waves and debris into the elevated building. This type of stair structure is a violation of the V-Zone free-of-obstruction requirement. (Gulf Shores)

Figure 4-73.
Stairway structures (circled) that will minimize obstructions to flow and potential adverse effects on the elevated building (Gulf Shores)

4.1.4 Debris Impacts

Besides the building damage that resulted directly from storm surge, wave action, and erosion, severe damage was often caused by floating debris. Debris damage was common along the barrier islands, but seemed especially abundant in the back bays due to the large debris fields generated by more seaward damaged or destroyed buildings, decks, and dune walkovers, and by numerous docks along the bay shorelines. It was not uncommon to see debris from barrier islands that had floated across sounds and bays, damaging houses along those inland shorelines. Also, below-BFE enclosures were destroyed by the thousands throughout the storm impact area, adding significantly to the debris field available to damage other buildings.

Typical examples of debris impacts are shown in Figures 4-74 through 4-81.

Figure 4-74.
Large accumulation of debris trapped between house and dune walkover (Gulf Shores)

Figure 4-75.
Ground level photograph of debris shown in Figure 4-74 (Gulf Shores)

Figure 4-76.
Marine pile debris washed into this house in the back bay. (Oriole Beach)

Figure 4-77.
Same marine pile as shown in Figure 4-76. Note the size and the length of the pile, which caused significant damage. (Oriole Beach)

Figure 4-78.
Boats and dock debris from a marina struck this pile-elevated building, deforming floor beams, breaking joist connections, and scarring pilings. (Big Lagoon)

Figure 4-79.
Typical view of destroyed docks contributing to floodborne debris (Big Lagoon)

Figure 4-80.
Small stones from a nearby revetment were likely propelled by waves into this north-facing sound side house, breaking windows and sliding glass doors. (Gulf Breeze)

Figure 4-81.
The small stone revetment contributed stones which were propelled by waves and struck the house, shown in Figure 4-80 (Gulf Breeze)

4.2 Wind

4.2.1 Wood Frames

Most of the wood-frame buildings observed by the MAT were residential buildings, both single family and low-rise condominiums. Overall, the predominant wind related damage to these types of buildings was not structural failure, but a failure of the building envelope, which will be discussed in Chapter 5.

The wood-framed buildings observed by the MAT generally consisted of superstructures supported by the load-bearing exterior wood-framed walls. Building floors and roofs were supported by wood rafters or trusses and plywood decks. This type of construction is known as light-frame construction and consists of nominal 2-inch thick framing members spaced 12 inches to 24 inches together and normally concealed by interior finish materials such as plaster, gypsum board, or wood paneling. Figure 4-82 shows a diagram of a typical residential building designed to meet high wind requirements.

Wood is favored as both a structural material and a finish material for its economy, architectural flexibility, and aesthetics. Although it is rarely used today for commercial buildings, wood is a very favorable material to use for residential buildings. Most construction contractors are familiar with wood as a building material. Small work crews can handle most wood members without special lifting equipment, cutting and fastening can be accomplished on site with hand held or portable power tools, and the skills needed for wood construction are easily learned. The ease of construction and the flexibility of wood construction also lead to one of the major problems with it as a system: it can be assembled or modified in so many different ways. Thus, it becomes more difficult to standardize details and to ensure that the contractor follows the plans and specifications. For example, a structural steel frame can generally be assembled only in the way the engineer and fabricator planned it to be. Otherwise, the beams and columns simply will not fit, and field modifications are difficult. In the case of wood framed construction, a supply of the basic raw materials (lumber, plywood, nails) are delivered to the job site, and there are many ways they can be cut and assembled. Wood is also one of the most difficult materials for the designer to master because it is virtually the only building material that is natural rather than manmade, which entails a number of uncertainties. Wood structures may be the simplest to build, but they are among the most complicated to design.

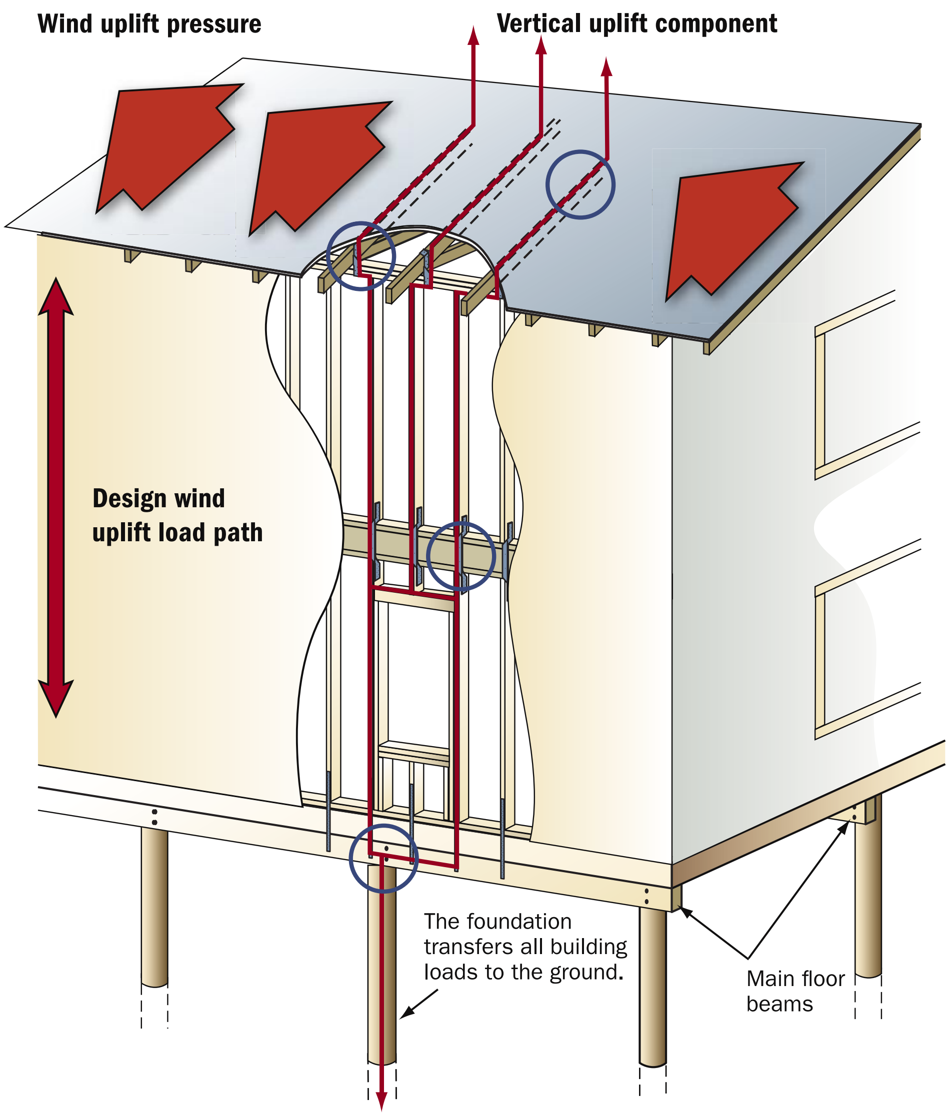


Figure 4-82.
Load path of a two-story building with a primary wood-framing system: walls, roof diaphragm, and a floor diaphragm

In the areas damaged by Hurricane Ivan, the MAT observed few houses new enough to have been built under the FBC 2001 or the IBC 2003. In addition, the actual wind pressures were below the code prescribed pressures; therefore, Ivan could not be considered a true "code design-level test." Therefore, it is difficult to evaluate the effect of new codes. It did appear that newer wood-frame houses generally performed well structurally. Efforts in the last 15 years to increase the quality of coastal construction, such as the SBC SSTD-10, Hurricane Resistant Residential Construction Standard, and FEMA 55, *Coastal Construction Manual*, have been successful. Many newer houses observed by the MAT had significant damage due to storm surge below their elevated floors as expected, but showed little signs of structural damage due to wind or water (see Figure 4-83).

Figure 4-83.
Storm surge damaged the lower portion of this house, but no wind damage was observed. (Gulf Shores)

The most common wind related structural failures observed in light-framed construction were roof framing failures. They were most commonly observed in older construction, but there were incidents of newer buildings experiencing the same damage. Insufficient attachment of roof sheathing panels to the supporting framing was the most common problem. The discovery of zones of high uplift pressures on the edges of roof surfaces through wind research over the last 25 years has caused newer codes to require much closer nail spacing in these zones. Older construction does not have these closer spacings in the sheathing nail patterns, and, thus, it is more susceptible to uplift damage. Once the sheathing attachments fail, a variety of other failure modes can happen. Attics that have been breached become pressurized and other structural elements may then become overstressed. This can lead to an "unzipping" effect of progressive failure where one failure leads to a series of subsequent failures.

Figure 4-84. Progressive failure of wood roof framing (Perdido Key)

Another common failure point was wood-frame gable end walls. These are commonly under designed or improperly constructed. Often, a typical roof truss is the only support element behind the wall covering of the gable as shown in Figure 4-85. Trusses are constructed with the weak dimension of the lumber turned normal to the plane of the truss. This means that when a typical truss is used alone as the wall framing for the gable end wall, the truss members must resist the wall's wind forces in their weak direction. On larger buildings, the height of the gable end wall from the plane of the ceiling up to the peak of the gable is often taller than the story heights below. In these cases, even wall studs would have to be strengthened in order to be adequate. The truss members are typically not capable of carrying the bending forces in this manner. In cases where adequate wall stud framing is present in the gables, the problem is typically the absence of adequate bracing where the gable end wall sits on top of the wall below. This point is a hinge and must be braced by framing to transfer the wind loads into the lateral load resisting system. Figure 4-85 illustrates the arrangement of these structural members in typical light-frame construction. The framing shown in Figure 4-86 shows a truss resisting the wind loads with its weak axis. This was in an upscale house under construction, so the problem is still not being addressed in all cases. The condominium building shown in Figure 4-87 had no evidence of any bracing at the hinge point in its gable end wall framing.

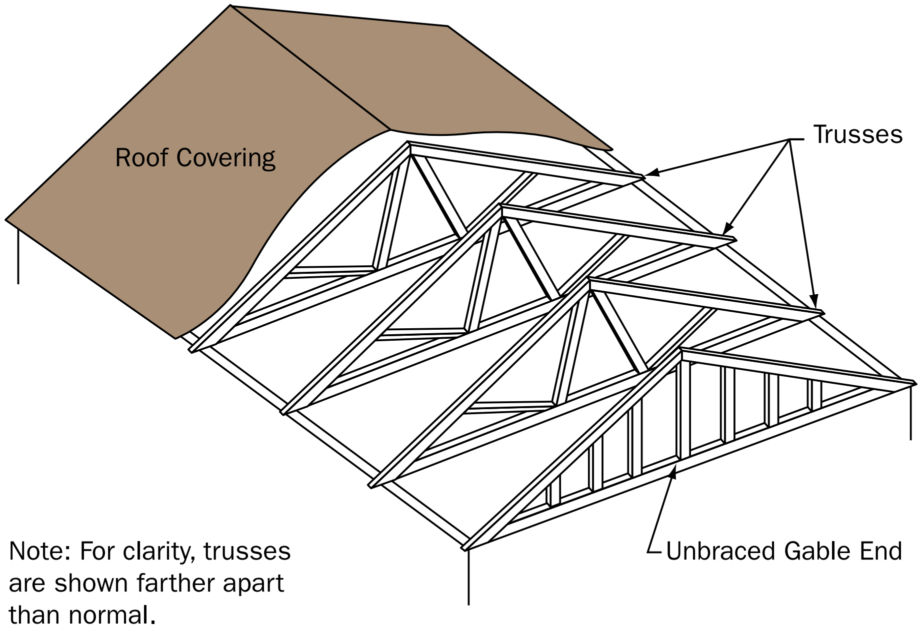


Figure 4-85.
Gable end wall framing diagram

Figure 4-86.
Roof truss with 2x4s oriented in the weak direction resisting the wind loads on a gable end wall (Ono Island)

The final observed failure mechanism in wood framed construction was the connections between the roof and wall members. Particularly evident in older buildings, the roof framing members were often inadequately anchored to the wall framing. Whether caused by no anchors, inadequate anchors, or improperly installed anchors, the failure to complete the load paths, as illustrated in Figure 4-82, was the cause of damage. The MAT observed several buildings such as the ones shown in Figures 4-88, 4-89, and 4-90, which suffered the total loss of the roof framing due to improper anchorage of the roof framing to the walls.

The MAT observed several wood framed houses under construction at the time of the storm. It allowed an opportunity to observe current construction practices. Although in general the quality of residential construction has improved over the last 30 years, there were still examples of poor practices being followed in new wood frame construction. Several improper installations of wood framing connectors were observed by the MAT. Several of these installations seemed to indicate a lack of understanding of the load path concepts illustrated in Figure 4-82. The houses in Figures 4-91 and 4-92 had connectors in place, but they were the wrong type, in the wrong place, installed without the proper number of nails, or were already corroding. Figures 4-93 and 4-94 show the wall studs between two garage doors in an upscale house under construction. The beams above the doors carry all the uplift of the roof framing above. However, note the lack of properly installed connectors to transfer these uplift forces from the beams to the wall studs and from the wall studs to the foundation. Progress is still needed in the design and construction of the load paths in wood framed buildings.

Figure 4-87.
Gable end wall failure due to lack of bracing at hinge point in wall (see arrow) (Perdido Key)

Figure 4-88.
Roof framing damage due to lack of connections from roof to wall (Orange Beach)

Figure 4-89.
Roof framing damage due to lack of connections from roof to wall (Pensacola Beach)

Figure 4-90.
Roof framing damage due to lack of connections from roof to wall (Ono Island)

Figure 4-91.
Improper use of a wood truss press plate connector to substitute for stud hold-downs (Oriole Beach)

Figure 4-92. Already corroded anchor bolt in new construction (Oriole Beach)

Figure 4-93. Improper strapping (Ono Island)

Figure 4-94.
Wall studs between garage doors with inadequate hold-downs (Ono Island)

4.2.2 Concrete Buildings

High-rise buildings, typically built of cast-in-place concrete, suffered little or no wind damage to the primary structural frame. The observed damage was to the building envelope. The building envelope performance is described later in Chapter 5.

4.2.3 Commercial Buildings

Masonry construction is commonly used for commercial buildings, such as shopping centers and office buildings. These buildings were supported on reinforced concrete foundations with shallow spread or deep foundation systems. Exterior load-bearing walls were constructed utilizing concrete masonry unit (CMU). The roof decks were observed to be supported by open web steel joists with metal deck. Very little structural damage was observed in this type of construction. Where structural damage was observed, it seemed to be isolated and a result of poor design or construction or a problem with a particular type of material installation such as shown in Figure 4-95. This building was in an area of relatively low wind speeds, yet suffered catastrophic failure while an adjacent retail center had only minor damage.

Figure 4-95.
Metal roofing failure (Foley)

4.2.4 Pre-Engineered Metal Buildings

A pre-engineered steel building system is generally the most economical commercial building system and is normally utilized for purposes such as warehouses, storage facilities, airplane hangars, and other similar open interior uses. These buildings are easily recognized by their sheet metal siding, tapered rigid frames, and long spans with open spaces. Secondary structural members consisting of girt and purlins are installed to support the metal siding and roofing panels.

As previously observed after other storms, of all the permanent structural framing systems evaluated, the pre-engineered metal framed systems performed the poorest. Exterior walls consisting of thin sheet metal siding failed prematurely, resulting in a penetrated building envelope and causing failure of the main structural framing members. It appeared that the age of the buildings was a factor in their performance, either because of the aging and corrosion of the materials or because of better design practice in more recent times. The MAT noted many newer metal buildings that performed adequately; however, all of the large boat storage facilities, new or old, were observed to have suffered significant damage that was out of scale for a wind event of this magnitude, as shown in Figures 4-96 and 4-97. Frequently, damage to boat storage facilities is caused by wind getting into the building and resulting in internal and external pressure acting simultaneously on the building. Therefore, even at lower wind speeds, these forces will cause significant damage to these types of open structures.

Figure 4-96.
Heavily damaged pre-engineered boat storage building (Orange Beach)

Figure 4-97.
Heavily damaged pre-engineered boat storage building (Orange Beach)

4.2.5 Accessory Structures

Structural damage to accessory structures was observed by the MAT throughout the path of Hurricane Ivan. Carports, canopies, fences, and screen walls were all observed to sustain wind damage. Typical metal canopies between buildings on school campuses did not fare well, as shown in Figure 4-98.

Figure 4-98. Collapsed metal canopy at a middle school (Pensacola)

5

Building Envelope Performance

Good structural system performance 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 building envelope includes:

- Sheathing on the underside of bottom-floor joists of elevated buildings,
- Exterior doors,
- Non-load-bearing walls, wall coverings, and soffits,
- Roof coverings,
- Windows, shutters, skylights, and
- Exterior-mounted mechanical and electrical equipment.

Historically, poor building envelope performance is the leading cause of damage to buildings and their contents in weak- to moderate-intensity hurricanes. Building structural capacities have improved because of stronger building codes and better enforcement, resulting in less structural damage overall from hurricanes such as Hurricane Ivan. As a result, the performance of the building envelope is becoming increasingly important. The following sections describe envelope performance during Hurricane Ivan as observed for residential, commercial, and critical and essential facilities.

5.1 Sheathing on the Underside of Elevated Buildings

Sheathing was typically installed on the underside of bottom-floor joists on elevated buildings. Besides protecting batt insulation that is placed between joists, sheathing can also protect electrical and plumbing lines from floodborne debris. A variety of sheathing materials were observed. Vinyl siding and plywood were the most common, but gypsum board was observed on three buildings, and corrugated metal was observed on one building. The majority of the buildings with vinyl experienced sheathing loss (Figure 5-1). For further discussion of vinyl siding, see Section 5.3.2.

Figure 5-1.
Loss of vinyl siding panels from the underside of an elevated residence in Gulf Shores (Laguna Key)

All of the buildings with gypsum board experienced sheathing loss (Figure 5-2). One of these buildings was a large apartment or condominium – essentially all of the gypsum board was torn away (the gypsum board typically pulled over the nail heads).

Figure 5-2.
Loss of gypsum board from the underside of an elevated residence in Gulf Shores (Laguna Key)

The plywood panels typically performed well, but some losses were experienced (Figure 5-3). Nails were typically used to attach the sheathing. Fastener corrosion was common and some of the nail heads were totally corroded away. Fastener spacing along the joists was often about 12 inches on center. Although the long edge of the sheathing typically occurred over blocking, fastener spacing along the long edge was often only about 16 inches on center.

Figure 5-3.
Loss of plywood from the underside of an elevated residence in Gulf Shores (West Beach)

Fast-moving floodwater and peaking waves likely caused some of the sheathing loss, including complete loss of gypsum board at one building. Gouging of sheathing (including penetration of plywood) by floodborne debris was also observed. However, the majority of the sheathing loss appeared to be caused by wind accelerating as it passed beneath the elevated building. ASCE 7, FBC, and IBC do not provide guidance on determining design wind loads on sheathing on the underside of elevated buildings. Hence, professional judgment in specifying attachment is needed.

5.2 Doors

Failure of an exterior door has two important effects. First, failure can cause a rapid increase in internal pressure, which may lead to exterior wall, roof, interior partition, ceiling, or structural failure. Second, wind can drive rainwater through the opening, causing damage to interior contents and finishes, and lead to the development of mold. The essential elements of good high-wind door performance include product testing to ensure sufficient factored strength to resist design wind loads (both static and cyclic loading); 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 against windborne debris damage, as discussed in Section 5.5.

5.2.1 Personnel Door Damage

Personnel door damage was observed on a limited number of buildings. Observed damage included broken window panes (caused by windborne debris) and door frames that disengaged from the building (likely caused by inadequate fastening to the building), as illustrated by Figures 5-4, and 5-5. The sliding glass door frame in Figure 5-5 had recently been installed in an existing building. The door assembly was rated for a load of +/- 50 pounds per square feet (psf). The applied loads were well below 50 psf. The frame was attached with nails spaced at 4 3/8 inches on center through a vinyl nailing flange. Although the edge distance was limited, the typical failure mode was nail pull-out.

Figure 5-4.
Tempered glass door broken by debris from a mortar-set tile roof (Pensacola)

Figure 5-5.
Sliding glass door frame blown from the wall

5.2.2 Garage Door Damage

Many damaged garage doors were observed in coastal areas. The majority of the doors were damaged by floodwater. Wind-induced damage was minimal. (For observations and discussion of garage door wind damage caused by Hurricane Charley, see FEMA 488, *Mitigation Assessment Team Report, Hurricane Charley in Florida.*) Figure 5-6 shows a combined garage door and wall covering failure. Where breakaway walls are installed, collapse of the garage doors is intended.

Figure 5-6. Floodwater collapsed the garage door at the left end of this residence. (Laguna Key)

5.2.3 Rolling and Sectional Door Damage

A limited amount of wind damage to rolling and sectional doors (e.g., service garage doors and loading dock doors) was observed, including damage to sectional doors at a fire station. (For observations and discussion of rolling and sectional door damage caused by Hurricane Charley, see FEMA 488, *Mitigation Assessment Team Report, Hurricane Charley in Florida.*)

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

Hurricane Ivan caused damage to several non-load-bearing walls, wall coverings, and soffits. Non-load-bearing walls included exterior insulation finish systems (EIFS) and stucco. Wall coverings included brick, metal panels, vinyl, and wood. Vinyl was typically used for soffits. The following factors are essential to good high-wind non-load-bearing wall, wall covering, and soffit performance: product testing to ensure sufficient factored strength to resist design wind loads; suitable anchoring of the wall, wall coverings, 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.

Note: For observations and discussion of breakaway walls, see Subsection 4.1.3.3.

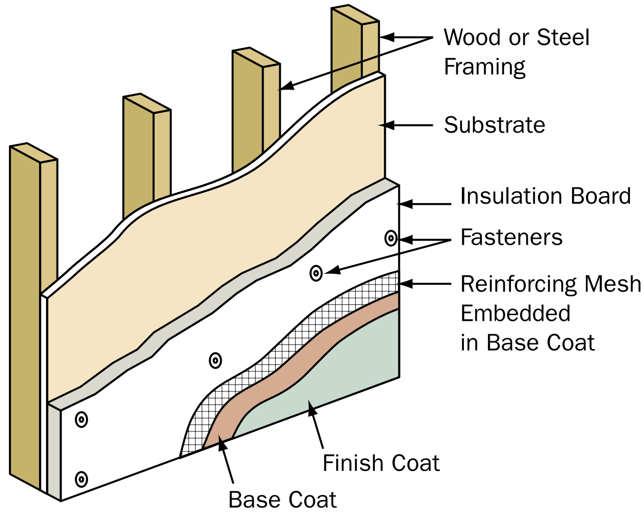
5.3.1 Non-Load-Bearing Walls

Non-load-bearing walls that were investigated included EIFS over studs and stucco over studs. EIFS and stucco wall coverings over bearing walls were also investigated and are included in this section. A large number of EIFS failures and several stucco failures were observed. With loss of the EIFS or stucco coverings, wind-driven rain was often able to enter the wall cavity or the building itself and initiate mold growth. EIFS and stucco coverings that became windborne debris were capable of breaking unprotected windows. Figures 5-7 and 5-8 show typical EIFS and Stucco assemblies.

Figure 5-7.
Typical EIFS assembly

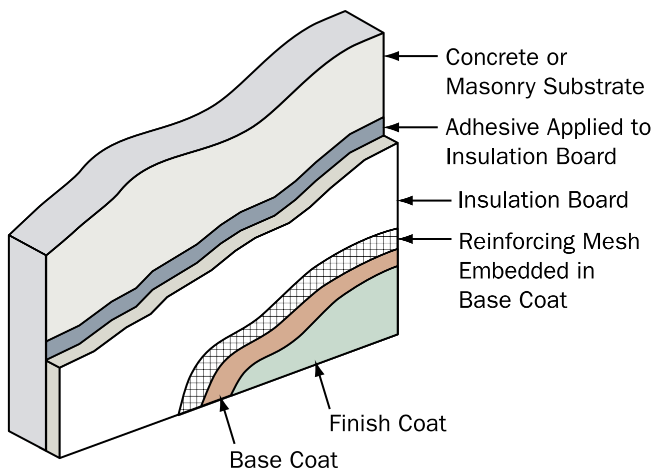
Option A

Steel or Wood Framing
EIFS may be attached by mechanical fasteners (as shown) or by adhesive (as shown below)



Option B

Concrete and Masonry
EIFS attached to concrete or masonry using adhesive. Mechanical fasteners may also be used.



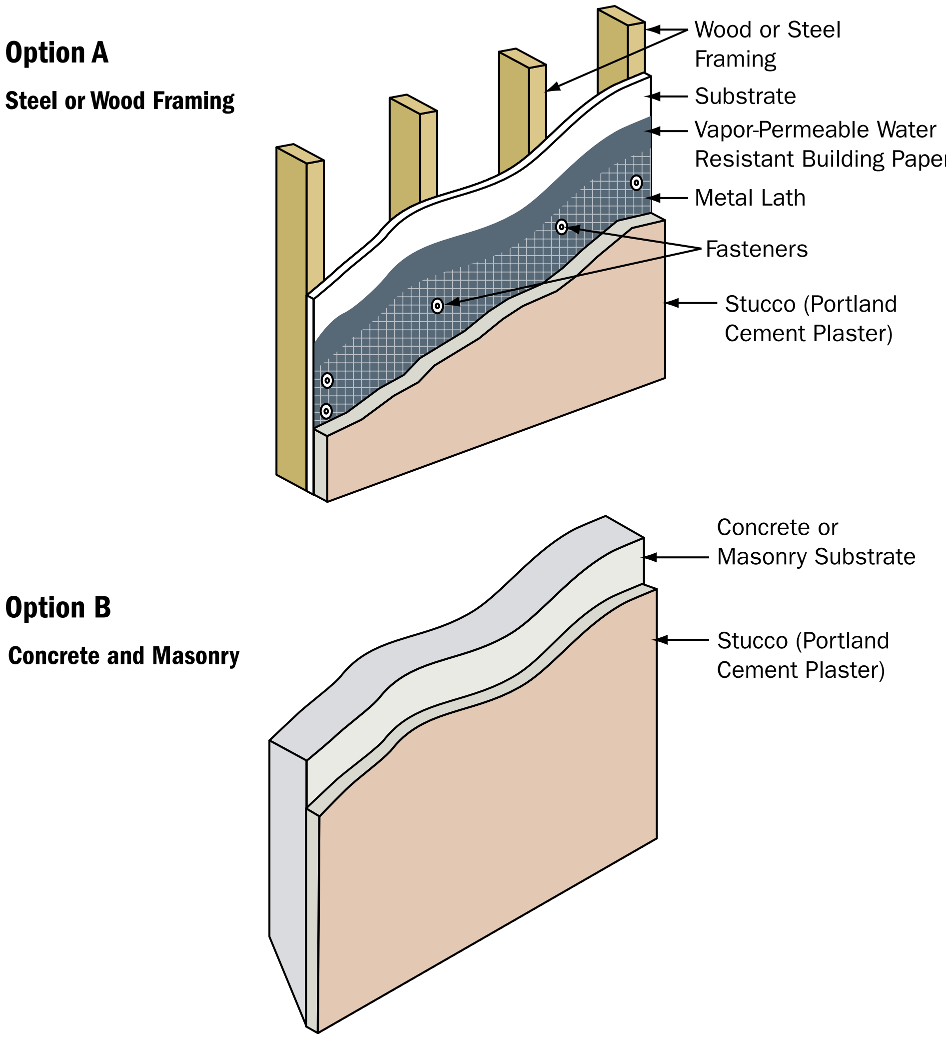


Figure 5-8.
Typical stucco assembly

EIFS

Fast-moving floodwater initiated damage at the residence shown in Figure 5-6, but a projecting wall band limited progressive peeling of the EIFS in the vertical direction. The synthetic stucco was applied over a cementitious board that was installed over housewrap. Floodwater broke away the wall and initiated progressive peeling of the synthetic stucco and cementitious board. However, the presence of the white band that projected about 2 inches out from the face of the wall inhibited vertical peeling.

At the residence shown in Figure 5-9, there was no projecting band, reveal, or other detailing to limit vertical peeling. The synthetic stucco was applied over polyisocyanurate insulation that was installed over asphalt saturated felt. Floodwater broke away the wall and initiated progressive peeling of the synthetic stucco and a portion of the polyisocyanurate. The facer on the polyisocyanurate peeled off with the synthetic stucco. The polyisocyanurate was attached with mechanical fasteners. The fasteners were poorly applied. There were fewer fasteners near the bottom edge than there were in the field rows. The fasteners were placed too close to the long edge of the board. At the end of the boards, fasteners were installed through the board joint, so that one fastener would hold the edge of two boards (see red circle in Figure 5-9). Rather than placing fasteners at the joints, fasteners should have been inward of the joint. If the fasteners had been properly located, several more fasteners would have been required.

Figure 5-9. Vertical peeling on a home in Gulf Shores due to lack of a projecting band or reveal after the breakaway wall failed (Laguna Key)

Figures 5-10 through 5-12 show dry rotted studs and sheathing, indicating long-term moisture intrusion behind the molded expanded polystyrene (MEPS) insulation. Both of these buildings used a barrier EIFS design, rather than the newer drainable EIFS design. (No drainable EIFS designs were observed.) At the condominium in Figure 5-10, the synthetic stucco was installed over MEPS over gypsum board over wood studs. Essentially all of the gypsum board blew off (the boards typically pulled over the fasteners). Some of the gypsum board on the interior side of the studs was also blown off. Note the missing studs on the second level at the left. Stud failure may have initiated the EIFS blow-off. Note the metal diagonal stud bracing straps. Two of the windows were broken by debris.

Figure 5-10.
All gypsum board blown off and two windows broken by debris. Note the missing studs. (Pensacola Beach)

Figure 5-11 is another view of the condominium complex shown in Figure 5-10. The studs were severely rotted and the metal connectors were very corroded.

Figure 5-11.
Severely deteriorated studs and corroded metal connectors

Figure 5-12.
Blown off EIFS revealed severely rotted oriented strand board (OSB) due to water infiltration at windows and wall penetrations. Roof decking blown off of a building with a 5-V crimp metal panel roof.

Figure 5-13 shows common planes of failure of EIFS installed over wood and metal studs. Typically, separation of the synthetic stucco from the MEPS is likely a secondary failure plane. Initial failure is likely caused by detachment of the MEPS from the gypsum board, or detachment of the gypsum board from the studs. When the MEPS detaches from the gypsum board, the gypsum board can suffer strength reduction due to wetting from the wind-driven rain, and it, too, will often then blow off during a hurricane.

On the building shown in Figure 5-13, wood studs were used in the center section and metal studs were used on adjacent sections. In the center area, gypsum board detached from the studs. Near the bottom of the wall and above the MEPS, the gypsum board is still attached, but the MEPS separated from the gypsum board. At the white area, the synthetic stucco separated from the MEPS. Note the attachment of the MEPS to the gypsum board. Adhesive is nearly continuous at the perimeter of the MEPS boards, and four vertical lines of adhesive occur in the field of the boards (the vertical lines are of different lengths and none of them extend all of the way to the board edges). Adhesive should have been continuously applied throughout the entire board area.

Figure 5-13.
Loss of EIFS on a commercial building

Figure 5-14 shows extensive damage to non-load-bearing EIFS walls on a multi-story building. Hurricane Ivan inflicted large areas of EIFS failure on many multi-story buildings.

Figure 5-14.
Multi-story building showing severe EIFS damage. The gypsum board typically detached from the studs. See Figure 7-11 for a close-up of the circled area.

Figure 5-15 shows extensive damage to non-load-bearing EIFS penthouse walls on a mid-rise medical office building (MOB) at a hospital. After failure of the EIFS, rainwater was able to blow into the elevator penthouse and damage the elevator controls. Loss of vertical transportation in mid- and high-rise buildings can severely interrupt functionality.

Figure 5-15.
The gypsum board detached from the studs at the penthouse. Rainwater infiltration damaged the elevator controls. (Pensacola)

Figures 5-16 through 5-19 show EIFS damage and very extensive secondary damages caused by EIFS failures at a hospital complex. Because of rapid emergency response by construction crews, the hospital remained functional. However, the damage was very costly and created hardships on hospital staff.

EIFS debris from the hospital shown in Figure 5-16 broke numerous windows in the MOB and several of the windows in the connecting walkway between the MOB and hospital. The projection from the right rear of the MOB is an elevator. The side walls of the elevator shaft were EIFS and windows were located in the front wall. Several windows were broken by EIFS debris. The EIFS (including the gypsum board substrate) blew off the metal studs in several areas. Water infiltration damaged the elevator controls. Several people were trapped in the elevator during the hurricane. Fortunately, the MOB had another bank of elevators, so vertical transportation was still possible, though handicapped by loss of this elevator.

EIFS (including the gypsum board) also blew off the MOB stair tower walls. Some of the gypsum board on the interior side of the studs collapsed into the stairway, thus trapping a maintenance worker who had gone to the mechanical penthouse during the hurricane.

Figure 5-16.
EIFS blew off the hospital building in the background (see red circle and Figures 5-18 and 6-2). EIFS debris broke numerous windows in the MOB in the foreground. (Pensacola)

Glass shards punctured the one-story roof (Figure 5-17) at the right of the MOB (red arrow in Figure 5-16), which housed the urgent care facility and regional dialysis unit. However, by quickly performing emergency roof repairs and cleaning up the interior, the dialysis unit was non-operational for only one day. The roof over the dialysis unit was a ballasted ethylene propylene diene monomer (EPDM) membrane roof. The roof deck was a concrete or lightweight insulating concrete topping over metal decking. The deck was effective in minimizing water infiltration into the facility. (Note: At the time the photo in Figure 5-17 was taken, the ballast had been repositioned into rows in preparation for removal.)

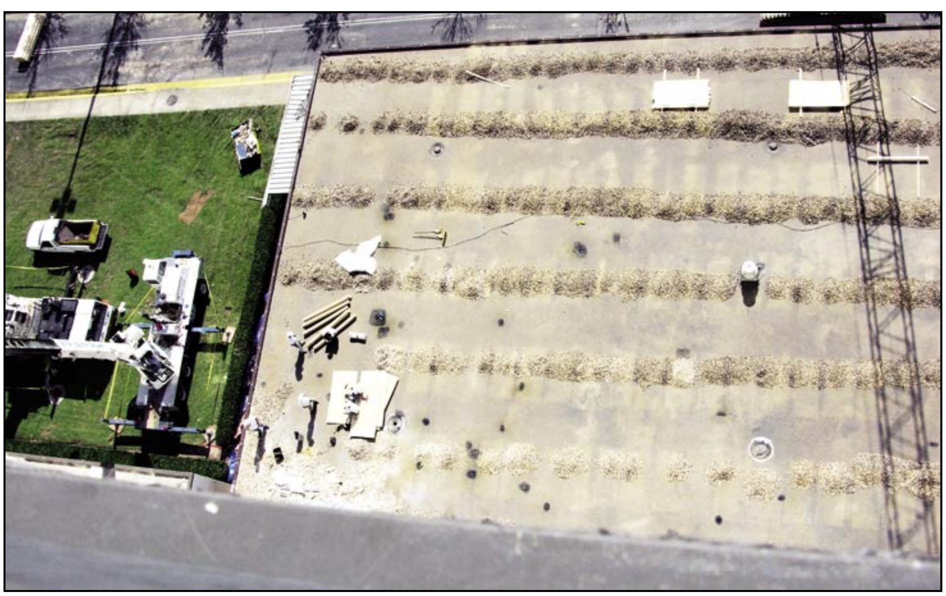


Figure 5-17.
Looking down at the one-story roof to the right of the MOB in Figure 5-16. The small dark areas are locations where emergency patches had been placed to repair punctures from falling glass shards.

The hospital's original concrete wall panels had been furred with metal hat channels and covered with EIFS (Figure 5-18). The majority of the gypsum board panels had blown off. The boards pulled over the screw heads. The screws and hat channels were moderately corroded.

Figure 5-18. Close-up of the damaged EIFS at the hospital

Figure 5-19 shows a close-up of the EIFS spandrel damage and glazing damage at the MOB. Although the majority of the glazing damage was caused by EIFS debris, some window frames were reportedly blown out. These failures were likely due to development of high internal pressure after windows on windward surfaces were broken by debris, combined with suction pressure on the exterior surface of windows on the leeward side of the building.

Figure 5-19.
Wood studs and gypsum board had been temporarily installed after the hurricane to prevent patients from inadvertently falling out of the MOB.

Most of the EIFS damage caused by Hurricane Ivan occurred over metal or wood stud walls. However, some damaged EIFS occurred over concrete walls, as shown in Figures 5-20 and 5-21.

Figure 5-20.
Hospital with EIFS blown off a cast-in-place concrete wall. Note the damaged rooftop ductwork. (Pensacola)

Figure 5-21.
Close-up of Figure 5-20. The light colored round marks indicate where adhesive had been applied. The adhesive did not make a good bond with the concrete and it should have been continuously applied.

For many buildings, the ramification of damage to EIFS assemblies was significant. With several of these failures, the cost of repairing the EIFS was minor in comparison to the cost of damage to other building components; the cost of rainwater damage and mold remediation to building interiors, furnishings, and equipment; and the cost due to loss of use of the building while repairs where made. EIFS installed over wood or metal studs is susceptible to disproportional failure, wherein a relatively minor deficiency (such as an inadequate number of screws to attach gypsum board) results in loss of the exterior wall, as shown in Figure 5-14. Typical EIFS assemblies (i.e., studs, gypsum board, insulation, and synthetic stucco) lack redundancy to protect the building from catastrophic wind and rainwater infiltration when wind initiates failure somewhere within the assembly.

The EIFS damage was primarily related to application and/or design deficiencies. Lack of design guides likely contributed to the design problems. The test method used to determine wind resistance of EIFS assemblies may have also contributed to some of the damage. These issues are discussed below:

- **Application:** In all cases that were investigated wherein adhered insulation boards separated from the gypsum board or concrete substrate, there was significant lack of adhesive. EIFS manufacturers currently specify that the entire surface of the insulation boards is to be covered with adhesive applied with a notched trowel.

In all cases that were investigated wherein gypsum board was mechanically attached, the fasteners were too far apart. Spacings of 12 inches on center were measured. However, for the Pensacola area, the spacings typically should have been a maximum of 6 inches on center for heights up to 30 feet.[1] For taller buildings, and buildings located near or at the coast, closer spacings would be necessary. Because contract documents were not available, it is unknown whether the spacing deficiencies were due to design or workmanship errors.

- **Design:** Deficiencies included lack of provisions to prevent breakaway wall failure, beneath coastal elevated buildings, from unnecessarily propagating vertically.
- **Testing:** The EIFS industry uses American Society for Testing and Materials (ASTM) E 330 to evaluate wind resistance of EIFS assemblies. Load is applied to the specimen for 10 seconds before being released. The load is then increased and applied for another 10 seconds, then released. This process is repeated until failure occurs. While none of the investigated failures were specifically attributed to deficiencies in the test method, the test method's load duration of only 10 seconds appears to be inadequate. ASTM E 1592 (a test for metal roof and siding panels) specifies that each load increment be maintained for a minimum of 60 seconds and until the gauges indicate no further increase in deflection. The load duration and deflection criteria in E 1592 appear prudent for EIFS.
- **Design guides:** The EIFS Industry Members Association (EIMA) has a *Guide to EIFS Construction*, but the Guide is silent on wind-related issues. Manufacturers of EIFS materials have specifications, but they are typically lacking in wind-related criteria. For example, to determine fastener spacing for gypsum board (which is a very critical element in the load path), designers are referred to gypsum sheathing manufacturers. Also, ultimate load values based on ASTM E 330 typically are given, but guidance on magnitude of the safety factor is often not given to the specifier.

  An EIFS wind design guide is needed to address the various design issues associated with successful performance of EIFS. It should include criteria related to studs and their attachment to the building, criteria related to attachment of sheathing and insulation boards, safety factor selection, and key elements of field observation.

[1] Based on an ICC Evaluation Report, assuming a 16 inches on center stud spacing.

- **Codes:** Neither the FBC nor IBC have specific wind-related criteria pertaining to EIFS. The International Code Council's Evaluation Service does have the AC24 Interim Criteria for Exterior Insulation and Finish System for evaluating EIFS. AC24 uses ASTM E 330 for the wind resistance evaluation. AC24 requires at least six load increments with a 10 second load duration for each increment. AC24 also requires a minimum safety factor of 3. (Note: The Standard Building Code Congress International's Evaluation Service previously used a safety factor of two. Hence, systems designed in accordance with that criteria would be much weaker than systems designed in accordance with the ICC criteria.)

Stucco

A few buildings with traditional stucco walls were observed. Figures 3-21, 5-22 and 5-23 show significant damage to non-load-bearing stucco walls on two mid-rise condominiums. In several areas, the metal stud system failed; in other areas, the gypsum sheathing blew off the studs; and in other areas, the metal lath and stucco blew off the gypsum. It appeared that failure of the stud track connections initiated most of these failures. Figure 5-23 illustrates a serious potential risk to residents.

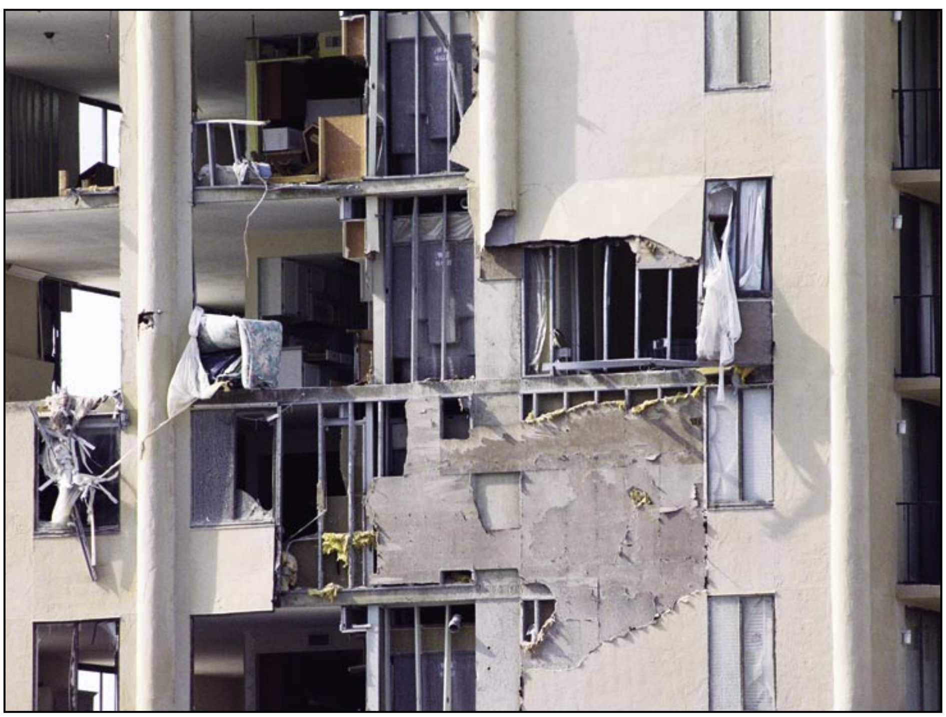


Figure 5-22.
Failure of non-load-bearing stucco wall (close-up of Figure 3-21) (Perdido Key)

Figure 5-23.
Close-up of Figure 3-21. With complete loss of the walls, the residents could have inadvertently fallen from the building. Although not shown in this photograph, several of the balcony railings had blown away. (Perdido Key)

On a few buildings, stucco was applied over plywood over wood studs. At the residence shown in Figure 5-24, the plywood was severely rotted. Figure 5-25 shows failure of stucco applied over cast-in-place concrete. Similar failures were observed in Puerto Rico following Hurricane Georges (see FEMA 339, *Hurricane Georges in Puerto Rico,* March 1999).

Figure 5-24.
Six-year old, stucco-sheathed residence with severely rotted plywood (Pensacola Beach)

Figure 5-25.
At the end wall of the center building, stucco blew off the concrete substrate. Some of the chimney walls made of stucco over gypsum board over wood studs were also blown away.

As with EIFS assemblies, attention to attachment of studs to the building, attachment of gypsum board to the studs, and attachment of the lath are critical in achieving good wind performance.

5.3.2 Wall Coverings and Soffits

Wall coverings that were investigated included brick veneer, metal panels, vinyl siding (and soffits), and wood siding. EIFS and stucco wall coverings were also observed; these were discussed in the previous section. In some instances, with loss of the coverings, wind-driven rain was able to enter the wall cavity and initiate mold growth. Some of the blown-off coverings became windborne debris that was capable of breaking unprotected glazing.

Brick

Several buildings with brick veneer were observed. Figure 5-26 shows failure on an office building. The majority of the corrugated ties remained attached to the steel studs. The ties were spaced approximately 18 inches on center vertically and 16 inches on center horizontally. According to another investigation team that had access to the building, the primary mode of failure was tension failure of the ties due to severe corrosion. Based on the Brick Industry Association's (BIA) *Technical Notes 28B – Brick Veneer/Steel Stud Walls*, "corrugated ties are not permitted when brick veneer is supported by steel stud backing." In part, this provision is based on the greater corrosion susceptibility of corrugated ties versus round ties (i.e., water is more likely to remain for a longer period of time on the flat surface of corrugated ties). The tie spacings were closer than the maximum recommended in *Technical Notes 28B*, which is 18 inches on center vertically and 32 inches on center horizontally, yet still failed due to corrosion.

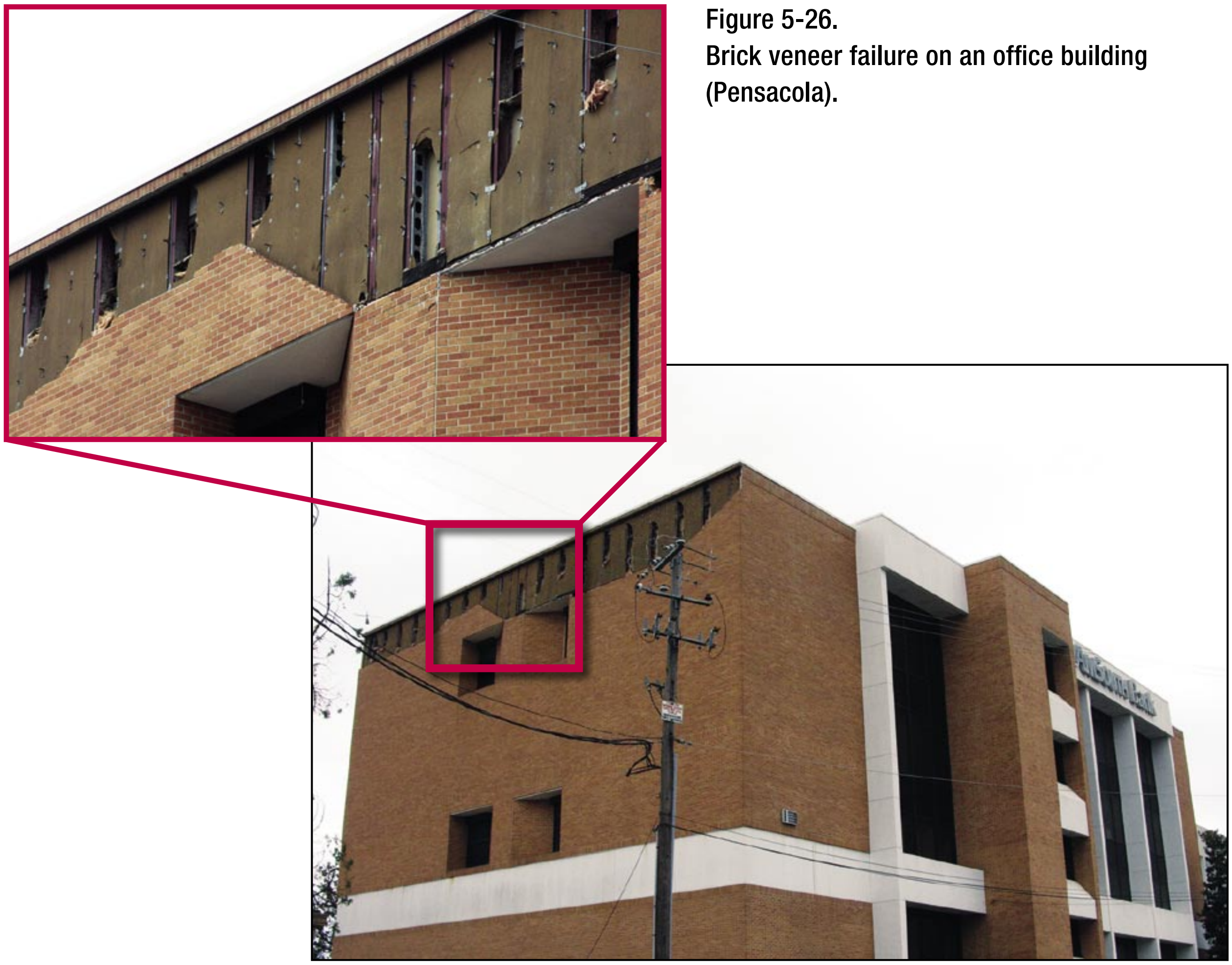


Figure 5-26.
Brick veneer failure on an office building (Pensacola).

Figure 5-27 shows failure at an older wood-framed residence. There were several failure modes:

- Several ties had never been embedded into the mortar joints
- The tie nails pulled from the studs
- Lack of bonding between mortar and brick
- Tie tension failure due to severe corrosion (this occurred on a tie embedded into the CMU foundation wall that extended about 4 feet above grade)

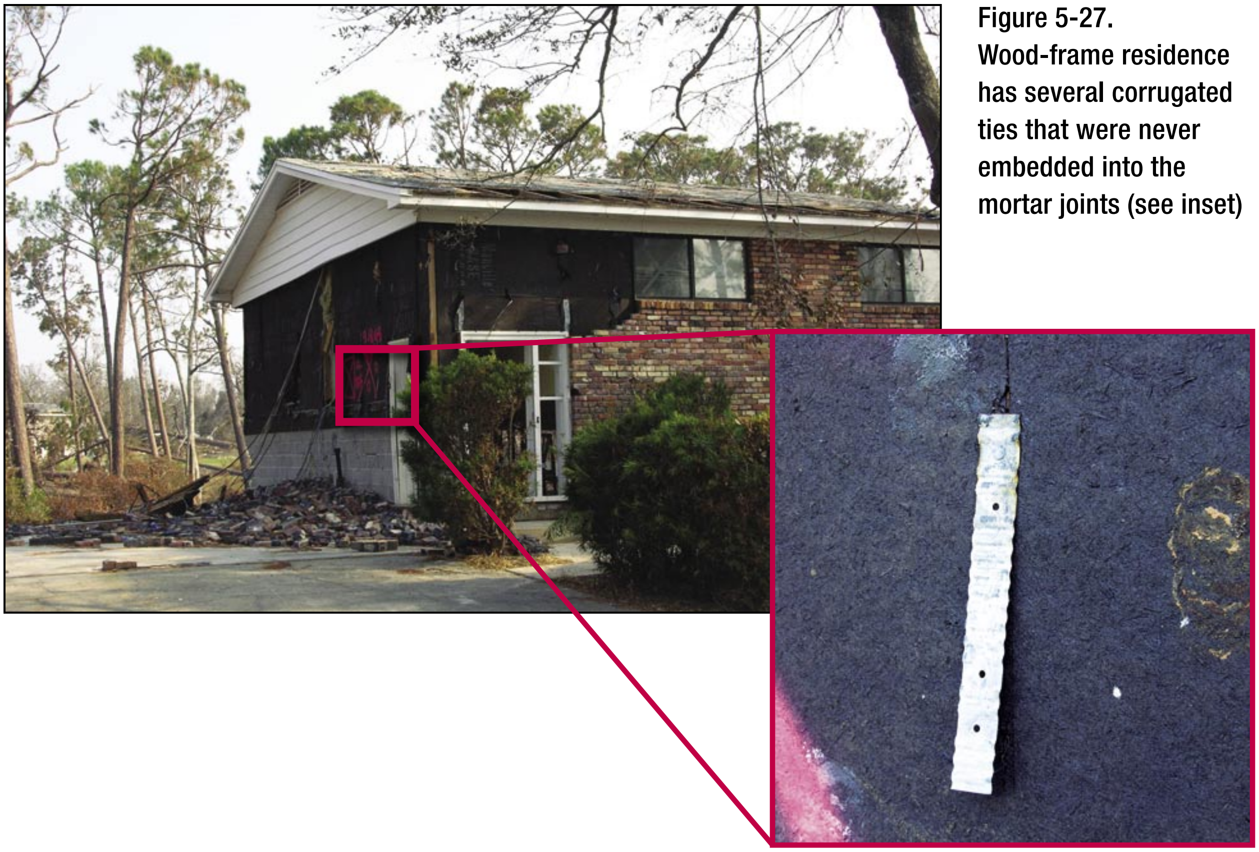


Figure 5-27.
Wood-frame residence has several corrugated ties that were never embedded into the mortar joints (see inset)

The MAT observed another house where a large number of the corrugated ties had never been embedded into the mortar joints. In areas where ties had been embedded, the smooth-shank nails pulled from the studs.

At a house under construction, ties had been embedded into the CMU foundation wall that extended a few feet above grade – the brick had not been installed. The ties were spaced at 16" on center vertically. At one area, the horizontal spacings were 22", 30", 20 ½", and 26 ½". BIA *Technical Notes 44b – Wall Ties for Brick Masonry* specifies a maximum vertical and horizontal spacing of 18" and 32" respectively.

For the building shown in Figure 5-26, because the contract documents were not available, it is unknown whether use of the incorrect ties was a design or application error. For the residence shown in Figure 5-27, failure to embed the ties into the mortar joints was a major workmanship error. Failure to embed ties was documented in a Hurricane Opal report by The Masonry Society (*An Investigation of the Effects of Hurricane Opal on Masonry*, The Masonry Society, July 1996). Opal struck the Florida Panhandle in 1995.

The Masonry Society deployed a team to assess performance of reinforced and unreinforced masonry and brick veneer. The team's report included limited information on performance of brick veneer. The report recommended a "close review of all brick veneer design," but the report did not provide specific guidance.[2]

Metal Panels

The MAT observed a limited number of metal wall panel failures. Failures were observed at two schools (Figures 3-25 and 5-28). Both schools used similar panels. The panels were attached with concealed screws. The screws were installed through concealed portions of the standing seams. The failures occurred due to unlatching of the seams.

Another wall panel failure was observed at a hangar (Figure 5-29). New panels had been installed over older panels. In one area, the top leg of a channel had been screwed at 63" and 43" to the old panels. The bottom leg had been screwed at 21" and 43". The new panels were attached with clips that were screwed at 12" on center to the hat channels. There were two screws per clip. The connections of the new panels to the hat channels were much stronger than the connections between the hat channels and old panels.

Figure 5-28. These panels were attached with concealed fasteners. They unlatched at the standing seams. In addition to generating windborne debris, loss of panels allowed significant rainwater infiltration.

[2] The Masonry Society, *Hurricane Ivan Investigation Report,* April 1, 2005.

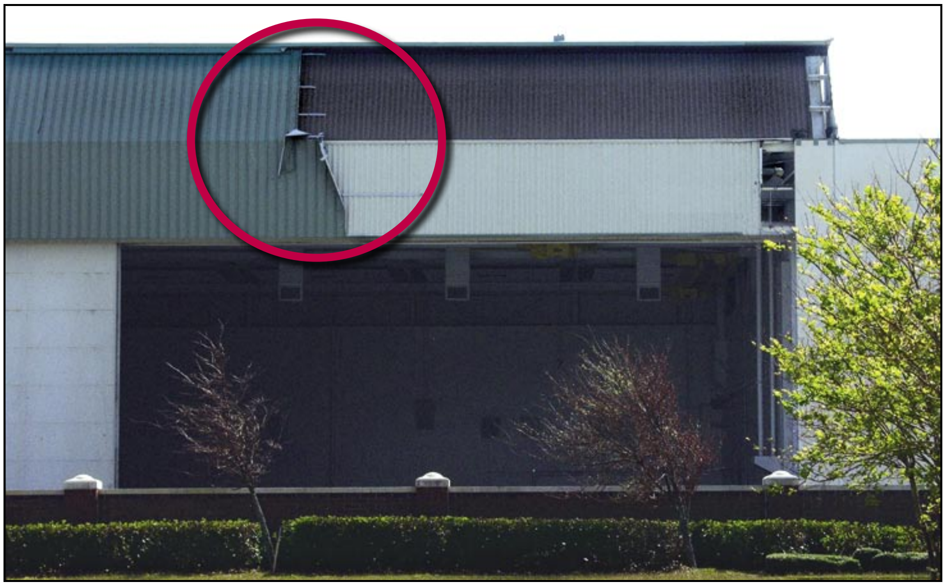


Figure 5-29.
The green fascia panels had been installed over a previous metal panel system. The original panels remained in place, but the newer panels blew off due to inadequate hat channel attachment. (Pensacola)

Vinyl Siding and Soffits

Vinyl was the predominant siding and soffit material observed on residences in the areas investigated by the MAT. Performance of the siding and soffits was very poor (see Figure 5-30). There were numerous significant failures throughout the areas observed by the MAT. Failures were observed on both new and old buildings. When vinyl siding was blown off, the underlayment (either asphalt-saturated felt or housewrap) was also often blown away, as shown in Figure 5-31. With loss of the siding and underlayment, wind-driven rainwater 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 glazing.

Figure 5-30.
Loss of vinyl soffits was common. Loss often led to water penetration into the building, with damage to attic and wall insulation, gypsum board ceilings, and building contents. (Orange Beach)

Vinyl siding manufactured for high-wind areas is available, but was observed on only one building (Figure 5-31). With high-wind siding, the nailing flange is folded over, so there is a double thickness of vinyl at the fastener points (Figure 5-32).

Figure 5-31.
Although a high-wind panel was used, extensive loss of siding and housewrap underlayment occurred. See Figure 5-32.

Figure 5-32.
A double thickness of vinyl occurred at the nailing flange. This provided greater fastener pull-over resistance. However, many of the panels pulled over the nail heads.

Vinyl siding that was blown off typically tore around the fastener points. Staples were used to attach the siding on some residences, but large headed nails were typically used. The 2003 IBC requires a maximum fastener spacing of 16". ASTM D 4756, *Standard Practice for Installation of Rigid Poly (Vinyl Chloride) (PVC) Siding and Soffit* also specifies a maximum spacing of 16". The 2001 FBC does not specify a maximum limit.

Thirty-four fastener spacing dimensions were measured on eight residences. The spacings on each of the residences were quite variable. On six of the eight residences, one or more spacings exceeded 16". The residence with the most excessive measurements had spacings of 27 ½", 25", 25" and 29". At the residence shown in Figure 5-31 with the high-wind siding, the greatest spacing was 21". However, of the eleven measurements taken at that residence, eight were 14" or less.

ASTM D 4756 specifies that the fasteners are to be driven into framing or furring members, rather than just into plywood or oriented-strand board (OSB). Most of the fasteners that were investigated by the MAT were just driven into sheathing. Although this practice did not comply with ASTM D 4756, no fastener pull-out problems were observed.

In some cases, the MAT believes that the blow-off was triggered by unlatching of the buttlock, which is the bottom portion of the panel (see Figures 5-33 and 5-68). 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 5-33.
When a panel becomes unlatched, it becomes very susceptible to blow-off.

Underlayment had not been installed at all on some residences (see Figure 4-17). Not installing underlayment is a poor practice because vinyl siding (like many other types of wall coverings) does not prevent rainwater from getting behind the siding. Underlayment should always be installed to intercept the leakage and drain it out of the wall.

Neither the 2001 FBC nor ASTM D 4756 currently require underlayment underneath vinyl siding. The 2003 IBC does require underlayment.

Some vinyl siding was damaged by windborne debris, and some vinyl soffit damage was observed (see Figure 5-30). Where soffits were blown away, a significant amount of water was often driven into the attics and ultimately into living spaces. Debris damage and soffit failure was more commonly observed by the MAT that investigated Hurricane Charley. Further discussion and analysis of debris damage and soffits are presented in FEMA 488, *Hurricane Charley in Florida*.

The vinyl siding damage was related to application deficiencies (i.e., excessive spacing between fasteners). However, other factors also likely contributed to the damage. In most of the failures investigated by the MAT, it did not appear that the siding was any stronger than that used in areas of the United States that have a 90-mph basic wind speed. There also appear to be weaknesses in the ASTM product and testing standards. ASTM D 3679, *Standard Specification for Rigid Poly (Vinyl Chloride) (PVC) Siding*, specifies a 1.5 safety factor. Considering the simplicity of the test method and the number of wind failures, the 1.5 factor appears too low.

ASTM D 5206 *Standard Test Method for Windload Resistance of Rigid Poly (Vinyl Chloride) (PVC) Siding* requires holding the test load for only 30 seconds before increasing to the next pressure level. ASTM E 1592 (a test for metal roof and siding panels) specifies that each load increment be maintained for a minimum of 60 seconds and until the gauges indicate no further increase in deflection. The load duration and deflection criteria in E 1592 appear prudent for vinyl siding. Another weakness is that D 5206 is a static test. Static tests can over-estimate the wind resistance of systems that experience significant deformations and/or fatigue failure. Considering the flexible nature of vinyl siding and the dynamic nature of wind loading, a dynamic test appears to be prudent for vinyl siding.

Wood Siding

Several residences had wood siding, either textured plywood or boards. The wind performance of wood siding was typically very good. Although there were several instances of failure of wood-framed exterior walls, such as that shown in Figure 5-34, loss of just the plywood wall siding was very rare (see Figure 5-35). Loss of board siding was also rare. There were instances where failure of other elements, such as decks or walls resulted in some progressive failure of board siding.

However, failure propagation was typically quite limited. An attribute of board siding is that it is typically very resistant to progressive failure, as shown in Figure 5-34. Large portions of the exterior wall failed in two areas, but loss of siding beyond the failed wall area was minimal. Had the building in Figure 5-34 been covered with vinyl siding or EIFS, the vinyl or EIFS failure would have undoubtedly significantly propagated beyond the wall failures.

The generally good performance of plywood and board siding is likely due to their inherent strength and stiffness. Low-energy missiles can easily penetrate vinyl siding and EIFS, but wood siding is quite resistant.

Figure 5-34.
Failure of wood framed exterior walls covered with wood siding

Figure 5-35.
Vinyl siding had been installed over textured plywood siding. Although a large area of vinyl blew off, the plywood was not damaged, leaving the building envelope intact. This scenario was observed on several buildings.

5.4 Roof Systems

Historically, damage to roof coverings and rooftop equipment is the leading cause of building performance problems during hurricanes. In the rains accompanying a hurricane, rainwater entering a building through damaged roofs can cause major damage to the contents and interior. Unless quick action is taken to dry a building, mold bloom can quickly occur in the hot, humid southern climate. Drying of buildings was hampered after Hurricane Ivan by the lack of electrical power to run fans and dehumidifiers. These damages are frequently more costly than the roof damages themselves. Rainwater 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.

5.4.1 Asphalt Shingles

The observations of the Hurricane Ivan MAT were similar and consistent with the observations of the Hurricane Charley MAT. Failures of hip/ridge trim shingles, and failures along the eaves and rakes were common. Enhancement of hip/ridge, eave, and rake details, and enhanced underlayment protection such as that shown in Hurricane Recovery Advisory Numbers 1 and 2 (see Appendix D) were not observed. Incorrect execution of the starter course was a common problem (Figure 7-12). Fastener mislocation was also common. Observed fasteners were typically located too high and too close or too far away from the ends of the shingles. Use of four nails per shingle rather than six was frequently observed, including on the school shown in Figure 6-8.

One notable difference between the Hurricane Charley and Ivan observations was shingle damage associated with raking. With the raking installation method, shingles are installed from eave to ridge in bands about 6-feet wide. Where the bands join one another, at every other course, a shingle from the previous row needs to be lifted up to install the end nail of the new band shingle. Sometimes installers do not install the end nail – in these applications, the shingles are vulnerable to unzipping at the band lines, as shown in Figure 5-36. The National Roofing Contractors Association recommends that the raking method not be used. Rather, starting at the eave, shingles should be laid one course at a time from rake to rake.

Figure 5-36.
The vertical lines of missing shingle tabs are indicative of installation via the raking method. When raked, end nails are frequently not installed.

A limited number of ridge vents were investigated. Figure 5-37 shows a metal ridge vent failure. Where the vent lifted, it was attached with roofing nails spaced at 22 ½" and 19¾" on one side of the ridge, and 21" and 17 ¾" on the other side. In an area where the vent was not blown off, the nails were spaced at 18 ½", 10", 11 ½" and 11 ½". The nails were moderately corroded. This residence was not originally constructed with a continuous ridge vent. The slot through the plywood roof decking was cut during a reroofing project. When the slot was cut, the blade of the power saw was not adjusted to suit the deck thickness. As a result, a deep cut was made through the trusses and metal connectors (Figure 5-37 inset).

Although the exposed opening through the roof at the damaged ridge vent was small, a substantial amount of water entered the residence during the storm. At the time of the investigation, the roof had been open for 15 days.

A few tabs blew off the roof shown in Figure 5-37. Where the tabs blew off, the fasteners were incorrectly located, and a nail was missing at one of the shingles (Figure 5-38). However, tab blow-off occurred because the tabs had not sealed rather than because of nailing problems.

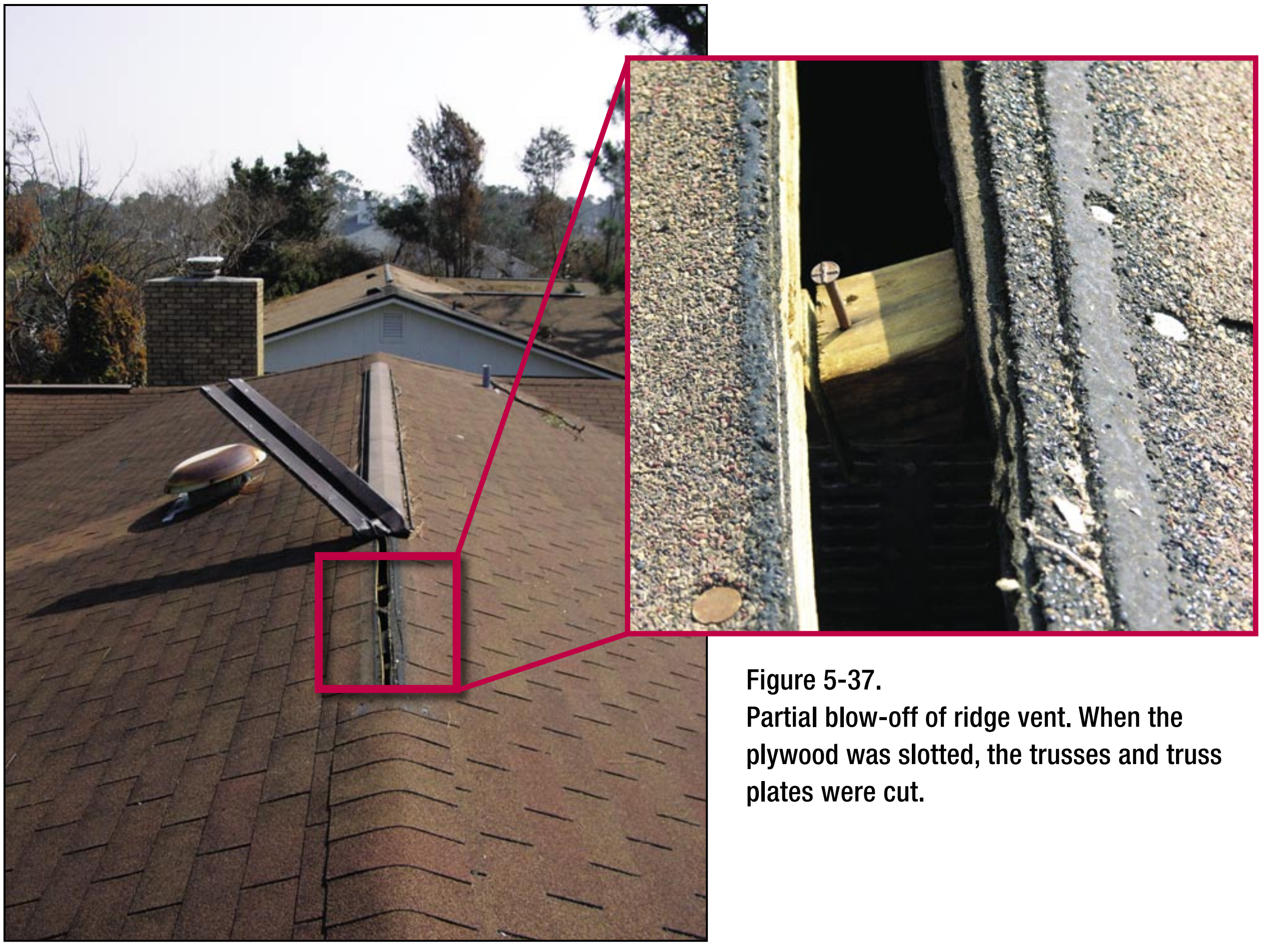


Figure 5-37.
Partial blow-off of ridge vent. When the plywood was slotted, the trusses and truss plates were cut.

Figure 5-38.
Missing tabs. All of the nails were installed too high, and two of the end nails were too far from the end. An end nail had not been installed at the lower tab.

5.4.2 Tile

Clay and concrete tiles were observed, with concrete being the most common. A variety of tile profiles (e.g., S-tile and flat) were 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. The observations of the Hurricane Ivan MAT were similar and consistent with the observations of the Hurricane Charley MAT. However, tile roofs were more common in the areas impacted by Hurricane Charley. Observations from Hurricane Charley, Frances, and Ivan were the basis for Hurricane Recovery Advisory Number 3 (see Appendix D).

Figure 5-39 illustrates typical tile damage in areas that experienced modest wind speeds. Eave, hip, ridge, and rake tile failures were common. In areas with higher wind speeds or on higher elevation roofs, large areas of tiles were blown away, such as shown in Figure 5-40, 5-43, and 5-46.

Figure 5-39.
This roof is indicative of tile failure at modest wind speeds, wherein failure of eave, hip, and rake tiles were most common.

Mortar-Set Tile Roofs

As observed after Hurricane Charley and Frances, mortar-set tile roofs typically experienced larger blow-off areas than did any of the other attachment methods.

Mechanically Attached Tile Roofs

Figure 5-40 shows a direct-to-deck mechanically attached clay tile roof that experienced large blow-off areas. The tiles were attached with two nails per tile; however, both nails were located in one corner (Figure 5-41). A clip near the end of the tile occurred along the eave row. However, the clips were ineffective. Many of the tiles were displaced by wind pressure, but much of the tile damage was caused by tiles or tile fragments impacting other tiles. The hip tiles were nailed with a single nail to a ridge board and set in mortar. However, similar to Figure 5-51, this attachment method was ineffective.

Figure 5-40. Direct-to-deck mechanically attached clay tile. The tiles were attached with two nails per tile. The nails typically remained in the deck. See Figure 5-41.

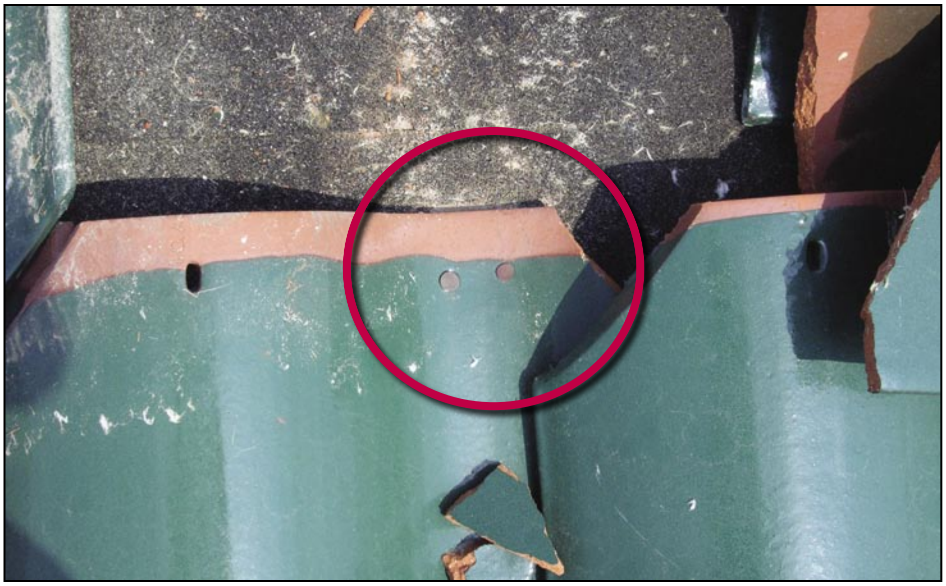


Figure 5-41.
Both nails were located in the right corner. Better load distribution would have been achieved by placing one of the nails in the far left nail hole.

Another direct-to-deck roof is shown in Figure 5-42. This six-year-old residence was adjacent to the ocean. Several of the fastener heads had corroded off, thus allowing the tiles to lift over the fasteners.

Figure 5-42.
The fastener heads on this direct-to-deck mechanically attached tile roof had corroded. The six-year old house sat near the ocean.

Several batten-attached roofs were observed. Tiles flying from a mid-rise building, such as that shown in Figure 5-43, can sail a considerable distance and have very destructive energy.

Figure 5-43. Loss of several batten-attached tiles from a mid-rise building

The tiles shown in Figure 5-44 were partially shielded from wind by nearby buildings. Hence, while some of the tiles were damaged by wind pressure, the majority were damaged by windborne debris (which included tile fragments from this roof). The field tiles were attached with a single 2 ½" long screw. The row of tiles along the eave were attached with two screws per tile.

Figure 5-44.
Although some of these batten-attached tiles were damaged by wind pressure, the majority were damaged by windborne debris (which included tile fragments).

The batten-attached tile damage shown in Figure 5-45 was due to increased wind pressure associated with turbulence created by the building projection at the upper right of the photograph. Elsewhere on this roof, there was intermittent damage to field tiles from windborne debris, likely consisting of tiles that were missing from the upper level roof and/or tiles blown from the area shown in Figure 5-45.

Figure 5-45.
The majority of these batten-attached tiles were displaced by wind pressure. The fasteners typically remained in the battens.

The batten-attached tile damage shown in Figure 5-46 was primarily caused by wind pressure. Several of the battens were blown away, thus indicating inadequate attachment of the battens.

Figure 5-46.
The majority of these batten-attached tiles were displaced by wind pressure. Many battens were blown away. See Figure 5-47 for a view of the lower-sloped roof.

Foam-set Tile Roofs

The building shown in Figure 5-46 had a lower-level roof that had a relatively low-sloped roof. The foam-set attachment method was used on the lower roof. The damage shown in Figure 5-47 was caused by wind pressure and windborne debris.

Figure 5-47.
The tiles on the lower sloped roof were foam-set. The damage on this roof was due to a combination of wind pressure and windborne debris.

Tiles were blown off of several areas of the roof shown in Figure 5-48. These failures were caused by significant workmanship errors, wherein too little adhesive was applied (Figures 5-49 and 5-50).

Figure 5-48.
These tiles were foam-set. See Figures 5-49 and 5-50.

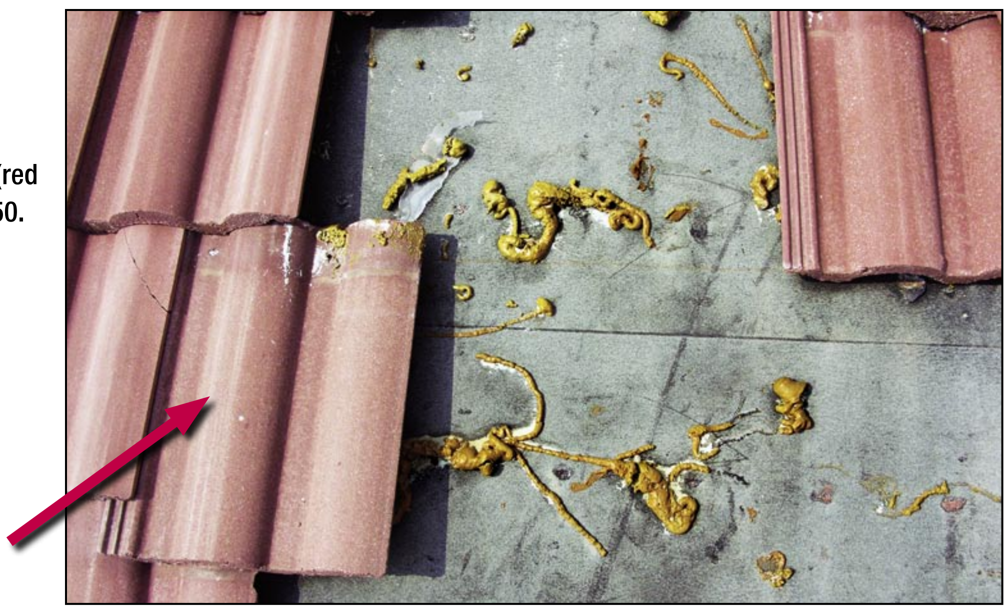


Figure 5-49.
A minuscule amount of foam was installed. Note that one tile slid down-slope about 2" (red arrow). See Figure 5-50.

Figure 5-50.
View of the underside of the tile that slid in Figure 5-49. Note the very limited amount of foam on the underside of the tile and underlayment.

Hip and Ridge Tiles

As observed in Hurricanes Charley and Frances, blow-off of hip and ridge tiles was very common, even when the trim tiles were nailed to a ridge board and set in mortar (Figure 5-51). On one of the observed roofs, the hip tiles were foam-set, but failure also occurred with this attachment method (Figure 5-52). Hurricane Recovery Advisory Number 3 (see Appendix D) provides recommendations for enhancing attachment of hip and ridge tiles.

Figure 5-51.
Significant loss of hip and ridge tiles. The trim tiles were set in mortar and were attached to a ridge board with a single nail near the head of the trim tile.

Figure 5-52.
These hip and ridge tiles were foam-set.

5.4.3 Metal Panel and Shingle Roofs

A variety of standing seam and exposed fastener panel systems was observed, as well as metal shingles. The observations of the Hurricane Ivan MAT were similar and consistent with the observations of the Hurricane Charley MAT. The performance of metal roofing varied greatly. Figure 5-53 shows a complex that lost several standing seam panels. At one area the panels remained on the roof, but a few of the seams opened up (Figure 5-54). In the opened condition, the panels were very susceptible to progressive failure, and they were no longer in a watertight condition.

Figure 5-53.
Loss of standing seam metal panels. See Figure 5-54. (Pensacola)

Figure 5-54. These panels nearly blew away. The seams on three of the panels opened up. (Pensacola)

As with Hurricane Charley, excellent performance was typically observed with 5-V crimp metal panel systems. Figure 5-55 shows special attention given to attachment along a rake.

Figure 5-55.
This 5-V crimp metal panel roof performed very well. The screws along the rake were very closely spaced; thus, this potentially vulnerable edge condition was well secured.

More metal shingles were observed in the area impacted by Hurricane Ivan than in the area impacted by Hurricane Charley. Several batten-attached metal shingles that simulated the appearance of tile were observed. While some of the metal shingles performed well, many failures similar to Figure 5-56 were observed. As with other types of roof coverings, attention to connections (including attachment of the battens for batten-attached systems) is important with metal shingles.

Figure 5-56.
This residence had metal shingles that simulated the appearance of tile. The shingles typically blew off the battens, but some of the battens were also blown away.

5.4.4 Low-slope Membrane Systems

The MAT observed several types of low-slope roof systems. These systems included built-up roofs (BURs), modified bitumen, and single-ply. Membrane damage was typically caused by windborne debris punctures and tears, and by membrane lifting and peeling after lifting of either the gutter, edge flashing, or coping. Figure 5-57 shows an edge flashing at a hospital that partially lifted. With the flashing in a lifted position, the membrane was very susceptible to peeling. Apparently, the winds subsided before this occurred.

Figure 5-57. Although the metal edge flashing lifted, a progressive membrane lifting and peeling did not occur. Some aggregate ballast was blown off an adjacent higher roof. (Pensacola)

Another type of edge failure is shown in Figure 5-58. At this hospital, the wooden nailer at the roof edge was bolted to a brick wall, but because of an inadequate load path, the bricks lifted up with the nailer. The nailer failure resulted in progressive lifting and peeling of the roof membrane. Nailer lifting may have also initiated the failure on the hospital roof shown in Figure 6-3, although as discussed in Section 6.2.2, that failure may have been initiated by lifting and peeling of the edge flashing or by debonding of the insulation from the concrete roof deck. The 4' x 8' polyisocyanurate insulation boards had been attached to the deck with hot asphalt. This attachment method can be very effective, but it requires good contact between the boards and asphalt, which can be difficult to achieve if the deck surface is not a relatively flat plane. The use of 4' x 4' versus 4' x 8' boards facilitates conformance to irregular substrates. Use of relatively thin boards (e.g., 1 ½" thick) also facilitates conformance.

Figure 5-58.
The edge nailer on top of an old brick wall was inadequately attached to the wall. Failure of the nailer caused a progressive lifting and peeling failure of the roof membrane. (Pensacola)

Figure 5-59 shows blow-off of a large portion of a BUR on an Emergency Operations Center (EOC). The membrane was mechanically attached to a lightweight insulating concrete (LWIC) deck. In one area the base sheet had been attached along the side lap with fasteners spaced at 8 ½", 9 ½" and 8½". At one of the adjacent intermediate rows, the fasteners were at 32 ½" and 32". The typical base sheet attachment specification is 9" at the laps and 18" at two intermediate rows. The failure may have been initiated because of inadequate attachment of the base sheet; however, it may have initiated at the parapet base flashing. The base flashing was mechanically attached to the parapet. Turbulence at a corner area (inset in Figure 5-59) likely generated high suction loads on the base flashing, which may have been sufficient to pull the base flashing off the parapet and cause a progressive lifting and peeling of the membrane. Parapet base flashing damage was also observed on a new hospital addition (Figure 5-60).


Figure 5-59.
Loss of a mineral-surfaced BUR installed over LWIC. Failure may have been due to inadequate attachment of the base flashing to the parapet (see inset). (Pensacola)

Figure 5-60.
Minor base flashing displacement on a new hospital roof (Gulf Breeze)

Figure 5-61 shows a single-ply membrane on a school that had been torn by windborne debris. This tear was still unprotected six days after it was damaged. Although this is a minor problem compared to a large blow-off such as shown in Figure 5-59, a substantial amount of water can enter the roof system through a tear such as this. Unless there is a secondary membrane as discussed in FEMA 424, *Design Guide for Improving School Safety in Earthquakes, Floods, and High Winds*, January 2004, significant interior water damage can be caused by minor punctures and tears. Figure 5-62 shows a hospital roof that was punctured in several locations by windborne debris.

Figure 5-61. Single-ply membrane torn by windborne debris (Pensacola)

Figure 5-62. This hospital roof had been punctured in several locations by windborne debris. When punctured, a secondary membrane, as discussed in FEMA 424, is needed to avoid water infiltration. (Pensacola)

Aggregate ballasted single-ply membrane roofs were observed at two hospital complexes (Figure 5-57 and 5-64). Some aggregates blew off of at least one of the roof areas. None of these roofs comply with the current edition of ANSI/SPRI RP-4 *Wind Design Standard For Ballasted Single-ply Roofing Systems*. Use of aggregate ballast on a hospital roof in a hurricane-prone region is not prudent.

5.5 Windows, Shutters, and Skylights

Exterior windows are very susceptible to missile breakage unless they are impact resistant (via use of laminated glass or shutters). The probability that any one window will be struck by windborne debris is typically small; however, 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 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 2.2.4.3. 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 MAT observed shutters on several residential and commercial buildings along the coast and inland areas. However, shuttering was not as prevalent as in the areas impacted by Hurricane Charley and Frances.

5.5.1 Unprotected Glazing

Figure 5-63 shows a residence along the coast. Several of the ocean-facing windows were broken by debris from the failed deck. Figure 7-10 also shows several ocean-facing windows in a mid-rise condominium that were broken by windborne debris that included balcony railings and non-load-bearing stucco wall components. The MAT observed many instances of windborne debris-induced failure of unprotected ocean-facing windows.

Although windborne debris-induced failure of unprotected glazing was more frequently observed on the barrier islands than in inland areas, broken glazing was observed in inland areas, including the

Pensacola area, as shown in Figures 5-4, 5-16, 5-64, and 6-4. In both coastal and inland areas, glazing damage more commonly occurred on the lower floors of buildings due to the greater amount of debris flying at lower elevations. However, broken glazing was observed on upper levels as shown in Figures 5-16 and 7-15.

As discussed in the Hurricane Charley MAT report, damage to unprotected glazing in inland areas is more likely to occur when wind speeds are 120 mph (3-second gust) or greater. With declining wind speed, the incidence of glazing damage is reduced. The Hurricane Charley MAT observed very few broken windows in inland areas where the wind speed was estimated to be less than about 100 mph 3-second gust. The Hurricane Ivan MAT's observations are consistent with those from Hurricane Charley. In the Pensacola area, where the estimated Exposure B wind speeds were between 90 and 100 mph 3-second gust, glazing damage was limited, except in areas where significant amounts of windborne debris were flying, as illustrated in Figures 6-4 and 5-16. Had Hurricane Ivan been closer to a design wind speed event, the amount of glazing damage in inland areas would have undoubtedly been higher.

At the condominium shown in Figures 7-8 and 7-9, an unusual window failure resulted in extensive secondary damages. The lower portion of the small windows shown in Figure 7-8 were inward-opening hopper windows (i.e., they were hinged along the bottom of the window frame). Because the latch at the top of the hoppers was very weak and incapable of resisting the positive wind pressure applied to the glazing, many of the hoppers opened. The open windows allowed an increase in the internal pressure. The high internal pressure pushed over the interior partitions (Figure 7-9). The high internal pressure also exerted load on the curtain wall facing the ocean, which combined with the exterior suction load to cause the curtain walls to fail. The curtain wall's metal stud tracks were attached with powder driven fasteners into the concrete slab. The number of fasteners was insufficient to resist the applied loads.

Figure 5-63.
Several windows on this ocean-front home were broken by windborne debris.

Figure 5-64.
The outer pane of this tempered glass window was broken by windborne debris (aggregate roof ballast, falling glass shards from windows above, or EIFS). (Pensacola)

5.5.2 Protected Glazing

The MAT did not observe any laminated glass that had been impacted by debris, other than a skylight as discussed in Section 5.5.3. However, a variety of shutters were observed. They were made of wood sheathing, metal panels, or plastic panels of various designs. The MAT observed a few cases where shutters were impacted by debris and were effective in preventing glass breakage (Figure 5-65).

Figure 5-65.
This shutter was impacted by high-energy debris.

A few problems were observed with shutters. At the school shown in Figure 5-66, shutters had been retrofitted. However, shutters were not placed over the windows above and below window air conditioners or over the glazed entrance doors. Although the shutters that were installed decreased the amount of exposed glass and, as a result, reduced the probability of glazing damage, a shuttering project should protect all exterior glazing. Another problem is illustrated by Figure 5-67, wherein metal panels did not completely cover the glazing. Also, at that shutter, wing-nuts were installed at only every other fastener stud. Installation of nuts on every other stud was observed on several different buildings. When all of the nuts are not installed, shutters are more susceptible of being blown away.

Figure 5-66.
Shutters had been retrofitted on this school, but the glazing above and below the window air conditioners and the glass entry doors were not protected. (Pensacola)

Figure 5-67.
These panels did not completely cover the glazing. Also, along the bottom track, a wing-nut was placed only at every other fastener stud. The shutter may have been impacted on the right side.

Two of the panes in the window unit shown in Figure 5-68 were broken because the window unit was not fully protected. It was unclear whether some of the shutter panels blew away or were never installed. At the lower shutter track, rather than employ fixed fastener studs, the studs were slid into the track at the track ends. This type of stud connector relies on friction to keep the studs from moving sideways. If the nuts are not snug, the panels can drift sideways and be blown from the track. It was clear that one of the panels had not been fabricated for this unit. This illustrates a potential problem with panel shutters. When shutter panels are removed from storage for installation, it is important for the panels to have been labeled so that the proper panels go over the intended windows.

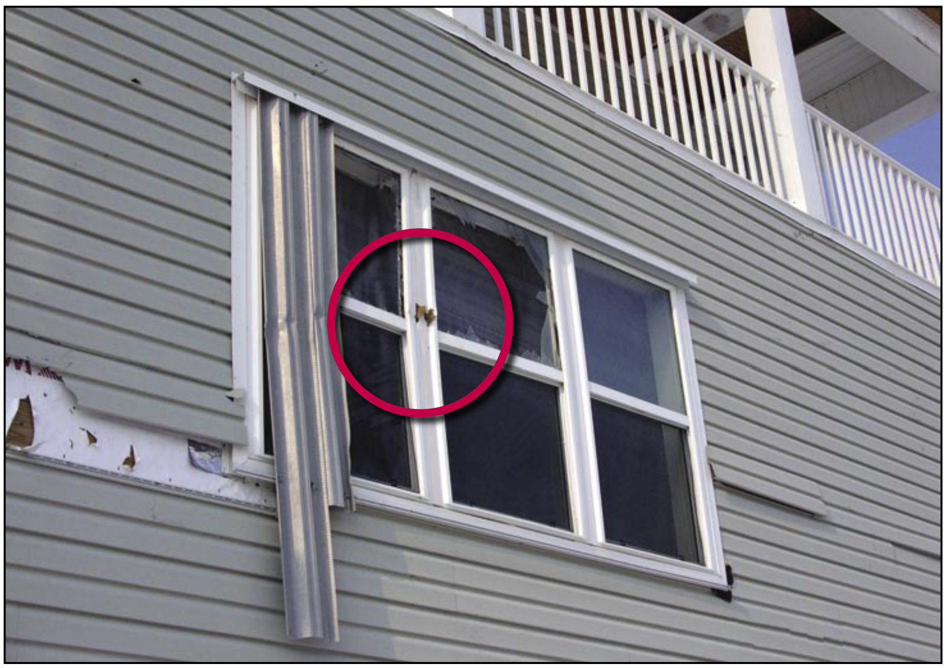


Figure 5-68.
It was unclear whether some panels blew away, or the glazing was not fully protected. Note the debris embedded in the window mullion.

5.5.3 Skylights

Figure 5-69 shows a skylight at a hospital canopy. Several of the laminated glass panels had been impacted by debris and were broken, but the glass remained in the frames.

When tempered glass breaks, it shatters into small pieces and falls out of the frame, as shown in Figure 5-64. However, as shown in Figure 5-69, when laminated glass breaks, the glass remains bonded to the plastic film between the panes, and the glazing remains in the frame. Although the broken laminated glass will need to be replaced, costly interior water and wind damage is avoided.

Figure 5-69.
Several laminated glass panes were broken, but they remained in their frames. The panes were likely broken by ballast, although falling glass shards or EIFS may have caused the damage. (Pensacola)

5.6 Exterior Mechanical and Electrical Equipment Damage

The MAT observed many damages to mechanical and electrical devices mounted on the exterior of buildings. 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 lightning protection systems (LPS) anchorage. Guidance for these design factors is provided in FEMA 424, *Design Guide for Improving School Safety in Earthquakes, Floods, and High Winds.*

For equipment susceptible to flooding, see Subsection 4.1.3.4 Utilities.

Commercial, and critical and essential facilities typically have a wide variety of mechanical and electrical equipment attached to their rooftops and elsewhere. Residences also frequently have rooftop equipment. Equipment lost included fan units and HVAC units, electrical and communications equipment, and LPS. 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 critical and essential facilities was not anchored more effectively than the equipment on common commercial buildings.

5.6.1 Rooftop HVAC Equipment

As frequently observed following previous hurricanes, many fan units were damaged. In some cases, the fans were blown off the curbs because too few screws were used to attach the fans to the curbs. In other cases, the fans remained attached to their curbs, but the cowlings were blown away (Figure 5-70). (FEMA 424 *Design Guide for Improving School Safety in Earthquakes, Floods, and High Winds* provides guidance for jobsite strengthening of cowlings.) Figure 5-71 shows loss of a hood over a relief air vent. The connectors attaching the hood had insufficient strength to resist the wind loads. Although the opening through the roof was small, a substantial quantity of rainwater was able to enter the school. Because of widespread damage in the Pensacola area, this opening remained unprotected for several days after the storm.

Figure 5-70.
Loss of two fan cowlings on an EOC. Blown-off cowlings can tear roof membranes and break glazing. (Pensacola)

Figure 5-71.
Loss of the hood at this relief air vent allowed rainwater to directly enter the school. (Pensacola)

Figure 5-72 shows loss of a relief air hood and displacement of a sleeper-mounted condenser. Sleeper-mounted condensers do not provide resistance to uplift or lateral wind loads.

Figure 5-72.
At this hospital, the condenser moved off the sleepers and a nearby relief air hood was blown away. (Pensacola)

Figure 5-73 shows that even large HVAC units are susceptible to damage at moderate wind speeds (winds were estimated to be 85 to 95 mph in this area). This unit reportedly weighed 18,000 pounds. It was 30' long, 10' wide, and 8' high. It was attached to a wooden curb with sixteen 1" x 1/8" thick straps. Each strap had a single screw into the unit and a single 1 ¾" long #14 screw into the curb. The majority of the screws pulled out of the curb, although some may have failed in shear. The unit was located approximately 20 feet from the edge of the building. After lifting off the curb, the unit hit and cut the roof membrane in several areas and then fell off the building and crushed two unoccupied vehicles. It was reported that approximately 2" of water collected on the second floor. The building was less than one year old.

Figure 5-73.
This large HVAC unit blew off a new medical office building. It was attached with 16 straps (see inset). (Gulf Breeze)

Another observed problem was loss of HVAC access panels (Figure 5-74). This type of problem was observed at two hospitals. Windblown panels can tear roof membranes and break unprotected glazing. Damaged rooftop ductwork was also observed at hospitals and an EOC (Figures 5-75 – 5-77). The damaged ductwork provided a direct path for water to enter the buildings. The majority of the damage was caused by wind pressure; however, the damage ductwork shown in Figure 5-77 was likely caused by roof membrane debris.

Figure 5-74.
Sheet metal access panels and shrouds were blown off this equipment at a hospital. Displaced panels can tear roof membranes and break glazing. (Pensacola)

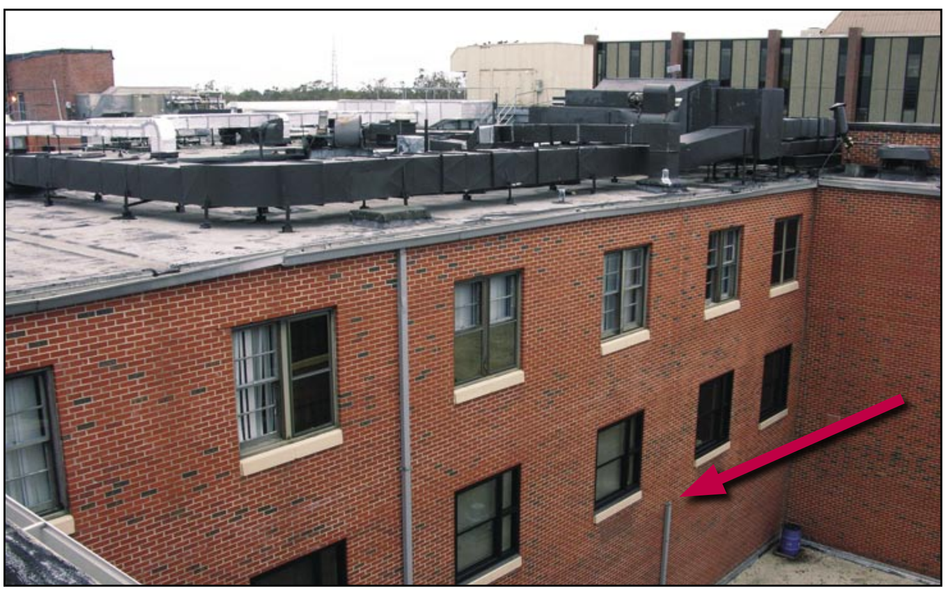


Figure 5-75.
Ductwork and fan units on this hospital were damaged in several locations. Some of the windows in this area were also broken. Note the missing downspout. (Pensacola)

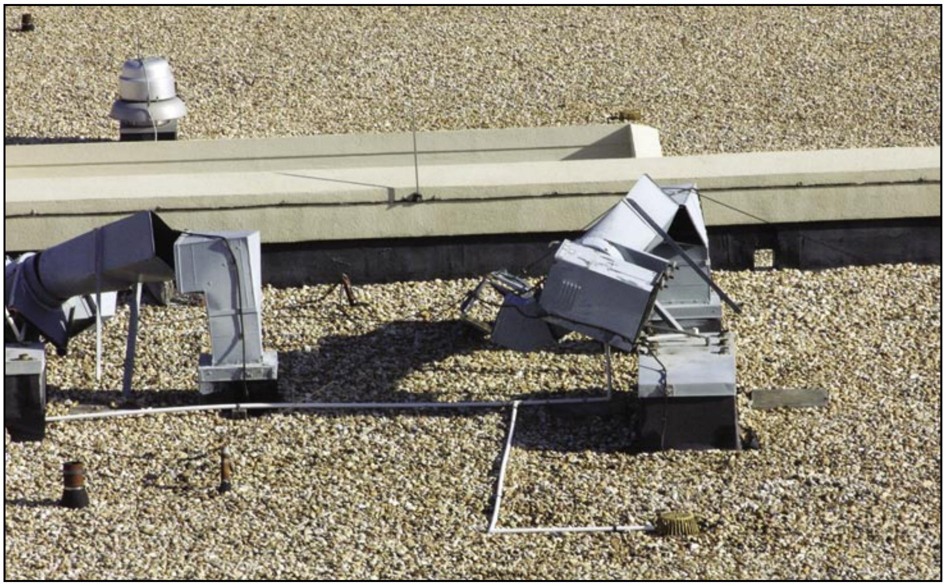


Figure 5-76. Damaged ductwork at a hospital (Pensacola)

Figure 5-77. Damaged ductwork at an EOC. This damage was likely caused by roof membrane debris that blew off a nearby area. (Pensacola)

Equipment screen damage was also observed (Figure 7-17). Screen panels that are blown away can tear roof membranes and break unprotected glazing.

5.6.2 Electrical and Communications Equipment

Rooftop electrical and communications equipment was also observed to be inadequately anchored. Problems included displacement of LPS and antenna collapse and debris damage. Collapsed parking lot light fixtures were also observed. Consequences of the damage included loss of communications, damage to roof coverings, and loss of lightning protection, the latter of which is significant, considering the frequency of lightning storms in Alabama and Florida.

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 5-78). Figure 5-79 illustrates the number of roof membrane punctures that can be caused by loose LPS conductors.

Figure 5-78.
The LPS on this hospital became detached. Loose LPS can severely damage roof membranes, and loose LPS does not provide the intended lightning protection. (Pensacola)

Figure 5-79.
The LPS conductor on this hangar became detached and punctured the roof membrane in several locations. (Arrows show ends of loose cable.) (Pensacola)

Figure 5-80 illustrates damage to antennas from windblown roof debris. Mounting the antennas on the penthouse wall was prudent, as this avoided penetrations through the roof membrane. However, to avoid damage from roof debris, the roof system needs to be sufficiently anchored to avoid blow-off. Figure 5-81 shows a collapsed communications tower. Collapse of this type of tower has frequently been observed following previous hurricanes.

Figure 5-80.
The antennas at this hospital were damaged when the roof membrane blew off. (Pensacola)

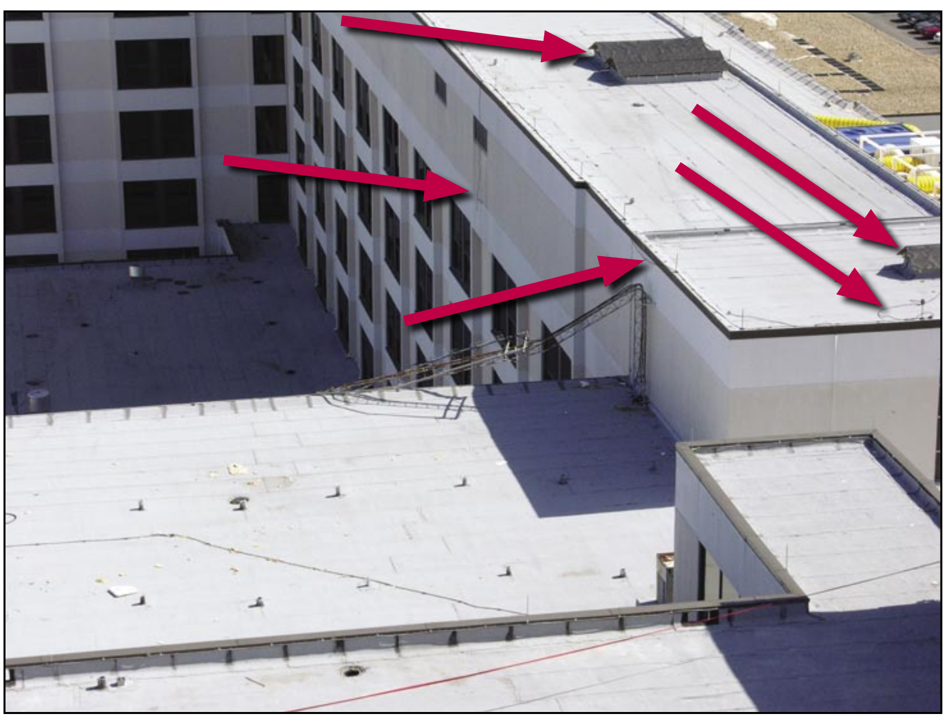


Figure 5-81.
The antenna at this hospital collapsed. The LPS was also displaced in a few areas (red arrows). Rooftop equipment was also damaged. (Pensacola)

Figure 5-82 shows collapsed light fixtures. These failures were caused by severe corrosion.

Figure 5-82.
Collapsed light fixtures at a hospital. The bottom of the tube was severely corroded (see inset). (Pensacola)

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 Ivan had a significant impact on critical and essential facilities. Though all of the buildings were subjected to winds that were below design conditions, the overall performance of the buildings the MAT observed was poor. The poor building performance placed additional burden on response and recovery personnel as they endeavored to provide assistance to their communities after the event. According to the 2003 IBC (Section 1604, Table 1604.5) and the 2001 FBC (Section 1606, Table 1606), critical and essential facilities include, but are 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. Schools are also listed in the IBC, but not the FBC. Because of the poor performance and reported damage to these facilities, the MAT assessed numerous facilities to document the damage and loss of function.

Critical and essential facilities that were damaged include an EOC/police station, jails, hospitals, schools, and shelters. Most damage was to envelope systems, though a few structural failures did occur (see Chapter 5 for photographs and discussion of envelope damage). Most of the damage was to older facilities; however, some newer facilities also experienced failure. 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.

The MAT observed minimal damages at several jail and fire station facilities. This consisted of minor damage to coping, edge flashing, and canopies, and loss of fan cowlings – none of which caused any significant functional disruption. Maintaining operation of the jails avoided transporting and housing inmates in other facilities and avoided placing additional burdens on law enforcement personnel. Maintaining operation of the fire stations avoided disruption of emergency response capability. However, all three of the fire stations that were observed by the MAT were older pre-engineered metal buildings. Had wind speeds been closer to a current design event, all three of these buildings would have likely suffered major damage to the sectional doors and/or the metal roof panels (see *Mitigation Assessment Team Report, Hurricane Charley in Florida*, FEMA 488 for a discussion of fire station performance in Hurricane Charley).

The MAT did not observe any critical or essential facilities located in areas affected by flooding. By being located outside of floodprone areas, these critical and essential facilities were able to provide community services without interruption due to flooding.

6.1 Emergency Operation Centers

EOCs are key buildings in preparing for and responding to an event from both local and state levels. The MAT observed only one EOC, which was located in the basement of the Escambia County Sheriff's Office (in Pensacola). This facility experienced several building envelope problems. However, although rainwater entered the building, it did not disrupt the EOC operations.

6.1.1 General Damage

The original building had two floors above grade. A new two-story addition was joined to the original building. Construction of the addition was essentially complete when Hurricane Ivan struck. A large roof membrane blow-off was experienced in one area (Figure 6-1). The damaged membrane was a BUR with a field-applied mineral surfacing over light weight insulating concrete (LWIC). The LWIC was likely installed over a structural concrete deck. Although the rooftop equipment was inadequately attached on both the original and new portions of the building, the equipment was likely damaged by windborne roof debris rather than wind pressure. The modified bitumen roof membrane on the new addition was also damaged. The membrane lifted and tore at a roof drain and the base flashing at the parapet was displaced. A portion of the coping was also displaced. Some of the windows on the original building were shuttered, but some were not – at least one window was broken (likely by windborne debris). A portion of the LPS on the new addition was dislodged.

Figure 6-1.
General view of the roof membrane and rooftop equipment damage at the Escambia County Sheriff's Office/EOC. The roof at the upper right is on the new addition. The mineral surfaced BUR landed on an aggregate surfaced BUR. (Pensacola)

6.1.2 Functional Loss

Some rainwater was able to enter the building at damaged rooftop equipment, but it was apparent that the roof deck was preventing major roof leakage in areas where the roof membrane blew off. Although the cost to repair the envelope and rainwater damage on the original and new portions of the building is significant, the EOC was able to continue functioning during and after the hurricane.

Six days after the hurricane struck, emergency repairs had not been made to the roof and open ductwork on this important facility. Demands for repair crews are enormous in the aftermath of a hurricane like Ivan. To ensure priority service, it is prudent for owners of critical and essential facilities to have pre-established agreements with contractors to perform emergency inspection and repair if needed.

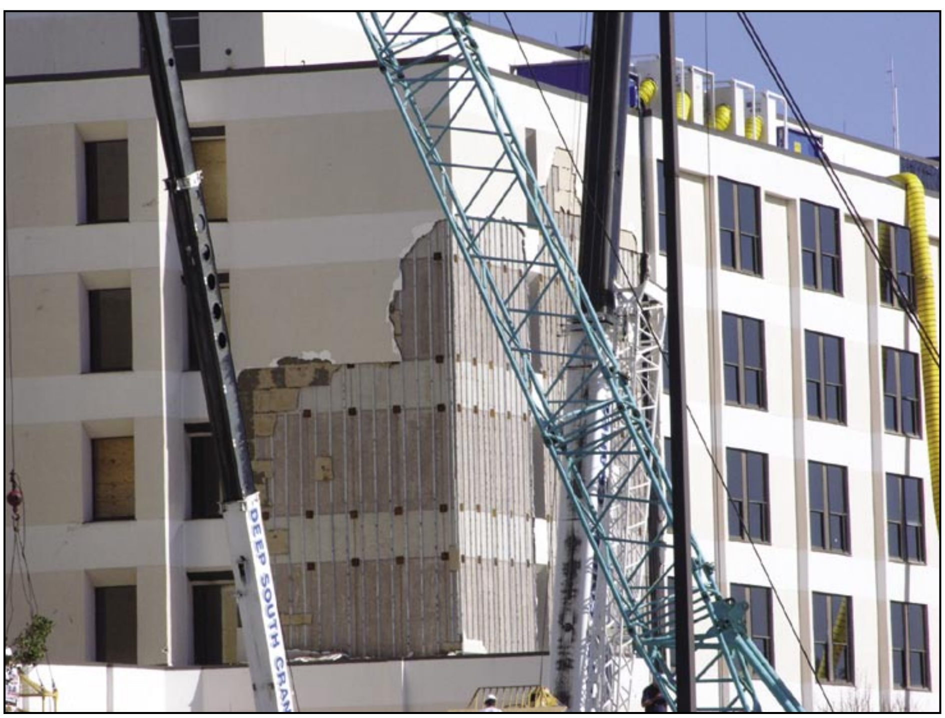
6.2 Hospitals

A hospital in Gulf Breeze and all four hospitals and a psychiatric-care hospital in Pensacola were observed. All experienced building envelope problems. Though none of the hospitals were taken out of service, the envelope damage placed significant burdens on several of the facilities.

6.2.1 General Damage

Buildings at four of the five hospital complexes experienced roof membrane damage – damage was significant at three of the facilities. Windows were broken at four of the complexes, with significant damage at one of them. EIFS blew off the walls at two complexes. At both complexes, the EIFS failures resulted in disruption of elevator service (see Figures 5-15 and 5-16). At one of the complexes, the EIFS failure resulted in significant glazing damage (see Figures 5-16 and 6-2). Rooftop equipment and LPSs were damaged at four of the complexes. Communications towers and antennas were damaged at two complexes. A loading dock canopy was blown away and several tall parking lot light fixtures collapsed at one complex. Sewage backed up in a cancer treatment facility because of power loss to a lift station. Tree-fall caused roof damage to a materials management building (an ancillary building at one complex).

Figure 6-2.
View of EIFS damage at hospital building (Pensacola)



6.2.2 Functional Loss

The damage described above placed burdens on hospital staffs and took portions of some of the facilities out of service. However, all six hospitals were able to continue to provide care. The following is a synopsis of the major disruptions:

- At the Pensacola Naval Hospital complex, two patient floors were taken out of service because of minor rainwater leakage due to roof membrane blow-off from a large portion of the roof (Figures 6-3 and 6-4). The concrete roof deck was effective in minimizing leakage. The modified bitumen membrane had been installed over polyisocyanurate insulation mopped to the concrete deck. The blow-off was initiated by lifting and peeling of the metal edge flashing, or lifting of the wood nailers that the edge flashing was attached to, or by debonding of an insulation board from the deck. Debris from the roof broke several of the second and third floor windows (including some glazed with tempered glass) (Figure 6-4). Roof debris also damaged several antennas (Figure 5-80).

Figure 6-3.
General view of upper roof of the Pensacola Naval Hospital. Note the missing insulation boards near the corner of the roof. (Pensacola)

Figure 6-4.
View of a portion of the lowest floor roof showing broken 2nd and 3rd floor windows and debris from the roof above shown in Figure 6-3

- At one hospital complex, a portion of the surgical suite and the intensive care unit was taken out of service during the hurricane due to rainwater infiltration. Sewage disposal was interrupted due to lack of power at a lift station – waste was bagged. This interruption was of short duration.
- At one hospital, elevator service at the MOB was interrupted due to rainwater infiltration at the elevator penthouse due to EIFS blow off (see Figure 5-15). The MOB was connected to the hospital. Sewage disposal was interrupted due to lack of power at a lift station. This interruption was of short duration.
- At one hospital complex there were numerous disruptions. Communications were lost about an hour after arrival of high winds. EIFS failure caused extensive glazing damage and disruption of elevator service. Glass shards fell and punctured the roof membrane over a regional dialysis unit and urgent care facility. However, the roof deck (concrete topping over steel decking) minimized rainwater infiltration. Emergency repairs were made, and the unit was opened after being out of operation for only one day. Rainwater from a punctured roof membrane entered a portion of the surgical suite. Sewage back-up disrupted the cancer treatment facility for one day. Loss of the canopy at the loading dock hampered materials handling. Quick and aggressive emergency repairs were responsible for minimizing the impacts of the service interruptions at this facility.

- At one hospital complex, a very large piece of HVAC equipment blew off the MOB roof (see Figure 5-73). Extensive rainwater damage occurred on the floor below. An emergency generator was brought in to run fans to dry out the facility.

6.2.3 Best Practices – Hospitals

Though all of the hospitals had to cope with building performance problems, there were observed successes and best practices that contributed to minimal damage, particularly in terms of operational actions:

- Shutters. Some of the buildings had shutters over lower-level windows. No shutter breaches were observed.
- Relocation of patients. At one hospital, patients were moved into the corridors in case patient room windows were broken. This practice may have been employed at other hospitals, although at one of the hospitals, a patient was in a room when a window broke. If patient room windows are not impact resistant or protected by shutters, moving patients out of the rooms during a hurricane appears to be a prudent practice.
- Satellite dish. At one hospital, satellite dishes were removed from their support stands and placed inside a penthouse prior to the hurricane. Had this action not been taken, the dishes would likely have been blown away and perhaps caused damage to the facility. An antenna that was not needed during the hurricane was also taken down.
- Damage response. One hospital experienced significant building problems; however, the hospital quickly mobilized contractors and cleaning crews. Quick action brought the cancer therapy facility and regional dialysis back online within a day, so those vital services were only minimally impacted. The rapid damage response also likely minimized rainwater damage costs. Rapid response was also observed at some of the other hospitals.

6.3 Schools

The MAT observed 13 schools, including elementary, middle, and high schools. In addition to their traditional role as educational facilities, schools often play an important role in providing space for sheltering, emergency response, and recovery after a hurricane. Thus, their loss of use can greatly impact a community's ability to rapidly respond to the needs of disaster victims. See Section 6.4 for additional discussion on schools used as shelters.

6.3.1 General Damage

A limited amount of structural damage was observed. It consisted of collapsed walkway canopies at a few schools (Figures 4-98 and 6-5), loss of a portion of wood joists and roof decking at one school, loss of roof decking at one school (Figure 6-6), loss of an auto shop roof structure and portion of a CMU load-bearing wall (Figure 6-7), and loss of roof joists and collapse of CMU walls at an HVAC chiller enclosure. At three of the schools that experienced structural damage, portions of the schools were used as shelters. However, the structural damage did not occur where people were sheltered.

All of the observed schools experienced building envelope damage, with damage to roof coverings and rooftop equipment being the most common problem. Other observed damage included soffit damage, metal wall panel damage, and the collapse of a non-load bearing brick wall.

Figure 6-5. Walkway canopy collapse at Bellview Middle School. Stronger winds could have turned the debris into lethal missiles. (Pensacola)

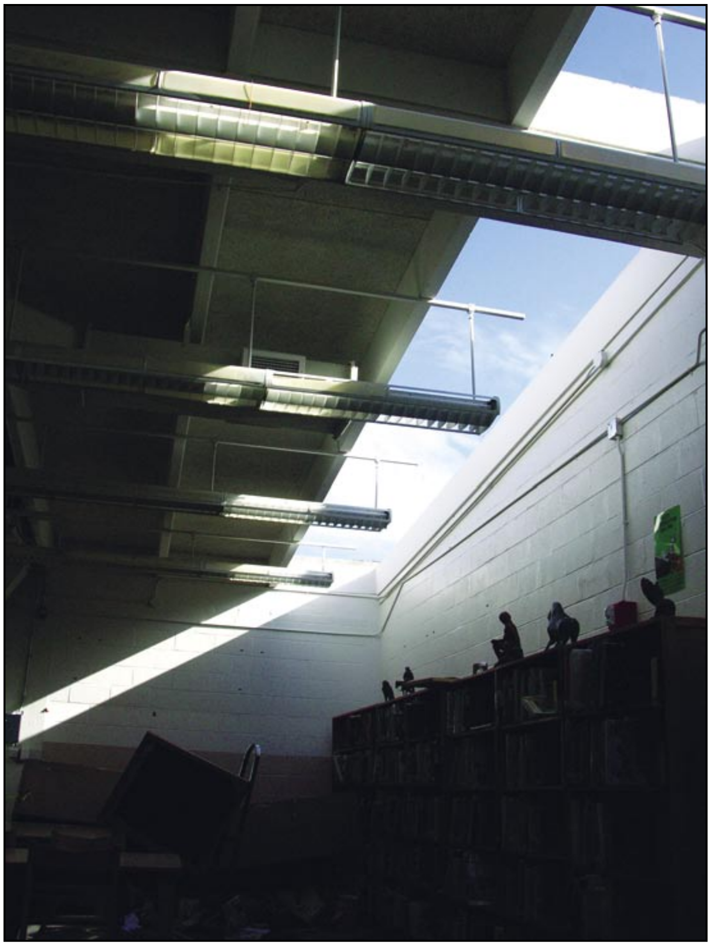


Figure 6-6.
Loss of cementitious wood-fiber roof deck panels at Workman Middle School (Pensacola)

Figure 6-7.
Loss of the roof structure and rear portion of the CMU load-bearing wall at the George Stone Career Center auto shop (Pensacola)

6.3.2 Functional Loss

Many of the observed schools experienced widespread rainwater damage due to breached building envelopes, which resulted in disruption or loss of school operations. In some cases, such as that shown in Figure 5-71, the envelope damage was minor, but lack of quick emergency repairs allowed significant rainwater to subsequently enter the building.

6.4 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 surge during Hurricane Ivan. The MAT assessed the performance of some of these storm shelters to document how these essential facilities performed.

Further, because portions of several school buildings evaluated by the MAT were designated as storm shelters, damages to schools in some communities led to loss of use of shelters that could protect residents from injury during subsequent hurricanes. The loss of use of schools that function as storm shelters is particularly difficult for 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.

For a discussion of the Florida Statewide Emergency Shelter Plan (SESP), see Chapter 6 in *Mitigation Assessment Team Report, Hurricane Charley in Florida*, FEMA 488.

6.4.1 General Damage

The MAT observed six shelters, five of which were schools. The other shelter was the Pensacola Civic Center (a large arena). Structural damage consisted of collapse of canopies at three of the schools (Figure 6-5), blow off of roof deck panels at one school (Figure 6-6), and damage to a stand-alone auto shop at the backside of one school (Figure 6-7). All five of the schools had roof covering damage, with the damage being significant at three of the buildings. One of the schools had an aggregate surfaced BUR. A substantial amount of aggregate was blown off and, subsequently, broke windows in one or more vehicles. Metal wall panels were blown off one of the schools and the Civic Center. Rooftop equipment was blown off of two schools and the Civic Center; a large fan from the Civic Center crushed an unoccupied car.

6.4.2 Functional Loss

Pensacola Civic Center had an occupant load of approximately 1,600 to 2,000 people at the time Hurricane Ivan struck. Five pieces of rooftop equipment over the arena floor were blown off. (For information on the roof membrane damage caused by the equipment blow off, see "Withstanding Hurricane Ivan" in the February 2005 issue of *Interface* (published by the Roof Consultants Institute).

However, the wind speeds quoted in the article are incorrect. As an added safety measure, people were moved out of the arena into peripheral areas of the facility before the high winds arrived. Thus, although rainwater entered the arena, people were not left exposed. Portable toilets were placed within the arena area prior to the hurricane. That proved to be prudent, for the center lost sewage service due to lift station power failure.

The Jim C. Bailey Middle School (built in 1995) was used as a shelter. Rainwater entered the building in several different areas where asphalt shingles, underlayment, rooftop equipment, and metal wall panels were blown off (Figure 6-8). The shingles were attached with only four nails instead of six, which the roofing industry recommends in high wind areas. The nails were incorrectly located (they were too high and at one of the shingles, an end nail was 2 ½ inches rather than 1 inch from the end). People were moved from one portion of the building to another to escape the rainwater leakage.

Figure 6-8.
Loss of asphalt shingles and underlayment at the Jim C. Bailey Middle School. Note the displaced wall panels at the upper left and the missing panel in the lower right. (Pensacola)

The Workman Middle School sheltered approximately 25 people, including about 10 police officers who came in from patrol shortly before arrival of the high winds. Although a portion of the school complex experienced structural damage (Figure 6-6), no injuries were reported. Occupants took shelter in a newer building on campus that did not experience structural failure. As shown in Figure 3-26, a substantial amount of windborne debris (primarily roofing and canopy components from the school) was airborne in this area.

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. For this reason, buildings selected for shelters should be designed and constructed to avoid loss of components. Items particularly susceptible to blow-off include aggregate roof surfacing. Roof coverings and rooftop equipment were also susceptible if adequate attention was not given to wind-resistant design and construction.

At the time of the MAT observations (six days after the hurricane), none of the five schools were being used. Some of the schools had too much rainwater damage to be of service.

7

Conclusions

The conclusions presented in this report are based on the MAT's observations in the areas studied; evaluations of relevant codes, standards, and regulations; and meetings with state and local officials, business and trade associations, contractors, and other interested parties. These conclusions are intended to assist the State of Alabama, the State of Florida, communities, businesses, and individuals in the reconstruction process and to help reduce future damage and impact from flood and wind events similar to Hurricane Ivan. The report and recommendations also will help FEMA assess the adequacy of its flood hazard mapping and floodplain management requirements and determine whether changes are needed or additional guidance required.

7.1 Flood Hazard Conclusions

Flood levels from Hurricane Ivan exceeded the mapped BFEs throughout many bays and sounds by several feet. Flood levels along Gulf front shorelines also exceeded the mapped BFEs but to a lesser extent. As discussed in Chapters 1 and 2, HWMs were clearly higher than the stillwater levels used to develop the flood maps and were also higher than the BFEs, which include wave heights that are not accounted for in the HWMs. Due to these high flood levels, the flooding extended beyond the SFHAs in most communities investigated. Since many homes were pre-FIRM construction and/or constructed to the minimum standards in mapped A Zones and the flooding extended beyond the current SFHAs, there was severe damage of single and multi-family buildings throughout the inland bays and sounds, and along the barrier islands in Baldwin County, Alabama, and the western Florida Panhandle (see Figure 7-1).

Two circumstances probably account for the fact that the high flood levels exceeded the BFEs:

1) Hurricane Ivan's storm surge was greater than the stillwater elevations of the mapped 100-year flood event. The stillwater elevations are used in the coastal flood analysis to determine the minimum elevations standards (BFEs). As noted in Chapter 1, the preliminary estimated return period for Hurricane Ivan was approximately a 150-year storm. However, the data used to develop this return period was extremely limited, and further analysis should be performed.

2) The storm surge overwashed the barrier islands, thus allowing more water to enter into the back bays and sounds, especially in those areas immediately behind the barrier islands (see Figure 7-2). This overwash effect was not accounted for in the initial storm surge modeling used to develop the stillwater elevations, which are the main input parameters in the wave height analysis to determine the BFEs and zone designations. Without the overwash effect, the flood levels in these back bays and sounds would be underestimated. In addition, the storm surge modeling was performed over 25 years ago and did not account for possible subsequent changes in the topography of the barrier islands. The barrier islands have been significantly altered over these last two decades as a result of numerous tropical storms and hurricanes, including Hurricane Opal, which drastically altered and destroyed many of the dunes on the barrier islands. When these dunes stood higher than 15-25 feet, as they did when the initial surge model was developed, they prevented the floodwaters from overwashing the barriers; the only way the storm surge entered the bays and sounds was through the inlets. Now that the barriers islands have been impacted and altered by Hurricane Ivan, the contribution of the overwash into the back bays and sounds will continue to be a factor for future events.

Figure 7-1.
Newly constructed house in Zone AE, which was damaged due to high flood levels and impacts from waves and floodborne debris. The effective FIRM shows the BFE as 9 feet, but the flood levels exceeded this by 3-5 feet. (Big Lagoon)

Figure 7-2.
Barrier island on Santa Rosa Island, east of Pensacola Beach, which was completely overwashed by storm surge. The storm surge then inundated the Santa Rosa Sound.

Floodborne debris and wave damage (characteristic of V-Zone damage) in A Zones was extensive, especially along bay and sound shorelines. The storm surge and wave impacts destroyed buildings, enclosures, stairs, utilities, and docks and piers, which all became floodborne debris. Structures that were not elevated higher than the storm surge were not only damaged by floodwaters and wave action, but also impacted by the floodborne debris.

Erosion was severe along the barrier islands of Alabama and Florida. Areas that had wide beaches before Ivan were less impacted than those with smaller, narrower beaches. Erosion along bay and sound shorelines was generally minimal, and structural damage there was predominantly due to storm surge, waves, and floodborne debris. The erosion undermined shallow foundations and piers with shallow embedment. Many areas were susceptible and impacted by past coastal storm events, which led to further erosion and impact from Ivan. The methodology used to develop the FIRMs takes into account the erosion that would likely occur during the 100-year event. However, this analysis accounts for only one event and not multiple events that change or alter the barrier islands and dunes. Based on the eroded conditions from this one 100-year event, a wave height analysis is performed to determine the BFEs and the zone designations. Buildings are constructed to the standards developed and mapped on the FIRMs. These standards remain in-place for years and/or decades until a significant event results in severe damage or the methodology has been modified. After Hurricane Opal, which impacted much of the same area as Hurricane Ivan, the FIRMs were revised due to the severe damage, the observed HWMs, and new coastal methodologies that had been developed. Although smaller events had affected the coastal topography on the barrier islands and the new methodologies had been in place for over five years, it took a severe event like Hurricane Opal to instigate a map change.

7.1.1 Lowest Floor Elevations

One of the critical factors for this event was that the amount of damage to the building was in direct correlation with the elevation of the lowest floor (see Figure 7-3). Generally, the lowest floor elevation was a function of the type of foundation chosen for the building. Pile foundations had the advantage of getting the lowest floor up a full story, which usually placed it several feet above BFE. Other foundation types often resulted in buildings that were at BFE or only slightly higher. For Hurricane Ivan, this difference in elevation made a great difference in flood and debris damages.

Most of the damaged buildings occurred in areas mapped as A Zone on the current FIRM, although many of the buildings were pre-FIRM construction and built on slab foundations. The elevation of the buildings varied throughout the impacted area as well as among houses in the same neighborhood and along the same street. Generally, buildings near or on the bays or sounds, constructed to the BFEs or below for the pre-FIRM buildings, experienced significant flood levels and damaging waves and floodborne debris. FIRM revisions over the past two decades have resulted in changes in flood hazard zone designations and BFEs. This has led to varied construction practices and different lowest floor elevations throughout the coastal areas. These map changes may explain some of the variations in structural damages observed. However, many newer structures that were constructed to the minimum NFIP standards were severely damaged by the high storm surge elevations, while many buildings that were constructed several feet higher than the minimum standards were much less damaged. Figure 7-1 is also an example of a building built to the current minimum standards that sustained severe damage.

Some of the variations in building elevations were based on:

- Changes in the BFE on the FIRMs
- Higher building elevation requirements such as SRIA
- Homeowners voluntarily chose to elevate higher than the BFE on pile foundations for various reasons: for a better view, to create additional parking or storage areas, as a cautionary measure because of the proximity to a large bay or sound and the potential flood hazard, and/or because other adjacent buildings were elevated several feet above the BFE
- Recommendations by contractors, engineers, architects, state and local building and floodplain management officials

Figure 7-3. Lowest floor elevation was one of the most important factors in determining building damage during Ivan (Gulf Shores, Little Lagoon)

7.1.2 Foundations and Structures

On the barrier island, relatively few pile failures were observed during field inspections of newer, post-Hurricane Opal homes. However, preliminary review of pre- and post-Ivan aerial photography indicates many pile-supported homes along the beachfront may have been destroyed due to some combination of erosion, flood, and wind effects. Poor structure-to-beam connections likely resulted in intact piles and beams with structures missing from atop the foundations. Had these structure-to-foundation connections been adequate, these structures would have been damaged but probably would have remained in place.

In areas subjected to coastal erosion and scour, shallow foundation damage was extensive and the structural failures dramatic. Shallow foundations are not appropriate for supporting structures in high risk coastal areas.

In the bays and sounds, there was generally very little scour or erosion that affected the foundations, although some was observed behind bulkheads. Overall, since scour and erosion was not a factor, newer stem wall and pile foundations performed well; however, once the flood levels and wave heights exceeded the lowest floor, severe damage resulted to the building. Many older pier and pile foundations failed as the result of flood and wave loads that were above the lowest floor and exerted pressure on the buildings. The failures occurred due to lack of connections, tie-downs, and reinforced concrete. Figure 7-1 is also an example of a building constructed on a stem wall foundation, which was not impacted by erosion or scour, but due to the elevation of the building, the high flood levels and wave and debris impacts totally destroyed the building.

7.1.3 Piers and Docks

The construction of pier and docks, which extend several hundred feet in the bays and sounds, was prevalent throughout the impacted coastal areas. Damage to these systems was extensive, and dock materials and pilings provided a significant source of damaging debris. Piles and dock sections were found in the lower areas of buildings, which contributed to the destruction of many homes.

Figure 7-4.
Docks along back bays contributed to flood debris causing extensive damage.

7.1.4 Construction Features beneath Elevated Buildings

The newer buildings built to V-Zone standards with adequate pile embedment, generally performed well. Breakaway walls functioned as intended with the exception of those situations where a clear breakaway joint separation was not achieved, which led to siding and building component damage above the breakaway wall. Utility damages were observed when utility connections were attached to or passed through breakaway walls. Enclosed areas and stairways were destroyed or severely damaged, as would be expected.

NFIP minimum standards require that buildings constructed in V Zones be elevated on piles or columns so that the bottom of the lowest horizontal structural member of the building is above the BFE. The area below the lowest horizontal member must be left free of obstructions or enclosed with non-structural breakaway walls, insect screening, or latticework, and the area's use be restricted to parking, building access, or storage. The standards were developed with the understanding that the area below the lowest horizontal member would be sacrificial and would be totally destroyed during a major flood event.

During Hurricane Ivan, these construction features (e.g., access stairs and enclosures) beneath elevated buildings were often destroyed. Not only were the enclosed areas, stairs, utilities, and other systems severely damaged, but they also become a significant source of floodborne debris. Many enclosed areas below the lowest floor were fully enclosed and, in some cases, finished as additional living space. These features are becoming more substantial and are a significant source of floodborne debris. Once dislodged by storm surge, wave action, or wind, these features can act as obstructions and create unanticipated loads on the foundations and increase the potential for structural failure for many buildings.

Stairs and building access features are becoming more elaborate and expensive, increasing the total dollar damages resulting from the event. Most of the damage below the lowest floor is preventable by limiting the construction of these enclosures and other systems beneath the elevated building.

Figure 7-5. Access stairs and enclosures that were constructed below the lowest floor were severely damaged.

7.1.5 Pools and Bulkheads

Pools and bulkheads suffered extensive damage and should be viewed as sacrificial features during a major hurricane.

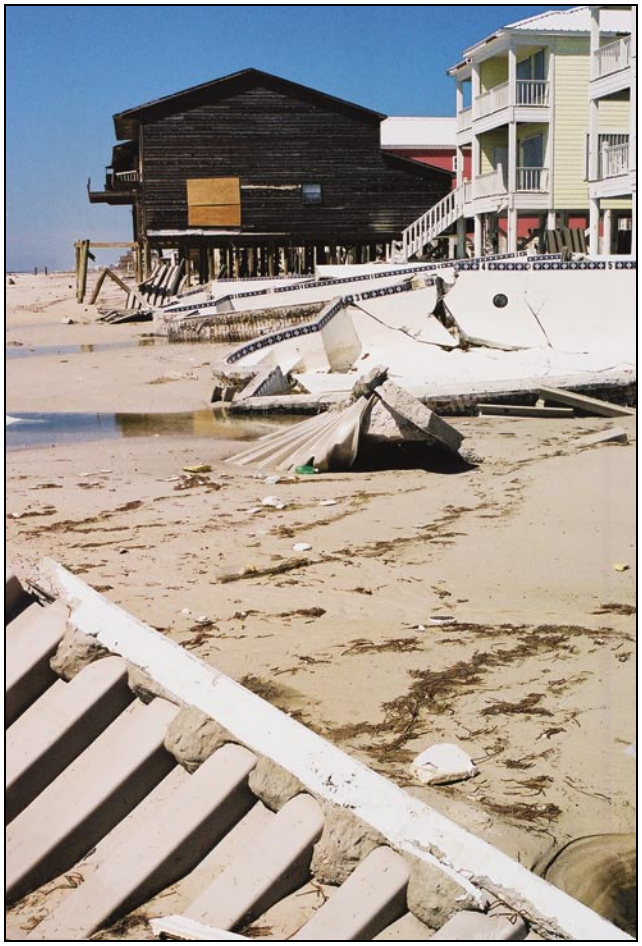


Figure 7-6.
Typical failure of swimming pools and bulkheads (Gulf Shores)

7.1.6 Utilities

Exterior utilities suffered extensive flood damage when not elevated or sited properly. The lack of design and installation attention resulted in destruction of building service utility lines, systems, and equipment, and led to the loss of function of the occupied space. Compliance with current FEMA publications and codes is essential to the future prevention of damages of this type. Figure 7-7 shows an inappropriately mounted condenser that was carried off its platform by high floodwaters.

Figure 7-7. Inappropriately mounted condensers for a coastal residential site that should have been mounted at a higher elevation and securely anchored to their platform

7.2 Wind Hazard Conclusions

While Hurricane Ivan is categorized as a Category 3 "major hurricane" by the NHC in its Tropical Cyclone Report with estimated 1-minute sustained wind speeds (over open water) of 121 mph, the actual wind speeds gathered on land (presented in Chapters 1 and 2) suggest Ivan was more typical of a Category 1 to 2 hurricane. Flood-related hazards such as storm surge, floodborne debris, inundation, and wave action were the primary cause of damage. The categorization of the storm by a single hurricane classification 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 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 in relationship to their location in the wind field, building code in effect at the time of construction, and mitigation efforts implemented on the building.

Although structural system failures tend to be perceived by the public and the building industry as the dominant issue of concern, it is clear that for buildings built in accordance with the 2001 FBC or the 2000/2003 IBC, structural issues have, in general, been resolved. Now, the arena in which improvements can and must be made are those related to water intrusion and protection of the building envelope (refer to Chapter 5). Protection of the building envelope is important to 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 or structure. In addition, failure in the building envelope often leads to progressive failures in structural systems.

Widespread building envelope damage was observed throughout the area visited by the MAT. Performance of building envelope elements such as roof coverings, roof mounted equipment, unprotected glazing, doors, soffits, and siding was generally poor and led to widespread damage to the interiors of residences, businesses, and critical/essential facilities.

Windborne debris damage was observed, but was not widespread across the entire path of the hurricane. Wind and structural engineering experts predict that significant windborne debris damage will begin in the 120-mph range in inland areas and in the 110-mph range when buildings are within one mile of the coast. In response to this, ASCE 7 requires that openings in the geographic areas described above be protected to resist windborne debris impact. Since Ivan's estimated gust speeds were generally below that level, it is expected that glazing damage during Ivan would be less common than in other more powerful storms, such as Hurricane Charley. Given that the actual wind speeds were below current code level wind speeds but at or near the older code level wind speeds, the occasional damage to the structural elements and the widespread damage to building envelopes can be characterized as wind-related damage caused by inadequate design, old construction methods, outdated codes, building age, lack of maintenance, and/or poor construction/code enforcement. Wind damage to the contents of residential and commercial buildings, and critical/essential facilities due to these failures is clearly preventable.

This report's conclusions and recommendations relate only to what was observed by the MAT in Hurricane Ivan. The conclusions and recommendations of the Hurricane Charley MAT report (FEMA 488) with regard to wind hazards are also relevant to design and construction in the areas impacted by Hurricane Ivan because similarities in damage observations exist. Hurricane Charley was a code level wind event along much of the hurricane's path, and readers are encouraged to obtain a copy of this report. In addition, a summary report for all four hurricanes that impacted Florida in 2004 is available (FEMA 490, *Summary Report on Building Performance 2004 Hurricane Season*, March 2005). This report is available online at http://www.fema.gov/fima/mat/fema490.shtm.

7.2.1 Building Performance and Compliance with the Building Codes, Statutes, and Regulatory Requirements of the States of Alabama and Florida

Most building damage and failures observed by the MAT appeared to be the result of inadequate design and construction methods commonly used before the 2000/2003 IBC and the 2001 FBC. Some observed damage and failures might be explained by lack of maintenance or poor condition of the building. 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 1/3 stress increase factor, are further refining the loads that new buildings must resist, thus ensuring better performance in wind events.

A summary of the historical code prescribed wind pressures over the last 25 years at two locations within the Hurricane Ivan damage zone is presented in Table 7-1. Typical single family residences in Gulf Shores, Alabama, and Perdido Key, Florida, as well as a small essential facility in the city of Pensacola, Florida, were selected for comparison. The table shows that the design wind pressures have been changing, and sometimes increasing, with each new code; therefore, it would be expected that failures of older buildings would be common if this were a code level wind event. For example, the required pressure for corner zones of roofs has increased more than 3 fold over that period. Corner zone pressures did not even exist in the 1979 SBC. These increases are a reflection of the findings of both wind tunnel research and post-storm investigations. The pressures have increased most dramatically on the parts of buildings that have suffered worst in wind storms.

To properly evaluate the compliance with past building codes, an analysis of the actual pressures experienced by the buildings in Hurricane Ivan was necessary. In addition to the design pressures for the current and two preceding codes, Table 7-1 also contains the estimated actual pressures thought to have been experienced at these locations. These pressures are based on the maximum recorded 3-second gust wind speeds at each location, using the latest code method of wind pressure determination in effect at each location. The resultant pressures range from 5 percent to 40 percent below the current design pressures, confirming that this was not a code level wind event with respect to the 2001 FBC or 2000/2003 IBC. However, it is important to note that in most cases, the actual pressures are in the same range as the 1997 SBC design pressures. These wind provisions were first introduced in the 1982 edition of the SBC and were largely unchanged through the 1999 SBC. Therefore, it is reasonable to expect that a significant number of buildings in the damage zone should have been built to withstand design pressures in the range of what was experienced in Hurricane Ivan. Considering the amount of wind damage observed by the MAT, it is evident that under-prediction of the design wind loads by past building codes for critical building areas such as roof and wall corners led to significant building envelope damage and may have led to some of the structural damage observed. However, investigation of the damage observed suggests compliance of the construction with the building codes was a much bigger factor.

Some elements of buildings constructed under older codes were vulnerable to damage because of the lack of specific provisions for those elements. Building envelope components such as roof coverings have much more stringent requirements in the current codes. Rooftop equipment and protection of glazing, for example, were largely ignored in older codes. 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 clear evidence 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 in enforcement and code compliance to ensure that component and cladding (C&C) elements are being engineered and designed per the code requirements.

For the State of Florida, the 2001 FBC and the recently completed 2004 FBC (to be adopted statewide by administrative rule effective October 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 IBC/IRC, NFPA 5000, and ASCE 7.

Table 7-1. Design Wind Pressures Building Code

	Equivalent Design Wind Speed (3-second gust)	Building Surface / Function			
		Exterior Walls		4 in 12 Roof Pitches	
		Main Frame	Components and Cladding	Main Frame	Components and Cladding
Single Family Residence in Gulf Shores, Alabama					
Standard Building Code 1979 Edition[1,2,3]	130 mph	+33 psf	+/- 27 psf	-25 psf	- 23 psf
Standard Building Code 1997 Edition[1,2,3]	115 mph	+32 psf	+25/-29 psf	-26 psf	+15/-52 psf
International Building Code 2003 Edition[1,2,5]	145 mph	+46 psf	+38/-51 psf	-40 psf	+22/-73 psf
Actual Maximum Recorded Wind Speed[1,2,4,6]	109 mph	+23 psf	+29/-39 psf	-31 psf	+16/-68 psf
Single Family Residence in Perdido Key, Florida					
Standard Building Code 1979 Edition[1,2,3]	125 mph	+30 psf	+/- 25 psf	-23 psf	- 21 psf
Standard Building Code 1997 Edition[1,2,3]	110 mph	+31 psf	+24/-28 psf	-25 psf	+14/-50 psf
Florida Building Code 2001 Edition[1,2,5]	135 mph	+40 psf	+33/-44 psf	-35 psf	+19/-63 psf
Actual Maximum Recorded Wind Speed[1,2,4,6]	119 mph	+31 psf	+25/-34 psf	-27 psf	+14/-49 psf

psf = pounds per square foot

1 The pressure calculations under each code for both main frame and components and cladding 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 gust wind speed is shown for comparative purposes only and was not used in the calculation of the design wind pressures.

4 Assumed Exposure Category C.

5 Assumed Exposure Category B.

6 Actual maximum recorded wind speeds were measured in 3-second gust speeds. Pressures were calculated under the current code for that location (IBC or FBC).

7.2.2 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 performed well and showed how improvements to the building codes have been successful in Florida. Adoption of the IBC in Alabama communities was so recent that few buildings had been constructed under those provisions; however, the same results as those in Florida are expected. Throughout the Hurricane Ivan damage zone, structural wind damage was common in certain construction types, at wind pressures 5 to 40 percent below design level in the code. The most prevalent construction type experiencing structural damage was residential wood roof framing. Inadequate nailing of roof sheathing panels, gable end wall failures, and lack of properly installed wood framing connectors were the major factors in these structural failures. Pre-engineered metal building structures suffered significant damage, particularly to older buildings.

7.2.2.1 Internal Pressures

Breach of the building envelope through broken windows, failed doors, or loss of sheathing led to significant changes of the internal pressures in buildings, which sometimes resulted in structural damage. 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, doors, and windows 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 observed window failures that resulted in interior partition failure and failure of exterior walls, as seen in Figures 7-8 and 7-9 (this failure is fully described in Subsection 5.5.1. The MAT saw other examples where wall materials or framing in the gable end walls failed, causing the attic space to become pressurized. In some cases, the pressurized attic pushed off the roof sheathing. In other cases, the pressurized attics failed the ceilings below them, pressurizing the interior spaces, and caused failures in the building envelope from the inside.

Figure 7-8.
Window damage caused exterior wall failure (Gulf Shores)

Figure 7-9.
Partition walls destroyed by interior pressurization due to window damage (Gulf Shores)

7.2.2.2 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 partial 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 during renovation work or during 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 much of the roof decking and roof structure failures observed after Hurricane Ivan.

In commercial, government, and critical/essential facility buildings, mitigation retrofit costs may be minimized if these types of projects are performed during tenant fit-out projects or during major capital improvement projects. Prioritization can be given to mitigating space used for critical and essential functions. Public schools are examples of places 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 that were once vulnerable to damage from wind and windborne debris.

7.2.3 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 houses built in accordance with the FBC 2001 and other model codes have, in general, resolved most structural issues. Now, the arena in which improvements can and must be made are those related to 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. Damage was noted throughout all areas observed. Ramifications of poor performance include the following:

- **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 rainwater 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 rainwater damage frequently resulted because of the heavy rains accompanying the hurricane and rains occurring in the following days and weeks. Rainwater entered the buildings through the breaches in the building envelope.

- **Loss of function.** Depending upon the magnitude of the wind and rainwater 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.

Building Envelope

Poor performance was a function of both inadequate wind resistance and damage from windborne debris impact. Inadequate resistance to high-wind pressures on building envelopes and rooftop equipment was responsible for much of the damage caused by Hurricane Ivan. In addition, windborne debris caused significant envelope damage (and virtually all of the glazing damage) that the MAT observed. 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.

The importance of the building envelope is illustrated by Figure 7-10. Although the structural frame performed well, poor performance of the building envelope resulted in significant damage. Balcony railings, stucco wall covering, and entire portions of the non-load-bearing walls were blown away. Glazing damage was extensive, although as shown in Figure 7-10, shutters were successful in preventing damage to those windows and glazed doors that were protected.

Figure 7-10.
Although this was a structural success, except for the excellent shutter performance, this building was an envelope failure.

Roof Coverings, Wall Coverings, and Soffits

Observations showed that roof coverings of all types continue to fail 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 design wind loads) while other failures were due to design and construction related issues or debris impact. Specifically, these observations are as follows:

- 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).

- The Brick Industry Association (BIA) sponsored research regarding windborne debris resistance of brick veneer walls versus walls with other coverings. The research demonstrated that brick veneer was quite resistant to debris impact. Based on the research BIA states that "brick provides safety for building occupants and security for property." This statement is only true if the brick veneer is not blown away. If wind-induced collapse of brick veneer does occur, as illustrated in Figures 5-26 and 5-27, the expected protection will not be present.

  As with many other building envelope elements, improved brick veneer design guidance and workmanship are needed.

- In general, EIFS performed very poorly. For many buildings, the poor performance resulted in significant rainwater infiltration damage (see Figure 7-11). Much greater attention is needed in the design and application of EIFS, and improvements are needed in design guides and testing.

Figure 7-11:
In this EIFS failure, the majority of the gypsum board detached from the studs. At some living units, the gypsum board on the interior side of the studs was also blown off, thus exposing the units directly to the hurricane.

- In general, vinyl sidings performed very poorly. The vinyl siding industry should evaluate the findings of the MAT and launch a program to more fully understand the causes of the poor performance.
- Asphalt roof shingles continued to fail below current 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 known methods for resisting blow-off in high-wind areas (Figure 7-12).

Figure 7-12.
Rather than cutting off the tabs, the starter course on this new roof was turned 180 degrees. Hence, the tabs of the first row were free to lift because they were not adhered in the self-seal adhesive on the starter.

- 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. 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 (Figure 7-13). 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.

Figure 7-13.
These batten-attached tiles were damaged by windborne debris. Much of the damage was caused by tile impacting other tiles. A tile was blown 140 feet from this building.

- Aggregate roof surfacing continued to cause debris damage when aggregate was displaced by high winds, becoming windborne missiles.
- 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 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 interior.
- In numerous buildings, 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.

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. The required protection of these openings in areas within the ASCE 7 windborne-debris region appeared justified from the amount of observed debris. (However, the lack of a FBC windborne debris region in the Florida Panhandle does not appear to be justified.) Using glazing protection to prevent full internal pressurization and to protect interior contents from being damaged is an effective means of damage reduction for all hurricane-prone regions. Specifically:

- Many homes and businesses that experienced only contents damage could have prevented these losses if their openings were protected. Success in designing the structural frame to resist wind loads and internal pressures was partially negated by significant losses to building contents (Figure 7-14).
- Most shutters observed on buildings during Hurricane Ivan performed well.
- In the ASCE 7 windborne-debris regions, unprotected glazing located with the first few floors above grade is typically more susceptible to breakage than glazing located several stories above grade. This is due to the greater quantity of windborne debris at lower elevations. However, as illustrated by Figure 7-15, glazing in tall buildings can also be broken. Breakage at upper levels can be caused by dislodged roof coverings, rooftop equipment, balcony railings or wall coverings from the building or an adjacent building. However, as discussed in the ASCE 7 C6.59 Commentary, the greatest threat to upper-level glazing is the presence of aggregate roof surfacing on the building or other buildings within 1,500 feet.

  If aggregate roof surfaces do not occur within the parameters given in ASCE 7, then for most buildings, glazing protection above 60 feet above grade is generally not needed (although isolated damage may occur as shown in Figure 7-15). On some critical or essential facilities, as a very conservative measure, protecting glazing above 60 feet may be prudent. For these buildings, a special evaluation, including consideration of the basic wind speed, characteristics and proximity of other buildings, and characteristics of the building being considered should be conducted to determine if glazing protection above 60 feet is appropriate.

Figure 7-14.
Glazing at the top two window units broken by debris, while the entire middle window unit was blown away. The shuttered window unit was not damaged.

Figure 7-15.
A few of the upper level windows were broken.

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 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 resulted in 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 rainwater infiltration at the displaced equipment.

7.2.4 The Need for High-Wind Design and Construction Guidance

Designers, contractors, and building officials need additional education and resources. Although many successes of design and construction were observed across the path of Hurricane Ivan, it was apparent that the load path concept was often not fully understood. It was also clear that many designers, contractors, and building officials do not fully understand the devastating effects that hurricanes can have on building envelopes and equipment. It was common to see fasteners spaced too far apart, fasteners that were too small, and fasteners with 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 and contractors, 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.

7.2.5 Performance of Critical and Essential Facilities (Including Shelters)

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

In general, buildings functioning as critical and essential facilities did not perform significantly better than their commercial-use counterparts. Despite codes of the past ten years that require higher 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 essential and critical facilities discussed in Chapter 6 were hampered or shut down and taken off-line after the hurricane.

Most critical and essential facilities in the impacted area were housed in older existing buildings and most, if not all, apparently were not mitigated to resist known hurricane risks. If key areas of the buildings 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 been reduced.

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

- 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 leads to significant loss of function at the facilities (Figure 7-16).

Figure 7-16.
An older hospital that experienced blown off roof coverings, gutters, downspouts, rooftop equipment (including lighting protection system components), and broken glazing

- 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 office buildings, and led to window failures and severe damage to building contents.
- Rooftop equipment loss such as loss of HVAC units and vents, antennas, communication dishes, and lightning protection systems was prevalent. In almost all cases, these failures caused damage to roof coverings that often resulted in rainwater intrusion into the facilities (Figure 7-17).

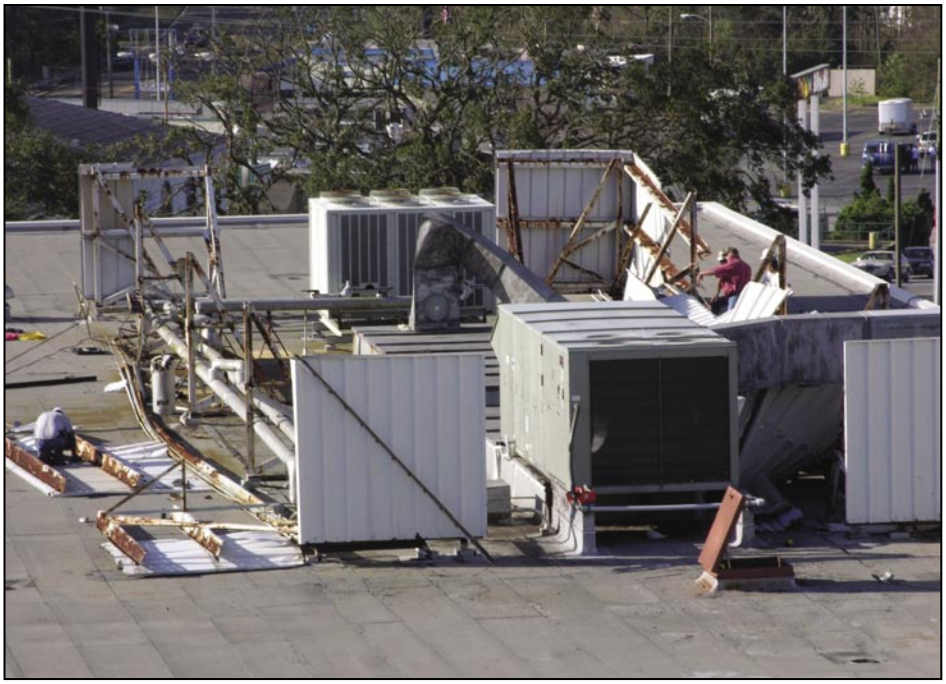


Figure 7-17.
Rooftop mechanical equipment damage at a hospital. Several of the equipment screen panels were blown away. Loose panel debris can break glazing and puncture roof membranes.

- Windborne debris could injure or kill first responders at EOCs, late arrivers at shelters, or those seeking medical attention at hospitals. Although people are not usually outdoors during hurricanes, buildings used as essential and critical 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.
- 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

Recommendations

8

The recommendations in this report are based solely on the observations and conclusions of the MAT, and are intended to assist FEMA, the States of Alabama, and Florida, local communities, businesses, and individuals in the reconstruction process and to help reduce damage and impact from future natural events similar to Hurricane Ivan. The general recommendations presented in Sections 8.1 (for flood) and 8.2 (for wind) 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.

8.1 Flood Related Recommendations

The most severe flood-related damages experienced during the 2004 hurricane season were associated with Hurricane Ivan. Recommendations and tables summarizing key recommendations are provided below:

8.1.1 General Hazard Identification Recommendations

- **Re-evaluate the hazard identification/mapping approaches in coastal AE/VE Zones –** Re-evaluate the methodology to determine flood zones and flood elevations in coastal areas, to address the inconsistencies between observed flood elevations (and damages) and BFEs (and anticipated damages). Re-evaluate the criteria for determining the AE/VE Zone boundary, which currently is based on a 3-foot wave. Areas subject to waves of 3 feet or higher are considered V Zones. Flood hazard mapping procedures and methodologies in coastal areas (especially on barrier islands, and on mainland, open coast shorelines) may need revisions to capture anticipated future coastal conditions (for instance, the possible effects of multiple storm events and long-term erosion).

- **Re-evaluate the storm surge modeling –** Review the storm surge data and modeling procedures that served as the basis for the effective FIRMs. Updates after Hurricane Opal (1995) were limited and did not affect areas north of Highway 98 in Escambia County. Conduct a revised tide frequency analysis, update storm climatology for the area, and utilize modern storm surge models to estimate the BFEs throughout the Ivan impact area.
- **Reconstruction Guidance –** Use Hurricane Ivan tide levels, inundation limits, and areas subject to wave effects as proxies for reconstruction guidance until such time as new, up-to-date regulatory studies and maps can be prepared and adopted.

8.1.2 Design Guidance

- Although not mandated by the IRC or the FBC, utilize ASCE 24-05 for flood-resistant design of one- and two-family structures (the IBC references ASCE 24, but the IRC does not). Design and construction practices specified in ASCE 24-05 will result in flood- and erosion-resistant foundations throughout coastal areas (not just V Zones) and the addition of freeboard to the lowest floor elevation, utility equipment that is protected from the flood damage, and the use of flood-resistant materials below the BFE.
- Use ASCE 7-05, Section 5.3 and the associated Commentary, for the calculation of flood loads during the base flood. The Commentary provides guidance for characterizing and calculating floodborne debris loads.
- Use the *Home Builder's Guide to Coastal Construction Technical Fact Sheets* (FEMA 499) and the Coastal Construction Manual (FEMA 55) for additional guidance related to flood- (and wind-) resistant design and construction.

8.1.3 Foundation Recommendations

- **Elevate the bottom of the lowest structural member above the BFE for coastal A Zones –** Elevate all new construction (including substantially improved structures and replacement of substantially damaged structures) in coastal A Zones with the bottom of the lowest horizontal supporting member above the BFE. This is a higher standard than the NFIP minimum requirement, which calls for only the top of the lowest floor (walking surface) to be at or above the BFE.

- **Freeboard** – Require freeboard for all structures in all flood hazard zones with the amount varying with building importance (see ASCE 7-05 and ASCE 24-05 for building importance classification and freeboard requirements) and anticipated exposure to wave effects (see Figure 8-1). When using pile foundations, elevate the lowest floor a minimum of one story above grade to allow for parking and storage, which is the current practice by some builders.

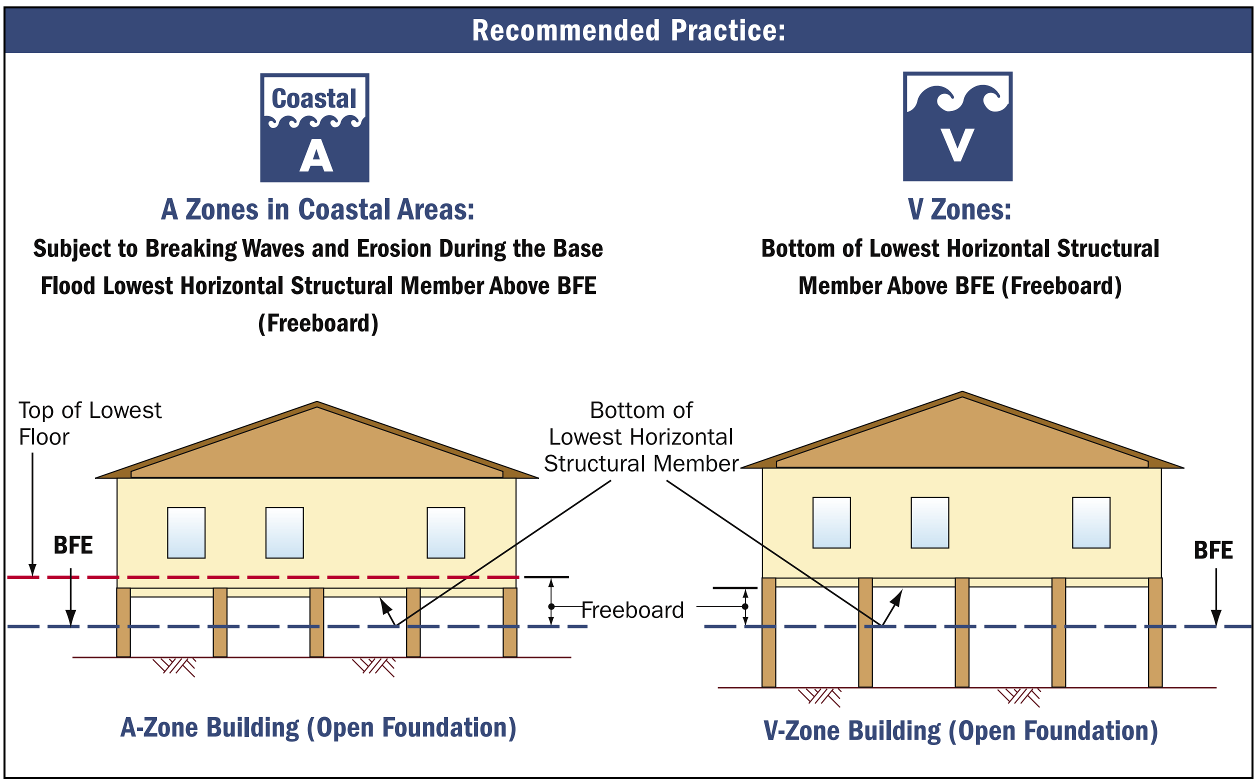


Figure 8-1. Freeboard and open foundations are recommended for V Zones and coastal A Zones.

- **V-Zone standards** – Require V-Zone design and construction for new construction in coastal A Zones subject to erosion, scour, velocity flow, and/or wave heights greater than 1.5 feet.
- **Foundations on barrier islands** – Use a deep pile and/or column foundation anywhere on a barrier island – including B, C, and X Zones – if erosion/or scour are possible. Use of other foundation types should be limited to those areas far outside the SFHA, not

subject to future flooding if dunes or other natural protective features are lost and not subject to erosion or scour. Other foundation types should be the exception, not the rule.

- **Foundations near bay/sound shorelines** – For sites near bay or sound shorelines, foundation selection should be based on several factors: erodibility of the soil; exposure to "damaging" waves (≥1.5 feet high); potential for velocity flow; potential for floodborne debris; and required resistance to lateral flood and wind forces. Aside from the lateral resistance issue, which will probably be a function of wind loads, Table 8.1 should be used to help select the appropriate foundation near bay/sound shorelines.

Table 8-1. Recommended Foundations for Coastal Areas near Bay/Sound Shorelines and Not Mapped as V Zone

Foundation Type	Base Flood Condition Present			
	Erodible Soils, Base Flood Inundation Possible	Wave Heights between 1.5 and 3.0 Feet*	Velocity Flow	Large Debris
Fill	no	no	no	no
Slab on grade	no	no	no	no
Crawlspace, shallow footing	no	no	no	no
Foundation walls, shallow footing	no	no	no	no
Stemwall, shallow footing	no	yes	no	yes
Stemwall, deep footing**	yes	yes	yes	yes
Pier, shallow footing	no	yes	no	no
Pier, deep footing**	yes	yes	yes	no
Post, shallow embedment	no	no	no	no
Pile/Column, deep embedment**	yes	yes	yes	yes

* wave heights greater than 3.0 ft mapped as V Zone: fill, slab, crawlspace, wall foundations not permitted

** deep means sufficiently deep to withstand erosion and scour, including that induced by the presence of the foundation itself

Absent a detailed study for a site, exposure to damaging waves ≥ 1.5 feet can be estimated based on three factors:

- Fetch (during the base flood) from the bay/sound shoreline across the water body. If the fetch is less than 1 mile, the potential for generation of damaging waves is low; if the fetch is 1 mile or greater, assume damaging waves can be generated.
- Stillwater depth at the site, after accounting for erosion. If the stillwater depth is 2 feet or greater, sufficient depth exists to allow passage of 1.5-foot waves; if the stillwater depth is less than 2 feet, waves may be present but should be less than 1.5 feet high.
- Obstructions between the site and the shoreline. If dense stands of trees or buildings/structures capable of withstanding the base flood occur between the site and the shoreline, it is reasonably safe to assume the height of any damaging waves will be reduced; if these obstructions do not exist (or if they exist but their future existence is questionable), assume the wave heights will not be reduced appreciably.

Pier foundations should be used only where soil characteristics and flood conditions permit, and where their design and construction are consistent with the details shown in Figure 8-2. Although this is a common foundation type, its performance in coastal areas has been poor where erosion, waves, and/or debris are present.

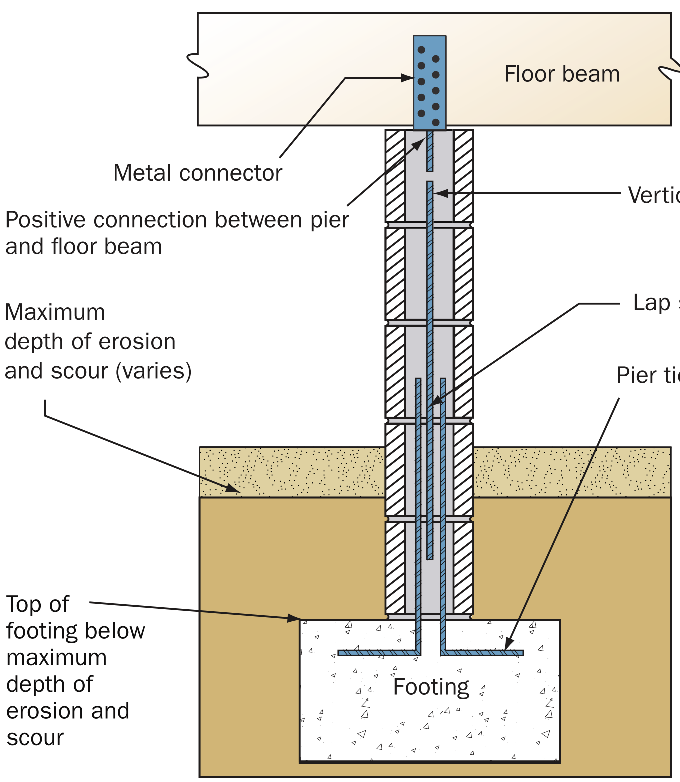


Figure 8-2. Recommended design details for masonry piers where this foundation type is appropriate

Although stemwall foundations (backfilled with a concrete slab on top) performed better than many other A-Zone type foundations near bay/sound shorelines, their use should be contingent on having footings deep enough to withstand erosion and scour, including that due to the presence of the foundation itself.

If there are any doubts as to the appropriate foundation to use near bay and sound shorelines, elevate the building at least one story above grade on piles or another deeply embedded open foundation, and leave the area below free of obstructions or enclose it with breakaway walls.

- **Debris Impacts –** Design foundations and structures to withstand loads from floodborne debris during a base flood event (100-year).
- **Multi-story Construction –** For barrier island sites outside the V Zone, the ground level floor of a multi-story building (typically used for vehicle parking and building access) should either: 1) use a lowest floor slab or floor system that will not collapse and can support all design loads, if undermined, or 2) use a slab or floor system that will collapse and break into small pieces if undermined. For V-Zone sites (on barrier islands and bay/sound shorelines), the ground floor system must collapse and break into small pieces if undermined.

8.1.4 Building Utilities

Electrical wiring and equipment and plumbing should be securely fastened to the landward side of an interior piling and should not be attached to breakaway walls or in areas exposed to wave and debris impacts.

HVAC equipment should be elevated above the BFE and preferably to the same elevation as the lowest floor of the building. The equipment should be supported to prevent damage from flooding and fastened to resist blow-off from high winds. The preferred approach is a cantilevered platform (see Figure 8-3). Other acceptable support systems include knee-braced platform supports (with the bottom of knee braces above wave and debris impacts), and pile supports (with piles substantial enough to resist all flood loads and anticipated erosion and scour). Shallow and/or small diameter post or pile supports should not be used under any circumstances in coastal flood hazard areas.

Figure 8-3.
A cantilevered platform.

8.1.5 Building Access Structures and Enclosures beneath Elevated Buildings

Although newer buildings elevated on piles that were built to V-Zone standards performed well structurally, there were considerable residual damages to the lower portions of the buildings to enclosed areas and elaborate staircases. These damages could have been avoided or at least reduced. Although many of these damages are uninsured and the costs of repair borne by the owner, there are some added costs to the NFIP, particularly for staircases. In addition, as these enclosures and stairways become larger, they are less likely to break away and, thus, more likely to become obstructions to flood flows increasing risk to the rest of the building. The following guidance is provided:

- Ensure that breakaway walls are designed and built to break away cleanly and do not cause additional damage to the building. Do not overlap piles or floor beams with breakaway walls. Provide a clean joint between the breakaway wall and the siding on the elevated portion of the building.
- Minimize the size of any enclosed areas to the amount necessary for parking and building access. Fully enclosing large areas below elevated buildings only increases repair costs and contributes to increased risk of debris impacts to the building and other nearby homes.

- Design staircases to provide a reasonable means of safe and convenient access to the building. Many of the more elaborate staircases on newer buildings were obstructions to flood flows under the building and may have contributed to increased damages and at a minimum, the repairs are costly.
- Flood insurance claims for stairs and building access structures should be limited to a reasonable fraction of the policy limit. The amount should be based on the costs to provide access to the building that is safe and convenient, but no more.
- Flood insurance rating and claims procedures should be modified to ensure that ratings and claims payments are accurate and reflect the risks, particularly in regard to enclosures and obstructions.

8.1.6 Pools and Bulkheads

Post-storm inspections consistently show pool and bulkhead failures and building owners need to understand that these will likely be destroyed during a major hurricane. The following guidance is provided:

- **Pools –** either elevate the pool above the BFE on a pile foundation (and design the pool without side support from soil), or install a frangible (breakaway) pool at grade level and consider it expendable. Do not rely on a bulkhead to protect the pool during a severe storm.
- **Bulkheads –** subject to local and state regulations for coastal armoring, assume that only heavy walls will provide protection during a severe storm, and note that even those may be overtopped by surge and waves. Consider lightweight bulkheads as temporary structures that may provide protection during minor storms, but which will likely fail during a major storm. Do not rely on bulkheads to protect soil supporting buildings; hence, construct buildings on pile foundations even if a bulkhead exists.

8.1.7 Public Outreach and Education

Tailor informational pamphlets to homeowners and building owners to:

- Educate about the risks of natural hazards and best practices for mitigating damages.
- Educate about the risk of constructing enclosures and accessory structures beneath the first floor and emphasize the significant damage that will result during a severe coastal flood event.

For architects, engineers, consultants, building officials, and contractors, prepare monographs for trade-wide distribution, and web-based tutorials and seminars. Encourage colleges, universities, and trade schools to augment existing curriculum with hurricane-resistant design and construction instruction. The following topics can be covered:

- Share post-disaster building performance information to maximize the value of lessons learned.
- Emphasize best practices such as those in the Coastal Construction Manual (FEMA 55) and the Home Builder's Guide to Coastal Construction Fact Sheets (FEMA 499).
- Emphasize importance of freeboard and strong structure-to-beam connections to prevent structure detachment from the foundations.
- Emphasize the importance of flood- and erosion-resistant foundations in coastal areas, even if not required by code and floodplain management regulations.

For elected officials, develop outreach efforts that clearly demonstrate the value of exceeding minimum floodplain and code requirements:

- Illustrate the fact that freeboard and V-Zone foundations are critical to building survival across entire barrier islands, not just sites near the shoreline.
- Show examples of other communities that have adopted higher standards and their experience with those higher standards.
- Assist elected officials in the revision of floodplain management ordinances, development regulations, and building codes to reduce future storm damage.

Tables 8-2 through 8-5 present the flood-related recommendations developed by the MAT and first presented in FEMA 490, *Summary Report on Building Performance 2004 Hurricane Season*, March 2005. Table 8-2 presents the recommendations for design and construction of buildings and accessory structures.

Table 8-2. Design and Construction Recommendations

Flood Hazard		
Building Component	**Recommendation**	**Action Required By[1]**
Design, Foundations and Structures		
Design guidance	Use ASCE 7-05, section 5.3 for the calculation of flood loads during the base flood.	D, C, G
Design guidance	Use ASCE 24-05 for the flood-resistant design of all structures in flood hazard areas, including one- and two-family structures.	D, C, G
Design guidance	Use the *Home Builder Guide to Coastal Construction Technical Fact Sheets* (FEMA 499) and the *Coastal Construction Manual* (FEMA 55) for additional guidance related to flood- (and wind-) resistant design and construction.	D, C, G
Floodborne debris	Design foundations and structures to withstand loads from floodborne debris during a base flood event (100-year).	D, C, G
Lowest floor elevation	Elevate all new construction (including substantially improved structures and replacement of substantially damaged structures) in A Zones with the bottom of the lowest horizontal supporting member above the base flood level. Freeboard for all structures in all flood hazard zones is desirable; the amount will vary with building importance (see ASCE 7-05 and ASCE 24-05) and anticipated exposure to wave effects.	D, C, G
Foundations on barrier islands	Require V-Zone standards for new construction in coastal A Zones subject to erosion, scour, velocity flow, and/or subject to wave heights greater than 1.5 feet.	G
High rise foundations on barrier islands	For areas outside the V Zone, the ground level floor of a multi-story building (typically used for parking or building access) should either: 1) use a lowest floor slab or floor system that will not collapse and can support all loads or 2) use a slab or floor system that will collapse into small pieces. For areas within the V Zone, the ground floor system must collapse and break into small pieces if undermined.	D, C, G
Foundations near bay and sound shorelines	For sites near bay or sound shorelines, foundation selection should be based on several factors as described in section 8.1.3 and an appropriate foundation should be selected as outlined in Table 8-1.	D, C, G
Utilities	Design and construct to ASCE 24-05. HVAC equipment should be elevated above the BFE and should be supported to prevent damage from flooding, wave, and debris impacts, and high winds. The support system should be a cantilevered platform or knee-braced platform with the bottom of the knee braces above the wave and debris impacts.	D, C, G
Dock and piers	Implement design requirements for docks and piers that minimize damage to other structures.	D, C, G

Table 8-2. Design and Construction Recommendations (continued)

Flood Hazard		
Building Component	**Recommendation**	**Action Required By[1]**
Accessory Structures		
Pools	Either elevate the pool above the BFE on a pile foundation (and design the pool without side support from soil), or install a frangible (breakaway) pool at grade level and consider it expendable.	D, C, G
Bulkheads	Do not rely on bulkheads to do any more than retain soil under normal and minor storm conditions; do not design building foundations or other structures that rely on bulkheads to retain soil during a base flood event.	D, C, O

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

Table 8-3 presents flood hazard identification and regulations recommendations.

Table 8-3. Hazard Identification and Regulations Recommendations

Flood Hazard	
Parameter	**Recommendation**
Hazard Identification and Regulation	
Storm surge	Re-evaluate storm climatology, water-level data, and storm-surge modeling; run modern storm-surge models as the basis for determining new BFEs.
A Zones in coastal areas	Re-evaluate the hazard identification/mapping approaches in coastal A Zones.
Zones B, C, and X on barrier islands	Re-evaluate flood and erosion hazards associated with areas outside the SFHA on barrier islands.
Open coast future conditions mapping	Flood hazard mapping of open coast areas should account for multiple storm events and future conditions (e.g., long-term erosion and sea level rise).

Table 8-4 presents recommendations to alert the public to the flood hazard.

Table 8-4. Public Outreach Recommendations

Flood Hazard	
Education Topic	**Outreach**
Building Owners and Homeowners	
Educate building and homeowners in the risks of natural hazards and best practices for mitigating damages.	Use FEMA *Home Builder's Guide to Coastal Construction Fact Sheets* (FEMA 499). Interview homeowners who have been through recent storms (both those whose buildings were not damaged and those whose buildings were). Use this information to prepare other informational pamphlets/video/web sites aimed at homeowners and building owners.
Educate homeowners on the risk of constructing enclosures and accessory structures beneath the lowest finished floor and emphasize the significant damage that will result during a severe coastal flood event.	Prepare pamphlet.
Architects, Engineers, Consultants, and Building Officials	
Architects, Engineers, Consultants	Distribute information in the areas of post-disaster building performance to maximize value of lessons learned. Emphasize best practices in *Coastal Construction Manual* (FEMA 55). Emphasize the importance of flood- and erosion-resistant foundations in coastal areas, even if not required by code and floodplain management regulations. Emphasize importance of freeboard and strong structure-to-beam connections to prevent structure detachment from the foundations.
Building Officials	Same as Architects/Engineers/Consultants, plus: Develop educational programs for annual seminars, specially designed to share "lessons learned" and receive training to address potential permitting/enforcement problems. Encourage building officials to obtain the new certification (coastal building inspector) being offered by ICC after July 2005.

Table 8-4. Public Outreach Recommendations (continued)

Flood Hazard	
Education Topic	**Outreach**
Elected Officials	
Educate elected officials on how to best design buildings for barrier islands.	Pamphlets, videos showing side-by-side photos and discussion of freeboard vs. elevating to BFE, V-Zone foundations vs. A-Zone foundations in coastal A Zones
Show elected officials examples of other communities that have adopted higher standards and their experience with those higher standards.	Interview community officials from communities that have adopted higher standards – what are the advantages and disadvantages of doing so? How much damage has been avoided in recent storms? Develop relationships with organizations of elected officials (county commissioners associations, league of cities, etc.), and get on the agenda for their national/state meetings – promote higher standards.
Assist elected officials in the revision of floodplain management ordinances, development regulations, and building codes to reduce future storm damage.	Obtain/prepare model ordinances, development regulations, and code revisions that mandate higher standards.
Contractors	
Share post-disaster building performance information to maximize the value of lessons learned. Emphasize best practices such as *Coastal Construction Manual* (FEMA 55) and *Home Builder's Guide to Coastal Construction* (FEMA 499). Emphasize importance of strong structure-to-beam connections to prevent structure detachment from the foundations while piles and beams are still intact.	Prepare monographs for trade-wide distribution. Prepare web-based tutorials and seminars. Encourage colleges, universities, and trade schools to augment existing curriculum with hurricane-resistant design and construction instruction.

The flood hazard recommendations in Table 8-5 are specific to critical and essential facilities.

Table 8-5. Recommendations Specific to Critical and Essential Facilities

Flood Hazard		
Parameter	**Recommendation**	**Action Required By[1]**
Critical/Essential Facilities		
Public shelters	Do not open shelters located in potential storm-surge inundation zones until after the hurricane makes landfall.	G, CFO
New structures	Elevate new structures in floodprone areas to the 500-year (0.2% annual exceedance) flood level or higher based on ASCE 24.	D, G, CFO
Existing structures	Evaluate vulnerability of existing structures in light of recent damage to similar facilities; strengthen and floodproof structures where feasible.	G, CFO, D

[1] Action required by: Designer (D), Government Official (G), Critical Facility Manager/Owner (CFO)

8.2 Wind Recommendations

As the people of southern Alabama and northwestern Florida rebuild their lives, homes, and businesses, there are a number of steps they can take to lessen the impact of wind damage from future natural hazards, including:

- Design and construct facilities to at least the minimum design requirements in the 2003 IBC in Alabama and the 2001 FBC and the 2004 FBC (after it becomes effective in the summer of 2005) in Florida.
- When renovating or remodeling for structural or building 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 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, and providing backup power and data storage to NOAA/NWS's surface weather monitoring systems, including the ASOS 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 land falling hurricane. Support should be provided for the real-time communication of data from all these platforms 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 the public as quickly as possible after a hurricane strikes.

8.2.1 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 positive 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 codes and statutes were developed and adopted. Incorporating the recommendations in this report into the next available code cycle is key to setting the new standard in hurricane-resistant construction in Alabama, Florida, and all hurricane-prone regions.

Subsections 8.2.1.1, 8.2.1.2, and 8.2.1.3 provide recommendations specific to the codes and statutes currently adopted and being enforced in the States of Alabama and Florida. If these recommendations are not codified by the states 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 as a discretionary matter.

8.2.1.1 Statutory Building Code Provisions – Alabama

- Adopt the 2003 IBC and IRC for all high-wind jurisdictions in the state.

- Do not modify the wind provisions of the IBC/IRC and ASCE 7-02 with local amendments that suspend some of the provisions, such as windborne debris protection.
- Require the use of high wind provisions for residential construction in wind zones of 100 mph and greater. The current 2003 IRC requirement is 110 mph; however, the IRC Code Development Committee has approved a code change proposal for the 2006 version lowering the threshold to 100 mph.
- Review the exemption in windborne debris regions that allows for residences to be designed as "partially enclosed" structures with unprotected openings. The MAT observed 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. The IBC Structural Code Development Committee has approved a code change proposal for the 2006 version eliminating the partially enclosed option. Based on observed damages in Hurricane Ivan, this exemption should not be allowed for any use (residential or commercial) in windborne debris regions.

8.2.1.2 Statutory Building Code Provisions - Florida

The following design criterion is 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).

- Review the exemption in windborne debris regions that allows for residences to be designed as "partially-enclosed" structures with unprotected openings. The MAT observed 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. The IBC Structural Code Development Committee has approved a code change proposal for the 2006 version eliminating the partially enclosed option. Based on observed damages in Hurricane Ivan, this exemption should not be allowed for any use (residential or commercial) in windborne debris regions.

8.2.1.3 Reference Standards – ASCE 7

All of the various building codes that govern the areas within the Ivan damage zone in one way or another reference ASCE 7 for wind loads. Within that standard is Table 1-1, which classifies buildings based on occupancy. This classification is used to determine the importance factors for wind, snow, and earthquake loads. The Ivan MAT discovered a loophole in this system of classification that needs to be examined by the ASCE 7 committee. The loophole was evident in the classification of various buildings on hospital campuses. Using Table 1-1, an MOB would be classified as a Category II building because it has no patients. Further, the table requires a patient bed count of 50 beds or more to move the building up to a Category III building, thus invoking the 1.15 safety factor. However, the MAT observed instances where clinical functions essential to the treatment of the community were housed in MOBs attached to the hospital. One example of this was a large dialysis clinic housed in an MOB. Although the building sustained major building envelope damage, it was able to quickly make temporary repairs and restore services. This could have easily not been the case, and many patients would have been denied treatment. Immediately after a hurricane, movement and access are problematic at best; hence, requiring patients to travel to more distant locations to receive life sustaining treatments is more than a mere inconvenience. Consideration should be given to changing Table 1-1 to include in Category III those buildings that house essential clinical treatment functions that are not easily available elsewhere in the community.

Designers should take care when classifying some facilities that provide care, such as nursing homes. For example, skilled nursing homes and Alzheimer's facilities should be Category III, but an assisted living facility might suitably be classified as Category II. Also, the occupancy trigger should be reexamined. A skilled nursing home or Alzheimer facility should be Category III regardless of the number of patients. It is, therefore, also recommended that the ASCE committee examine Table 1-1 with respect to nursing homes.

8.2.2 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.

- **Sheathing on the Underside of Elevated Buildings.** Preservative-treated plywood is recommended in lieu of gypsum board and vinyl siding. It is recommended that the plywood be attached with stainless steel nails or screws. As discussed in Section 5.1, because of lack of guidance on determining wind loads, it is recommended that designers use professional judgment in specifying the fastener type, size and spacing.

- **EIFS.** Many of the failures of EIFS systems observed by the MAT were related to the design and installation of fasteners of the EIFS systems. In many other cases, failure modes could not be determined but could result from one or more of the following: material defects, inadequate test standards and methods, specification of inappropriate system by designers, or poor installation. Nevertheless, the failures were so common, and the consequences of the failures were so severe, that continued use of EIFS is not recommended in high wind coastal areas. When these systems are used, fastening of the systems could be improved if the following methods and approaches are considered:
  - As discussed in Section 5.3.1, it is recommended that two revisions be made to test method ASTM E 330. In lieu of a 10-second load duration, a 60-second duration is recommended. It is also recommended that deflection criteria specified in test method ASTM E 1592 be incorporated into ASTM E 330.
  - It is also recommended that the EIFS Industry Members Association (EIMA) consider all elements of the EIFS assembly. Although EIMA members may not manufacture or supply assembly components such as metal framing, sheathing, or sheathing fasteners, these other elements are also critical in achieving suitable wind performance.
  - It is recommended that manufacturers re-evaluate their training programs because it was evident that many EIFS assemblies were installed improperly, most likely by inadequately trained workers.
  - For EIFS installed over sheathing, it is recommended that designers specify attachment requirements for all elements of the assembly, including framing and sheathing attachment. It is also recommended that designers specify special inspections to ensure proper application of all elements of the assembly.
- **Vinyl Siding.** As discussed in Section 5.3.2, it is recommended that two revisions be made to test method ASTM D 5206. In lieu of a 30-second load duration, a 60-second duration is recommended. It is also recommended that deflection criteria specified in test method ASTM E 1592 be incorporated into ASTM D 5206. It is also recommended that the ASTM task group responsible for ASTM D 5206

give consideration to dynamic testing of vinyl siding in lieu of the static testing now prescribed in ASTM D 5206.

It is recommended that ASTM D 3679 be revised to require a minimum safety factor of 2 versus the 1.5 factor currently specified. It is recommended that ASTM D 4756 be revised to require installation of a water-shedding underlayment (e.g., asphalt-saturated felt or housewrap).

The method used to determine the pressure equalization factor currently specified in ASTM D 3679 appears to be questionable. It is therefore recommended that the ASTM task group responsible for the Standard reevaluate the magnitude of the pressure equalization factor (0.36).

Tables 8-6 through 8-9 present the wind-related recommendations developed by the MAT and first presented in FEMA 490, *Summary Report on Building Performance 2004 Hurricane Season*, March 2005. A full discussion of these recommendations can be found in the Hurricane Charley MAT report (FEMA 488). Hurricane Charley was a code level wind event, and readers are encouraged to obtain a copy of this report.

Table 8-6 presents design and construction recommendations to avoid or lessen potential wind hazard damage to accessory structures, the building envelope and exterior equipment.

Table 8-6. Design and Construction Recommendations

Building Component	Recommendation	Action Required By[1]
Wind Hazard		
Accessory Structures		
Attached and detached	Add additional anchors at corner post connections to concrete.	D, C
Attached and detached	Use AAF *Guide to Alluminum Construction in High Wind Areas* until FBC 2004 is adopted.	D
Attached and detached	Increase wind resistance of accessory structure walls parallel to primary building (e.g., tension cable, solid “K” bracing).	D
Attached and detached	Provide lateral bracing in roof planes using rigid diagonal structural members.	D, C
Attached	Ensure attached building and primary building can withstand equal wind pressures.	D, C
Attached	Determine implications to primary building if attached structure collapses.	D, C

Table 8-6. Design and Construction Recommendations (continued)

Building Component	Recommendation	Action Required By[1]
Wind Hazard		
Building Envelope		
Detached	Determine ability to withstand windstorm events to reduce windborne debris.	D, C
Doors		
Exterior doors	Specify wind-driven rain resistant weather-stripping at exterior doors (see FEMA 424).	D
Entrance vestibules	Design entrance vestibules in areas where basic wind speed is greater than 120 mph.	D
Rolling and sectional doors	Consider type, size, and spacing of door, frame, and frame fasteners to loads. If frame is attached to wood blocking, attention should also be given to the blocking attachment.	D, C
Rolling and sectional doors	Maintain adequate edge distances for frame fasteners placed in concrete or masonry.	C
Soffit		
Soffits	Design Guidance: Develop design guidance for attaching soffits, including design of baffles or filter media to prevent wind-driven rain from entering attics.	
Roof Assembly		
Roof systems	Testing: Roof assemblies susceptible to dynamic loading should be dynamically tested to obtain realistic measure of their wind resistance. Higher safety factors should be used for those assemblies requiring dynamic testing, but for which dynamic test methods are not available.	D, C, G
Reroofing	Tear off old roof (do not re-cover) in areas where basic wind speed is 110 mph or greater.	D, C
Reroofing	Install additional sheathing fasteners if existing sheathing attachment is not in compliance with current building code.	D, C
Asphalt shingles	Ensure manufacturers' installation instructions are followed (i.e., starter strips and nail locations) and use Recovery Advisory Nos. 1 and 2.	D, C
Asphalt shingles	Re-evaluate attachment of factory-laminated tabs.	M
Metal panel roof system	Chalk-line clip locations for panels with concealed clips and ensure clip locations are not excessively spaced.	C
Metal panel roof system	Base uplift resistance on ASTM E 1592.	M, D
Metal panel roof system	Specify close spacing of fasteners at eaves, and hip and ridge flashings.	D
Tile roof system	Use Recovery Advisory No. 3.	D, C

Table 8-6. Design and Construction Recommendations (continued)

Building Component	Recommendation	Action Required By[1]
Wind Hazard		
Roof Assembly (continued)		
Tile roof system	Develop tiles with improved ductility via internal or backside reinforcement or bonding film in hurricane-prone regions (e.g., develop tile similar to laminated glass).	M
Tile roof (foam-set) system	For foam set tile, simplify number of installation options and clarify requirements.	M
Tile roof (foam-set) system	Modify training and certification programs to ensure that foam-set roof installers are adequately trained.	M, C
Tile roof (foam-set) system	Use a higher safety factor (e.g., 4) to account for application and testing issues.	M, D
Mechanically attached roof systems	FRSA/TRI re-evaluate use of safety factor of 2. Either develop dynamic test method or use existing test method with higher safety factor (e.g., 3).	M, D
Built-up roofs	Develop and codify technically based criteria for aggregate surfacing on built-up and sprayed polyurethane foam roofs.	M, G
Edge flashings and copings	Comply with ANSI/SPRI ES-1 (2003). Use safety factor of 3 for critical and essential facilites and a factor of 2 for other buildings.	D
Edge flashings and copings	Install edge flashings on top of membrane to clamp it down.	D, C
Edge flashings and copings	Place a bar over roof membrane near edge of flashing and coping to provide secondary protection (see FEMA 424).	D, C
Gutters and downspouts	Use professional judgment to specify and detail gutter uplift resistance.	D
Gutters and downspouts	Design Guidance: Develop design guide, test method, and code criteria for gutters, including attachment of downspouts.	M, C
Rooftop walkway pads	Research wind resistance of roof walkway pads.	M, G
Windows		
General	Develop window assemblies that are more wind-driven rainwater-resistant.	M
General	The window industry should re-evaluate current test procedures to better represent wind-driven rain produced by hurricane and tropical storm winds.	D, C, M, G
Exterior Equipment		
General	For all exterior equipment, recommend safety factor of 3 due to uncertainties pertaining to wind load.	D
General	Design Guidance: Develop guidance and code criteria for attaching condensers and rooftop mechanical equipment (including ductwork).	D, G

Table 8-6. Design and Construction Recommendations (continued)

Building Component	Recommendation	Action Required By[1]
Wind Hazard		
Exterior Equipment (continued)		
General	Evaluate the need to better secure exterior devices, such as pool equipment and roof-mounted solar heaters.	D, C, O, CF
Cowlings	Anchor cowlings on exhaust fans to curbs using cables (see FEMA 424).	M, D, C
Access panels	Modify access panels attached by manufacturer to ensure secure attachment (see FEMA 424).	M, D, C
Lightning protection systems	Develop guidance and code criteria for attachment of lightning protection systems (see FEMA 424), communications towers, and satellite dishes.	M, D, C

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

Table 8-7 presents building code recommendations to avoid or lessen damage from potential wind hazards to the building envelope, windows and shutters, exterior equipment, and critical and essential facilities.

Table 8-7. Building Code Recommendations

Wind Hazard	
Building Component	**Recommendation**
Building Envelope	
Soffit	
Soffit	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.
Roof Assembly	
Edge flashing and coping	**FBC Section 1503** (Weather Protection): Compliance with American National Standards Institute (ANSI) SPRI ES-1.
Gutters	**FBC Section 1503** (Weather Protection) **and IBC/IRC**: Develop and add criteria regarding uplift resistance of gutters.
Ridge vents	**FBC Section 1503** (Weather Protection) **and IBC/IRC**: Add criteria regarding wind and wind-driven rain resistance of ridge vents. Attachment criteria require development, but TAS 110 could be referenced for rain resistance.
Metal panel roof system	**FBC Section 1504** (Performance Requirements): Require compliance with ASTM E 1592 for testing the uplift resistance of metal panel roof systems.

Table 8-7. Building Code Recommendations (continued)

Wind Hazard	
Building Component	**Recommendation**
Roof Assembly (continued)	
Roof system	**FBC Section 1510.3** (Recovering vs. Replacement) and IBC/IRC: Require removal of existing roof covering down to the deck and replacement of deteriorated sheathing in areas where basic wind speed is 110 mph or greater. If existing sheathing attachment does not comply with loads derived from Chapter 16, require installation of additional fasteners to meet loads.
Asphalt shingles	**FBC Section 1507.2** (Roof Covering Application) **and IBC/IRC**: Require compliance with UL 2390. Also require six nails per shingle and require use of asphalt roof cement at eaves, rakes, hips, and ridges where basic wind speed is 110 mph or greater (refer to Recovery Advisory No. 2).
Mortar-set tile roof system	**FBC Section 1507.4** (Clay and Concrete Tile) **and IBC/IRC**: Provide an alternative to the use of mortar to attach field tiles and hip/ridge tiles.
Built-up roof	**FBC Section 1508** (Roof Coverings with Slopes Less Than 2:12): Add technically based criteria regarding blow-off resistance of aggregate on built-up and sprayed polyurethane foam roofs.
Windows and Shutters	
Shutters	**IBC and FBC Section 1606.1.4** (Protection of Openings): Add requirement to label shutters (other than wood) because without labels, building owner does not know if shutters are suitable.
Windborne debris region	**FBC:** Revise the Florida Panhandle criteria to match ASCE 7.
Manufactured Housing	Revise Chapter 15C of the Rules and Regulations of Florida to provide window protection systems (and a strengthened structure around openings) on Zone II and Zone III units being installed in the windborne regions defined by Chapter 16 of the FBC.
Exterior Equipment	
General	**FBC Section 1522.2** (Rooftop Mounted Equipment): Make applicable throughout the State of Florida for all wind speeds. Develop and add criteria that pertain to attaching lightning protection systems. Provisions also included in electrical codes.
Critical and Essential Facilities	
General	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.

Table 8-7. Building Code Recommendations (continued)

Wind Hazard	
Building Component	**Recommendation**
Critical and Essential Facilities (continued)	
General	For hurricane shelters and Enhanced Hurricane Protection Areas (EHPAs), adopt wind speed recommended by FL DCA in the SESP and the ASCE 7-02/2001 FBC wind speed map design wind speed plus 40 mph. This is also the recommended best practice in the FL DCA shelter design guidance and in FBC Section 423, Part 24; change to *a requirement*. This criterion should be required by the SESP and should be used until the International Code Council's High Wind Shelter Standard is completed in 2006/2007 and available for adoption.
General	Minimum debris impact protection should be per ASTM E 1996 Category E for a 9-pound 2x4 (nominal) missile traveling at 50 mph. This criterion should be required by the SESP and should be used until the ICC's High Wind Shelter Standard is completed in 2006/2007 and available for adoption.
General	As an alternative to designing shelters to the SESP or ASCE criteria, design or retrofit buildings to be used as shelters to the design guidance provided in FEMA 361, *Design and Construction Guidance for Community Shelters*.

Table 8-8 presents recommendations to alert building owners and homeowners; architects, engineers, and consultants; building officials; contractors; manufacturers; and associations, institutions, and societies of steps they can take to avoid or lessen potential damages from wind hazards.

Table 8-8. Public Outreach Recommendations

Wind Hazard	
Education Topic	**Outreach Method**
Building Owners And Homeowners	
Plan and budget construction projects that incorporate natural hazard mitigation measures. Select design and construction teams knowledgeable in effective construction methods in hurricane-prone areas. Prepare and protect building prior to hurricane landfall. What to do after hurricane passes (building inspection for damage, emergency repairs, and drying out building interiors). Rebuild damaged structure in manner that protects against future damage. Inspect exterior connections and fasteners for wear, corrosion, and other deterioration. Educate building owners on how wind-driven rainwater enters buildings, the resulting implications (loss of electricity, mold), and prevention methods.	✓ Tailor informational pamphlets to homeowners and building owners. ✓ Develop strategy to distribute information (e.g., standardized information sheets during sale of building). ✓ Enlist assistance of real-estate companies and organizations such as the Building Owners and Managers Association. ✓ Provide public service notices at start of each hurricane season. ✓ Develop informational materials on how wind-driven rainwater enters buildings, the resulting damage, and prevention methods.
Architects, Engineers, Consultants	
Improve the technical proficiency of building envelope design. Provide adequate level of design details for connecting rooftop equipment, including mechanical, electrical and lightning protection. Share post-disaster building performance information to maximize the value of lessons learned.	✓ Prepare monographs for trade-wide distribution. ✓ Prepare web-based tutorials and seminars. ✓ Encourage colleges and universities to augment existing curriculum with hurricane-resistant design instruction.

Table 8-8. Public Outreach Recommendations (continued)

Wind Hazard	
Education Topic	**Outreach Method**
Building Officials	
Share post-disaster building performance information to maximize the value of lessons learned. Train building officials to identify structural weaknesses that may cause structure or building component failure during a hurricane (e.g., unbraced gable ends, missing truss bracing, truss' anchorage, window/door anchorage). Implement effective enforcement techniques to maintain a high construction quality.	✓ Conduct annual seminars for building officials and plan reviewers in coastal areas to share lessons learned. ✓ Implement hurricane disaster building inspection training program and "train the trainer" program.
Contractors	
Educate contractors who construct building envelopes and install rooftop equipment on hurricane resistant fastening and anchoring systems. Educate contractors on how wind-driven water enters buildings, the resulting implications (loss of electricity, mold), and prevention methods.	✓ Develop and distribute visual tools such as instructional videos or DVDs. ✓ Conduct on-the-job training to highlight failures that occur when simple anchoring techniques are not applied. ✓ Encourage trade schools in hurricane-prone areas to augment their curriculum with courses on state-of-the- art hurricane-resistant construction.
Manufacturers	
Educate manufacturers of building envelope materials and rooftop equipment on the performance of their products during hurricanes. Encourage manufacturers to provide special guidance for use of their products in hurricane-prone areas. Develop improved products and systems for hurricane-prone areas. Manufacturers should educate designers and contractors on their products.	✓ Develop and distribute informational notices to manufacturers.
Associations, Institutes, and Societies	
Advocate hurricane-resistant design and construction to their membership.	Develop educational materials for distribution to their members and industry.

Table 8-9 presents wind-hazard recommendations specific to critical and essential facilities.

Table 8-9. Recommendations Specific to Critical and Essential Facilities

Wind Hazard		
Component	**Recommendation**	**Action Required By[1]**
General		
Detailing and notations on the building plans	Facility plans should delineate the facility area designed to function as a shelter or hardened area. Details of the shelter or hardened area and the envelope elements should be provided to ensure that the construction requirements are clearly understood by the builder and building official. Provide facility design criteria and maximum design pressures for the main wind force resisting system (MWFRS) and for components and cladding.	D, C, CFO
Material selection	Reinforced concrete roof deck and reinforced concrete and/or reinforced and fully grouted concrete masonry unit (CMU) exterior walls are recommended. FEMA 424, *Design Guide for Improving School Safety in Earthquakes, Floods, and High Winds*, and FEMA 361, *Design and Construction Guidance for Community Shelters,* provide detailed guidance on material selection for structural and building envelope systems.	D, C, CFO
General	Develop additional criteria to help ensure continuity of function. See FEMA 424 and FEMA 361.	CFO
General	Emphasize best practices for schools and shelters described in FEMA 424 and FEMA 361 respectively, and in the latest codes and standards for wind resistance (ASCE 7).	CFO
Design guidance	Develop a comprehensive design guide to complement FEMA 424 for mitigating existing facilities.	D, G
Perform vulnerability assessment	Perform vulnerability assessment to ensure continuity of operations. The assessment should evaluate the building performance and utilities that service critical/essential facilities so that the building owner understands impacts to the facility during a storm and operational impacts due to limited utility services.	CFO

Table 8-9. Recommendations Specific to Critical and Essential Facilities (continued)

Wind Hazard		
Component	**Recommendation**	**Action Required By**[1]
General (continued)		
General	Implement mitigation measures or structurally retrofit critical/essential facilities to design levels other than minimum code requirements for general use buildings. Do not house critical facilities in lightly engineered buildings such as pre-engineered metal buildings.	CFO, D
General	Educate designers: buildings designed to minimum EHPA requirements does not guarantee that building used as shelter will be properly designed and constructed to resist extreme wind events. Emphasize best practices for shelters described in FEMA 361.	D, C
General	Educate designers: American Red Cross 4496 provides a baseline for a shelter's integrity and performance, but meeting this criterion does not guarantee that the building will resist wind and windborne debris associated with hurricanes. Emphasize best practices for shelters described in FEMA 361.	D, C
General	Conduct special inspections for key structural items and connections to ensure performance of critical facilities.	CFO, C
General	Design critical and essential facilities with wind loads using an importance factor of 1.15 in accordance with ASCE 7. For some facilities, design using the 40-mph increase with importance factor of 1 (recommended for shelter EHPA design in FBC Section 423, Part 24).	D
General	Incorporate hazard mitigation peer review into design approval process to ensure that critical and essential facilities are adequately designed to resist extreme winds.	D
Accessory Structures		
Detached	Strengthen the anchorage of structures and portable classroom buildings at schools.	D, C, G, CFO
Building Envelope		
General	Contract drawings and specifications for new construction and remedial work on existing building envelopes and rooftop equipment should undergo rigorous peer review, submittal review, field observation (inspection), and testing prior to construction.	D, C, G
General	Implement mitigation measures in buildings not built to current building codes to protect roof coverings, wall coverings, window and door systems, and rooftop equipment.	D, CFO

Table 8-9. Recommendations Specific to Critical and Essential Facilities (continued)

Wind Hazard		
Component	**Recommendation**	**Action Required By[1]**
Building Envelope (continued)		
General	Conduct special inspections for key building envelope components to ensure performance of critical/essential facilities. Inspect roof top equipment twice a year. Inspect doors, windows, and wall coverings at 5-year intervals. Conduct special inspections of the entire facility (both structural and building envelope systems) after storms with wind speeds in excess of 90 mph 3-second gust winds.	CFO
Doors		
Doors	Design or mitigate to the FBC or IBC design wind speed.	D
Rolling and sectional doors	Purchase and install high wind-rated, sectional/rolling doors to protect against high wind.	D, CFO
Rolling and sectional doors	Ensure sectional rolling doors are properly installed and reinforced to prevent catastrophic door failure and building pressurization. Replace or retrofit existing doors that lack adequate resistance.	D, CFO
Roof Assembly		
Roof structure	Install hurricane clips or straps on inadequately connected roof beams and joists in those buildings that will be occupied during a hurricane.	C, CFO
Roof decks	Strengthen inadequately attached roof decks.	CFO
Roofing	Replace aggregate-surfaced roof systems with non-aggregate systems.	D, C, CFO
Roof system	Design roof system that will prevent water infiltration if roof is hit by windborne debris.	D
Edge flashings and copings	Install exposed fasteners to weak metal edge flashings and copings.	D, C, CFO
Gutters and downspouts	Install tie-down straps on gutters to avoid membrane blow-off.	D, C, CFO
Rooftop equipment	Anchor all rooftop equipment.	D, C, CFO

Table 8-9. Recommendations Specific to Critical and Essential Facilities (continued)

Wind Hazard		
Component	**Recommendation**	**Action Required By[1]**
Building Envelope (continued)		
Windows		
Windows	Implement window protection systems to protect critical facilities from windborne debris.	CFO, D
Shutters	Install shuttering system on all exterior glazing that is not windborne debris resistant. Install power-operated shutters or laminated glass, or apply an engineered film system to the glazing and frame on upper-level floors.	D, C, CFO

[1] Action required by: Designer (D), Government Official (G), Critical Facility Manager/Owner (CFO)

A

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C

Acronyms and Abbreviations

A

AAF	Aluminum Association of Florida
ADEM	Alabama Department of Environmental Management
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 Systems
ASTM	American Society for Testing and Materials
ATCT	air traffic control tower
AWOS	Automated Weather Observing System

B

BFE	base flood elevation (1-percent annual exceedance probability)
BIA	Brick Industry Association
BOAF	Building Officials Association of Florida
BPAT	Building Performance Assessment Team
BUR	built-up roof

C

C&C	components and cladding
CFR	Code of Federal Regulations
CMU	concrete masonry unit
CHWM	coastal high water mark

D

DFO	Disaster Field Office

E

EDT	Eastern Daylight Time
EHPA	Enhanced Hurricane Protection Area
EIFS	exterior insulation and finish systems
EIMA	EIFS Industry Members Association
EMS	Emergency Medical Services
EOC	Emergency Operations Center
EPDM	ethylene propylene diene monomer
ESRI	Environmental Systems Research Institute

F

FAA	Federal Aviation Administration
FBC	Florida Building Code
FCMP	Florida Coastal Monitoring Program
FDEP	Florida Department of Environmental Protection
FEMA	Federal Emergency Management Agency
FHBA	Florida Home Builders Association
FIRM	Flood Insurance Rate Map

FIS Flood Insurance Study

FLASH Federal Alliance for Safe Homes

FL DCA Florida Department of Community Affairs

FRSA Florida Roofing, Sheet Metal and Air Conditioning Contractors Association, Inc.

G

GDT Geographic Data Technology

GPS global positioning system

H

HAZUS-MH Hazards US – Multi-Hazard

HWM high water mark

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	lighting protection system
LWIC	lightweight insulating concrete

M

MAT	Mitigation Assessment Team
MEPS	molded expanded polystyrene insulation
MOB	medical office building
mph	miles per hour
MWFRS	main wind force resisting system

N

NAHB	National Association of Home Builders
NAVD	North America Vertical Datum
NCDC	National Climatic Data Center
NFIP	National Flood Insurance Program
NFPA	National Fire Protection Association
NGVD	National Geodetic Vertical Datum
NHC	National Hurricane Center
NIST	National Institute of Standards and Technology
NOAA	National Oceanographic and Atmospheric Administration
NRCA	National Roofing Contractors Association
NWS	National Weather Service

O

OFCM Office of the Federal Coordinator for Meteorological Services and Supporting Research

OSB oriented-strand board

P

psf pounds per square foot

PVC polyvinyl chloride

R

Rmax 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 (New name of the Single Ply Roofing Institute)

SRBOAF Suwannee River Building Officials Association of Florida

SRIA Santa Rosa Island Authority

T

TAS	Testing Application Standard

U

UL	Underwriters Laboratories
URM	unreinforced masonry
U.S.	United States
USACE	U.S. Army Corps of Engineers
USGS	U.S. Geological Survey

W

WG/NDR/PSDA	Working Group for Natural Disaster Reduction and Post-Storm Data Acquisition

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

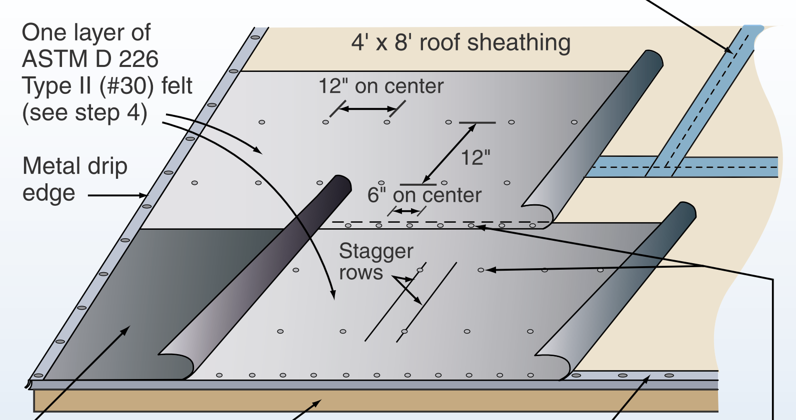
> **Note:** This fact sheet provides general guidelines and recommended enhancements for improving upon typical practice. It is advisable to ***consult local building requirements*** for type and installation of underlayment, particularly if specific enhanced underlayment practices are required locally.

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).

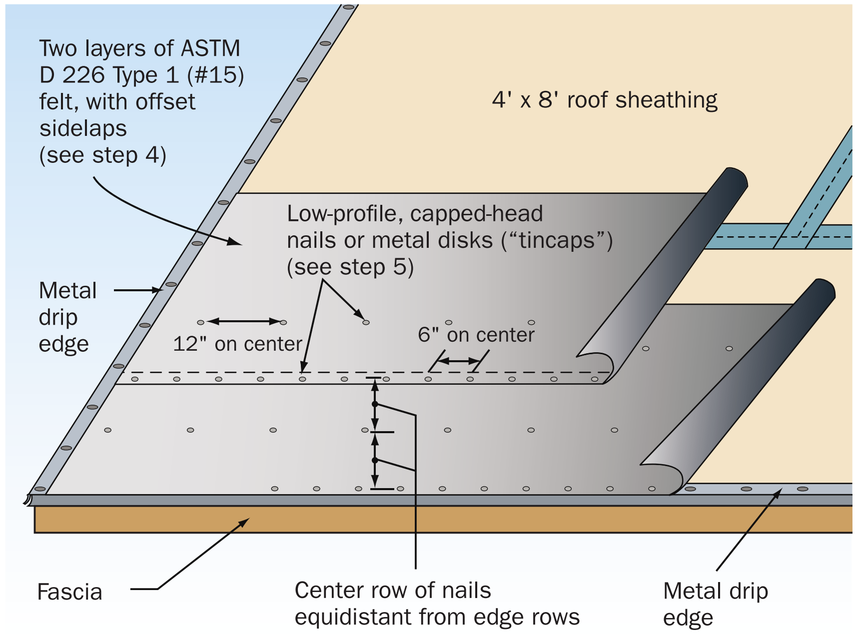
Installation Sequence – Option 1[1]

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.



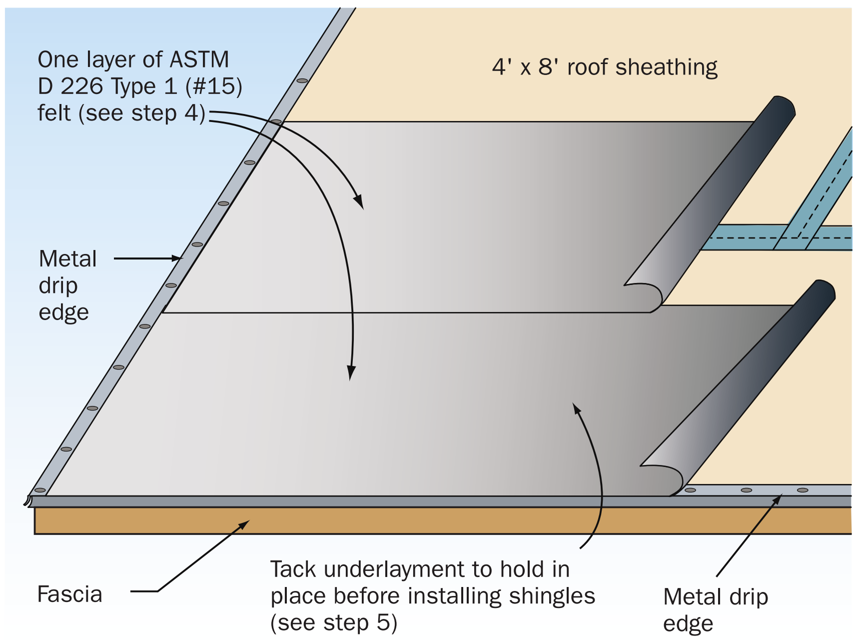
Installation Sequence – Option 2[1]

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).

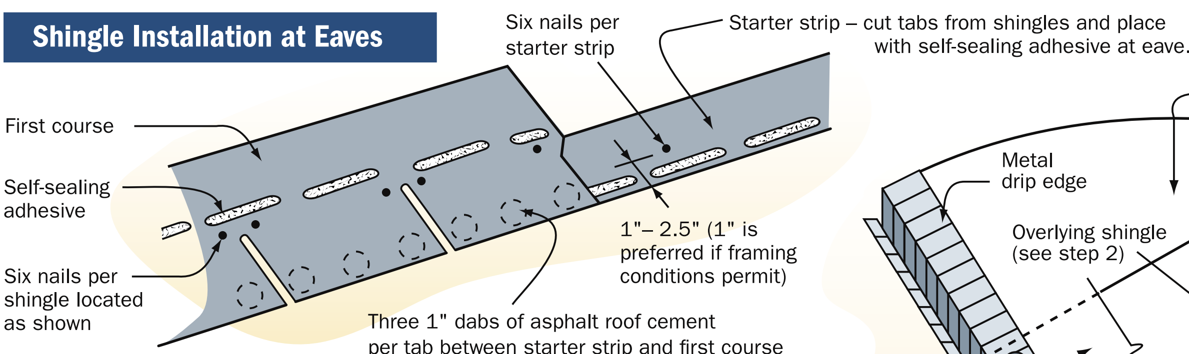
Key Issues

- 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

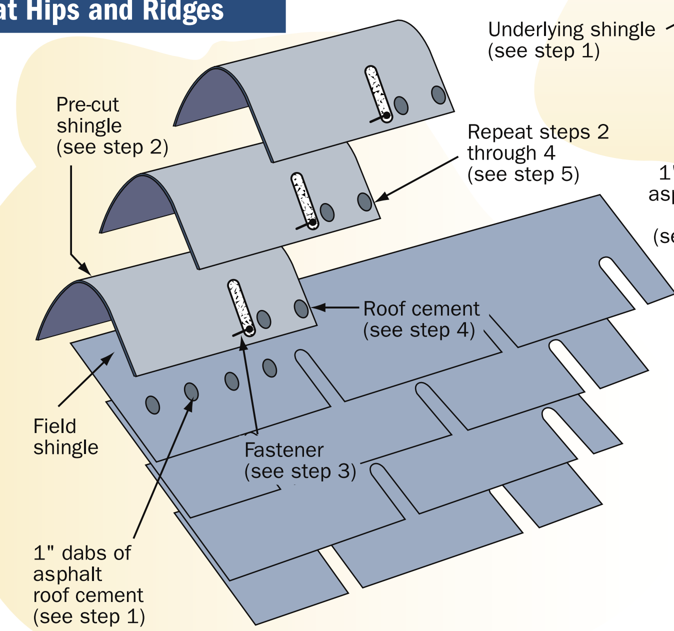
1 Follow shingle installation procedures for enhanced wind resistance.

Shingle Installation at Eaves

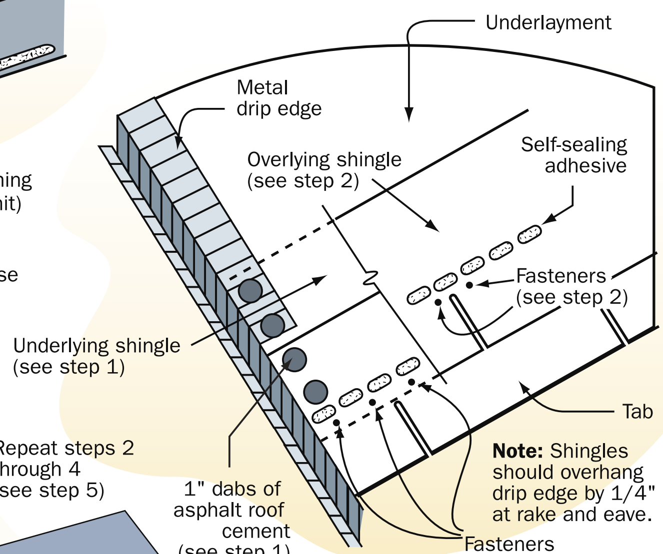


Shingle Installation at Hips and Ridges

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

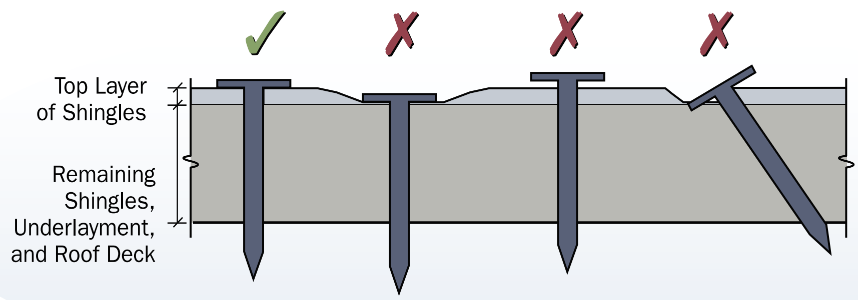
1. Design wind speed based on 3-second peak gust.
2. ASTM D 3462 specifies a minimum fastener pull-through resistance of 20 lb at 70° F. If a higher resistance is desired, it must be specified.
3. Neither ASTM D 225 or D 3462 specify minimum bond strength. If minimum bond strength is desired, it must 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)

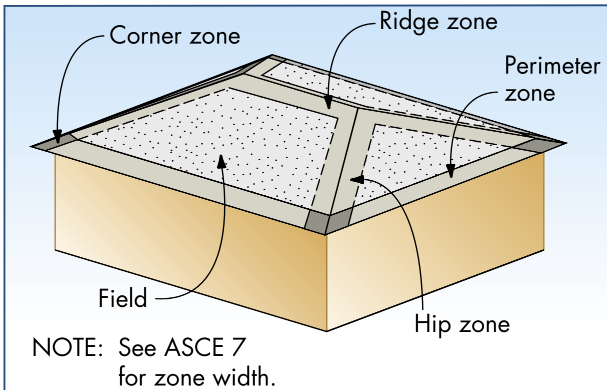


Figure 1. For critical and essential facilities, clip all tiles in the corner, ridge, perimeter, and hip zones.

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.

Coastal Building Successes and Failures

FEMA
www.fema.gov

HURRICANE RECOVERY ADVISORY *Recovery Advisory No. 4*

Purpose: To discuss how coastal construction requirements are different from those for inland construction. To discuss the characteristics that make for a successful coastal building.

Is Coastal Construction That Different From Inland Construction?

The short answer is, ***yes,*** building in a coastal environment is different from building in an inland area:

- ***Flood levels, velocities,*** debris, and ***wave*** action in coastal areas tend to make coastal flooding more damaging than inland flooding.
- Coastal ***erosion*** can undermine buildings and destroy land, roads, utilities, and infrastructure.
- ***Wind speeds*** are typically higher in coastal areas and require stronger engineered building connections and more closely spaced nailing of building sheathing, siding, and roof shingles.
- ***Wind-driven rain, corrosion,*** and ***decay*** are frequent concerns in coastal areas.

***Figure 1.** Poorly sited building on shallow foundation undermined by erosion.*

In general, homes in coastal areas must be designed and built to withstand ***higher loads*** and ***more extreme conditions***. Homes in coastal areas will require ***more maintenance*** and upkeep. Because of their exposure to higher loads and extreme conditions, homes in coastal areas will cost more to design, construct, maintain, repair, and insure.

Building Success

In order for a coastal building to be considered a "success," four things must occur:

- The building must be designed to withstand coastal forces and conditions.
- The building must be constructed as designed.
- The building must be sited so that erosion does not undermine the building or render it uninhabitable.
- The building must be maintained/repaired.

A well-built but poorly sited building can be undermined and will not be a success (see Figure 1). Even if a building is set back or situated farther from the coastline, it will not perform well (i.e., will not be a success) if it is incapable of resisting high winds and other hazards that occur at the site (see Figures 2 and 3).

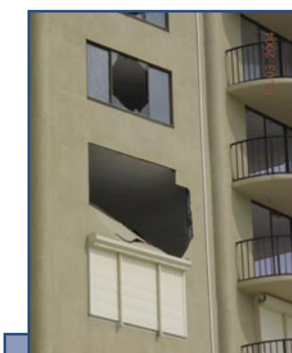


***Figure 2.** Well-sited buildings that still sustained damage due to building envelope and connection failures.*

***Figure 3.** Well-sited building that still sustained damage due to building envelope and connection failures.*

Similarly, a building compliant with the regulatory requirement that the lowest floor be elevated to the Base Flood Elevation (BFE) can still be damaged when the flood elevation exceeds the BFE (see Figure 4 and the discussion of lowest floor elevation in item 3 on the next page). The BFE is the expected elevation of flood waters and wave effects during the 100-year flood.

***Figure 4.** Compliant building damaged when the flood elevation exceeded the BFE.*

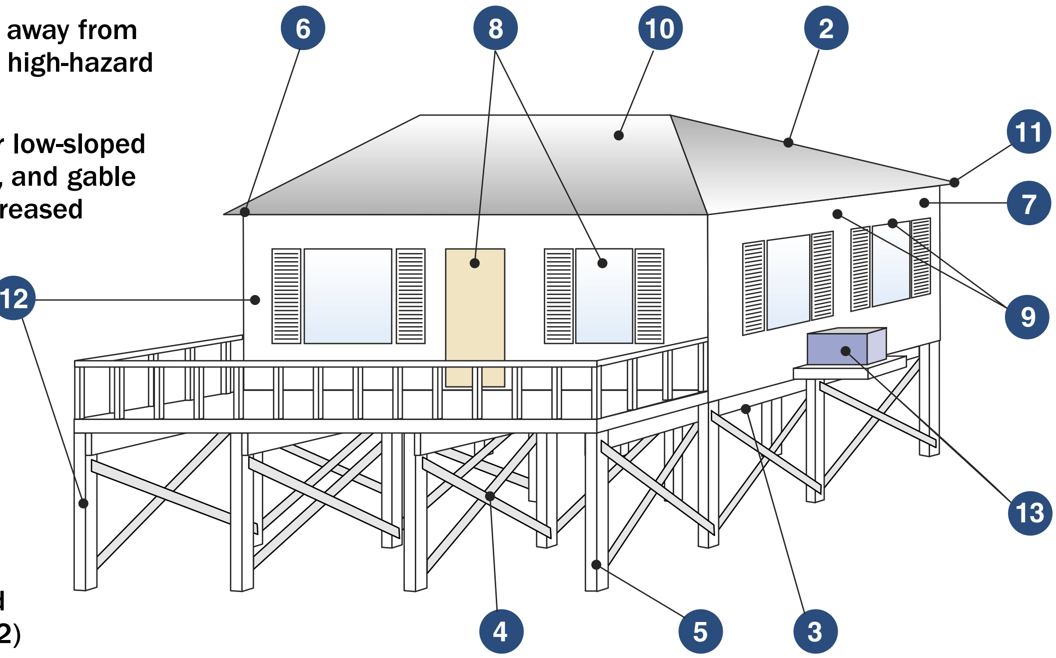
What Should Owners and Home Builders Expect From a "Successful" Coastal Building?

In coastal areas, a building can be considered a success only if it is capable of resisting damage from coastal hazards and coastal processes over a period of decades. This statement does not imply that a coastal residential building will remain undamaged over its intended lifetime. It means that the impacts of a design-level flood, storm, wind, or erosion event (or series of lesser events with combined impacts equivalent to a design event) will be limited to the following:

- The building **foundation** must remain intact and functional.
- The **envelope** (walls, openings, roof, and lowest floor) must remain structurally sound and capable of minimizing penetration by wind, rain, and debris.
- The **lowest floor** elevation must be sufficient to prevent floodwaters from entering the elevated building envelope during the design event.
- The **utility connections** (e.g., electricity, water, sewer, natural gas) must remain intact or be restored easily.
- The building must be **accessible** and **usable** following a design-level event.
- Any damage to **enclosures** below the Design Flood Elevation (DFE)* must not result in damage to the foundation, the utility connections, or the elevated portion of the building.

*The DFE is the locally mandated flood elevation, which will be equal to or higher than the BFE.

Recommended Practice



1 **Siting –** Site buildings away from eroding shorelines and high-hazard areas.

2 **Building Form –** Flat or low-sloped porch roofs, overhangs, and gable ends are subject to increased uplift in high winds. Buildings that are both tall and narrow are subject to overturning. Each of these problems can be overcome through the design process, but each must receive special attention. In the design process, chose moderate-sloped hip roofs (4/12 to 6/12) if possible.

3 **Lowest Floor Elevation –** Elevate above the DFE the bottom of the lowest horizontal structural member supporting the lowest floor. Add “freeboard” to reduce damage and lower flood insurance premiums.

Freeboard is a factor of safety, usually expressed in feet above flood level, that is applied to compensate for unknown factors that could contribute to flood heights greater than those calculated for a selected flood. Freeboard is advisable in coastal areas where storms often cause flooding that exceeds the 100-year flood elevation.

4 **Free of Obstructions –** Use an open foundation. Do not obstruct the area below the elevated portion of the building. Avoid or minimize the use of breakaway walls. Do not install utilities or finish enclosed areas below the DFE (owners tend to convert these areas to habitable uses, which is prohibited under the National Flood Insurance Program and will lead to additional flood damage and economic loss).

5 **Foundation –** Make sure the foundation is deep enough to resist the effects of scour and erosion; strong enough to resist wave, current, and flood forces; and capable of transferring wind and seismic forces on upper stories to the ground.

6 **Connections –** Key connections include roof sheathing, roof-to-wall, wall-to-wall, and walls-to-foundation. Be sure these connections are constructed according to the design. Bolts, screws, and ring-shanked nails are common requirements. Standard connection details and nailing should be identified on the plans.

7 **Exterior Walls –** Use structural sheathing in high-wind areas for increased wall strength. Use tighter nailing schedules for attaching sheathing. Care should be taken not to over-drive pneumatically driven nails. This can result in loss of shear capacity in shearwalls.

8 **Windows and Glass Doors –** In high-wind areas, use windows and doors capable of withstanding increased wind pressures. In windborne debris areas, use impact-resistant glazing or shutters.

9 **Flashing and Weather Barriers –** Use stronger connections and improved flashing for roofs, walls, doors, and windows and other openings. Properly installed secondary moisture barriers, such as housewrap or building paper, can reduce water intrusion from wind-driven rain.

10 **Roof –** In high-wind areas, select appropriate roof coverings and pay close attention to detailing. Avoid roof tiles in hurricane-prone areas.

11 **Porch Roofs and Roof Overhangs –** Design and tie down porch roofs and roof overhangs to resist uplift forces.

12 **Building Materials –** Use flood-resistant materials below the DFE. All exposed materials should be moisture- and decay-resistant. Metals should have enhanced corrosion protection.

13 **Mechanical and Utilities –** Electrical boxes, HVAC equipment, and other equipment should be elevated to avoid flood damage and strategically located to avoid wind damage. Utility lines and runs should be installed to minimize potential flood damage.

14 **Quality Control –** Construction inspections and quality control are essential for building success. Even "minor" construction errors and defects can lead to major damage during high-wind or flood events. Keep this in mind when inspecting construction or assessing yearly maintenance needs.

Will the Likelihood of Success (Building Performance) Be Improved by Exceeding Minimum Requirements?

States and communities enforce regulatory requirements that determine where and how buildings may be sited, designed, and constructed. There are often economic benefits to exceeding the enforced requirements (see box). Designers and home builders can help owners evaluate their options and make informed decisions about whether to exceed these requirements.

Adopting and enforcing modern building codes (e.g., IBC, IRC, and FBC) and educating residents, businesses, contractors, and community officials on "best construction practices" with regard to the design of new structures and the mitigation of hazards to older structures are recommended.

Benefits of Exceeding Minimum Requirements

- Reduced building damage during coastal storm events
- Reduced building maintenance
- Longer building lifetime
- Reduced insurance premiums*
- Increased reputation of builder

Next Steps

To improve coastal construction practices, consider the following:

- Contact your local building official to obtain the latest applicable building code requirements for coastal construction.
- Review best practices guidelines and recommendations contained in FEMA's *Coastal Construction Manual*. The *Coastal Construction Manual* is available in Adobe® Portable Document Format (PDF) on CD-ROM (FEMA 55CD) and as a print publication (FEMA 55). Both versions are available from the FEMA Distribution Center. Call 1-800-480-2520 and request either FEMA 55CD or FEMA 55.

*Note: Flood insurance premiums can be reduced up to 60 percent by exceeding minimum siting, design, and construction practices. See the V-Zone Risk Factor Rating Form in FEMA's *Flood Insurance Manual* (http://www.fema.gov/nfip/manual.shtm).

E

Ivan Flood Recovery Maps

Hurricane Ivan made landfall on September 16, 2004, at approximately 2 a.m. (Eastern Daylight Time) near Gulf Shores, Alabama, with maximum sustained winds of 130 miles per hour. Hurricane-force winds extended outward up to 105 miles from the center of the storm. Coastal storm surge flooding of 10 to 16 feet above normal tide levels, along with large and dangerous battering waves, occurred near and to the east of where the center of the storm made landfall. Widespread damage occurred, including the damage and/or destruction of homes, infrastructure, and beach erosion.

In the wake of this devastating event, the Federal Emergency Management Agency (FEMA) initiated a short-term project to produce high-resolution maps that show flood impacts from the storm for portions of Okaloosa, Escambia, and Santa Rosa Counties in Florida, and Baldwin County, Alabama. The maps, which are available from the Ivan maps link on www.fema.gov/ivanmaps, show high water mark flood elevations, flood inundation limits from Hurricane Ivan, the inland limit of waterborne debris (trash lines), and storm surge elevation contours based on the high water marks. The maps also show existing FEMA Flood Insurance Rate Map (FIRM) flood elevations for comparison to the Hurricane Ivan data.

These maps are intended to help state and local officials, as well as homeowners, to identify existing and increased flood hazards caused by the storm, and to use this information during recovery and redevelopment to avoid future flood damages.

Hurricane Ivan maps are for advisory purposes only; they do not supersede effective FIRMs. The Ivan data presented are preliminary and subject to update as additional data become available. Figure E-1 shows a flood recovery map for Gulf Shores, Alabama.

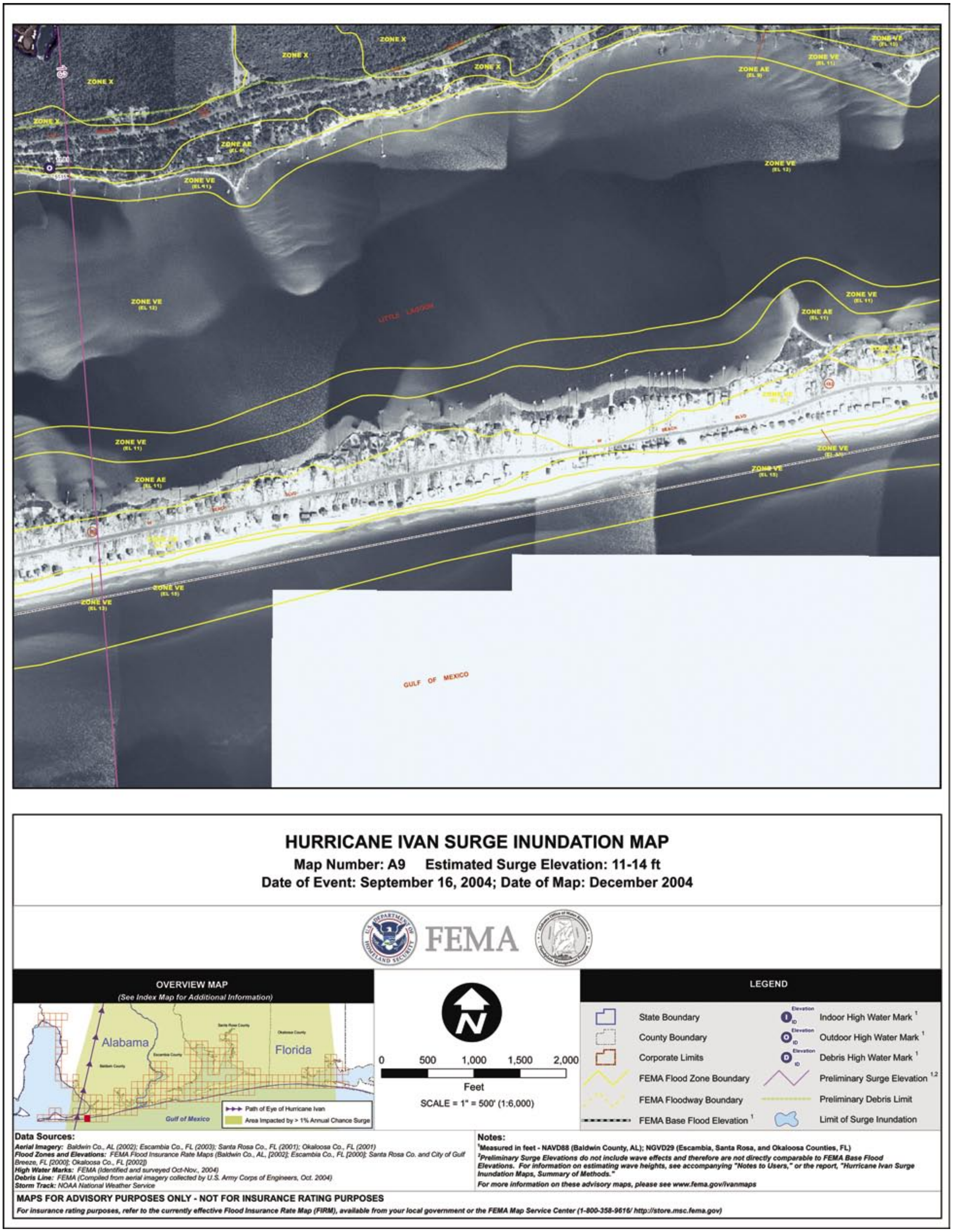


Figure E-1. Sample Flood Recovery Map A9 for Gulf Shores, Alabama.

F

Orange Beach High-Rise Study

Post-Ivan High-Rise Damage Survey

High-rise buildings along the Orange Beach, Alabama, Gulf of Mexico shoreline (seaward of Perdido Beach Boulevard.) were inspected by FEMA contractors between November 3 and 18, 2004. The purpose of the inspections was to determine the numbers and elevations of lowest floor living units that were damaged or destroyed by flood effects during Hurricane Ivan. Given the large number of damaged multi-family buildings that would not be classified as substantially damaged, an attempt was made to identify those lowest floor living units that could be repaired or reconstructed in-place, and which would have been classified as substantially damaged had they been individual buildings.

Building data were collected using a data sheet (see Figure F-1) and information from the data sheets was tabulated. A total of 43 buildings were inspected (see Figure F-2). Two buildings collapsed and would be classified as substantially damaged, and were removed from the study sample. Characteristics of the remaining 41 buildings are summarized in Table F-1.

Table F-1. Summary of Orange Beach, Alabama, High-Rise Buildings Inspected

Buildings Inspected (43)	
Number of Buildings Inspected	43
Total Number of Living Units	3,567
Collapsed Buildings (2)	
Number of Buildings Collapsed	2
Number of Living Units, Collapsed Buildings	70
Standing Buildings (41)	
Number of Buildings	41
Number of Living Units	3,497
Average Number of Living Units (range = 18 to 247)	85
Average Number of Stories (range = 5 to 15)	11
Number of Buildings with Living Units on Lowest Floor	39
Number of Living Units, Lowest Floor	233
Number of Buildings with Lobby/Common Area on Lowest Floor	28

Figure F-3 shows the lowest floor elevations of the 41 buildings used for the analysis. Figure F-4 shows the numbers of lowest floor living units versus lowest floor elevation.

FEMA

PROJECT: FEMA 1549DR-Alabama, Hurricane Ivan - Building Failure Analysis for Coastal Construction

COMM. NO. 01003C **PREL.** 12/17/2004 **FINAL** **SHEET** Bald-6

Unit ID: 1003
Building Name:
Address: Perdido Beach Boulevard
Closest Municipality: Orange Beach **County:** Baldwin **State:** AL

Survey Project: Hurricane Ivan Condominium Report **Survey Date:** 11/18/2004
Survey Company: **Survey Crew:**
Survey Latitude: 30.2616 **Northing:** 94150 **Vertical Datum:** NGVD1929
Survey Longitude: 87.6157 **Easting:** 1931466 **Horizontal Datum:** NAD1983

Use on Lowest Floor (check all that apply)
Parking ☐ **Lobby/common** ☑ **Living Units** ☑
No. of Living Units on the Lowest Floor: 4 **Elevation of Top of Lowest Floor (ft NGVD):** 18.66
Elevation of Bottom of Lowest Horizontal member Supporting the Lowest Floor (ft NGVD): 13.74
HVAC: Units on roof damaged

	Lowest Slab Damage*				Wall/Interior Damage**		
	No Damage	Damaged	Destroyed	Vertical Erosion Height below slab (ft)	No Damage	Damaged	Destroyed
Living Units***			4	8			4
Common Area			x	6			x
Parking Area							

* Slab damage: no = intact, no major cracking; damaged = major cracking, partial settlement; destroyed = total or major collapse
** Wall/Interior damage: no = walls and interior intact; damaged = portions of wall pushed in, windows/doors broken; destroyed = entire wall collapsed interior gutted
*** Indicate number of living units with no slab damage, damaged slabs, destroyed slabs. Indicate number of living units with no wall/interior damage, damaged walls/interior, destroyed walls/interior

Comments:
Some walls on 2nd floor damaged.

BLHM = **B**ottom of **L**owest **H**orizontal **M**ember **TLF** = **T**op of **L**owest **F**loor **BL** = **B**asement **L**evel

Street Side

Erosion

Figure F-1. Sample data sheet for Orange Beach high-rise study

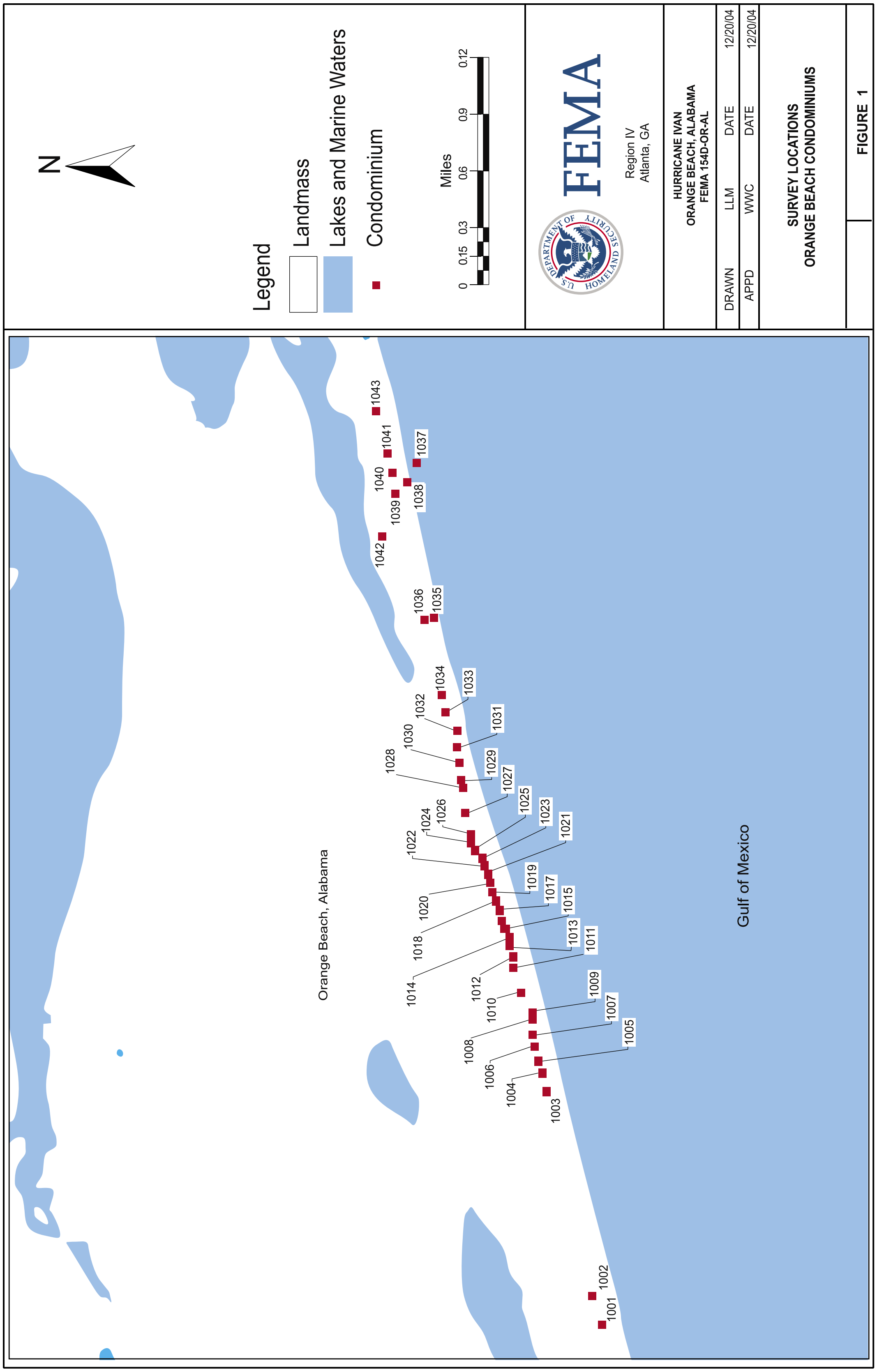


Figure F-2. Locations of 43 high-rise buildings inspected in Orange Beach, Alabama (numbers are code numbers assigned during inspections)

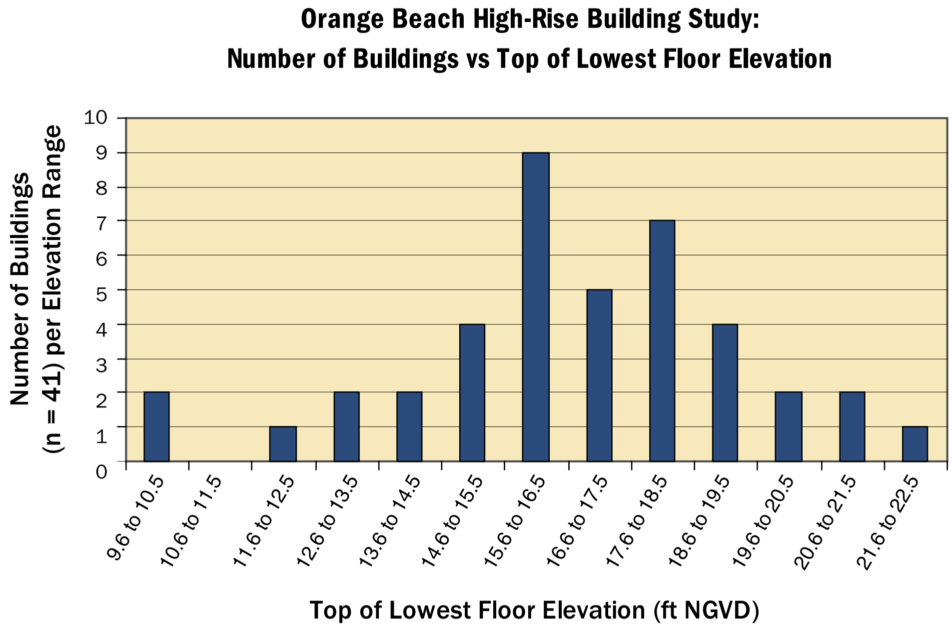


Figure F-3. Top of lowest floor elevations for Orange Beach high-rise buildings

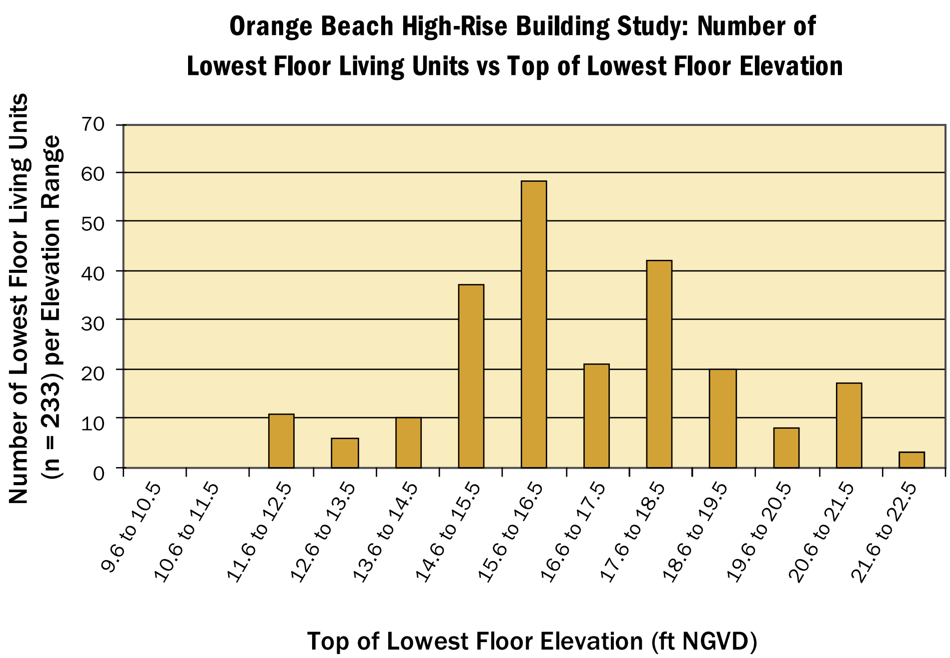


Figure F-4. Lowest floor living unit elevations

The lowest top-of-lowest-floor elevation was 10 feet the National Geodetic Vertical Datum (NGVD), but the lowest living units were at 12.5 feet NGVD; the highest top of a lowest floor was 21.9 feet NGVD. Approximately two-thirds of the tops of lowest floors and lowest floor living units were between 14.6 feet NGVD and 18.5 feet NGVD.

Inspections showed the bottom of the lowest horizontal supporting member (BLHM) of the lowest floor (excluding pile caps) varied from approximately 1 feet to 7 feet below the top of the lowest floor (average difference approximately 2.5 feet). Thus, for most of the buildings and lowest floor living units, the bottom of the lowest horizontal supporting members (excluding pile caps) lie between approximately 10 feet NGVD and 18 feet NGVD (average BLHM elevation approximately 14.5 feet NGVD).

Although the dates of construction for the inspected buildings are not known, these floor elevations are consistent with the 1983, 1985 and 2002 FIRMs for the region (see Section 2.2.1), which mapped the area seaward of Perdido Beach Boulevard as zones C, B, AE (elevation 9 to 13 feet NGVD) and VE (elevation 10 to 16 feet NGVD).

Building Damage States

Lowest floor damages were classified into nine "damage states" (see Table F-2) based on combinations lowest floor damage and damage to walls at the lowest floor level. The best case was no damage (lowest floor intact, walls intact). The worst case was complete destruction (lowest floor destroyed, walls destroyed).

Table F-2. Description of Damage States Used in the Orange Beach High-Rise Study

Component	Damage State	Description
Lowest Floor	Intact	intact, no major cracks
Lowest Floor	Damaged	major cracking and/or partial settlement
Lowest Floor	Destroyed	total or major collapse
Walls	Intact	walls and interior intact
Walls	Damaged	portions of walls pushed in, and/or doors/windows broken
Walls	Destroyed	entire wall collapsed and interior gutted

Table F-3 summarizes the frequency of observed damage states at the 41 buildings inspected. Table F-4 summarizes the frequency of observed damage states for the 233 lowest floor living units. A review of Tables F-3 and F-4 shows:

- 13 percent of the buildings and 12 percent of the lowest floor living units sustained no damage whatsoever (floor intact, walls intact). See Figure F-5.

- The most common lowest floor living unit damage state encountered was "floor intact, walls destroyed," occurring in 44 percent of the buildings and 43 percent of the lowest floor living units. See Figure F-6.
- 31 percent of the buildings and 25 percent of the lowest floor living units sustained complete lowest floor destruction (floor destroyed, walls destroyed). See Figure F-7.
- 183 (79 percent) of the lowest floor living units sustained wall destruction (across all floor damage states). These units would likely have been classified as substantially damaged had they been individual buildings instead of units of high-rise structures.

Table F-3. Orange Beach High-Rise Buildings (n = 41) Classified by Lowest Floor Living Unit Damage States

		Floor Condition			Sums	
		Intact	Damaged	Destroyed		
Wall Condition	Intact	6	0	0	6	6
	Damaged	2	1	1	4	42
	Destroyed	21	2	15	38	
Sums		29	3	16	*	
		29	19			*

* sums exceed 41 since some buildings experienced more than one floor-wall damage combination

Table F-4. Numbers of Lowest Floor Living Units Classified by Damage States (n = 233) for 41 Orange Beach High-Rise Buildings

<table>
<tr><th colspan="2"></th><th colspan="3">Floor Condition</th><th colspan="2" rowspan="2">Sums</th></tr>
<tr><th colspan="2"></th><th>Intact</th><th>Damaged</th><th>Destroyed</th></tr>
<tr><th rowspan="3">Wall Condition</th><th>Intact</th><td>28</td><td>0</td><td>0</td><td>28</td><td>28</td></tr>
<tr><th>Damaged</th><td>18</td><td>1</td><td>3</td><td>22</td><td rowspan="2">205</td></tr>
<tr><th>Destroyed</th><td>101</td><td>24</td><td>58</td><td>183</td></tr>
<tr><th colspan="2" rowspan="2">Sums</th><td>147</td><td>25</td><td>58</td><td>233</td><td></td></tr>
<tr><td>147</td><td colspan="2">86</td><td></td><td>233</td></tr>
</table>

Figure F-5.
Floor intact, wall intact damage state

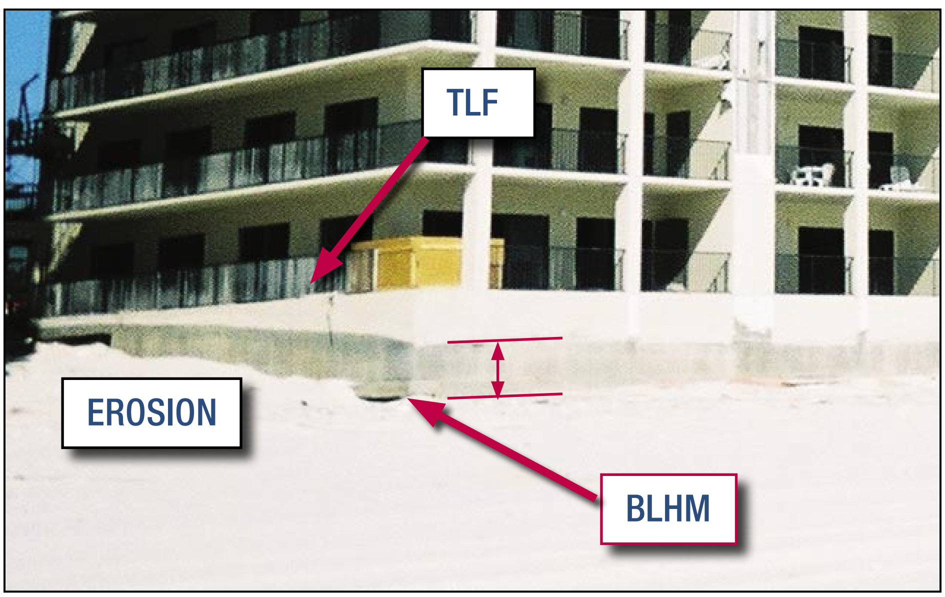


Figure F-6.
Floor intact, wall destroyed damage state

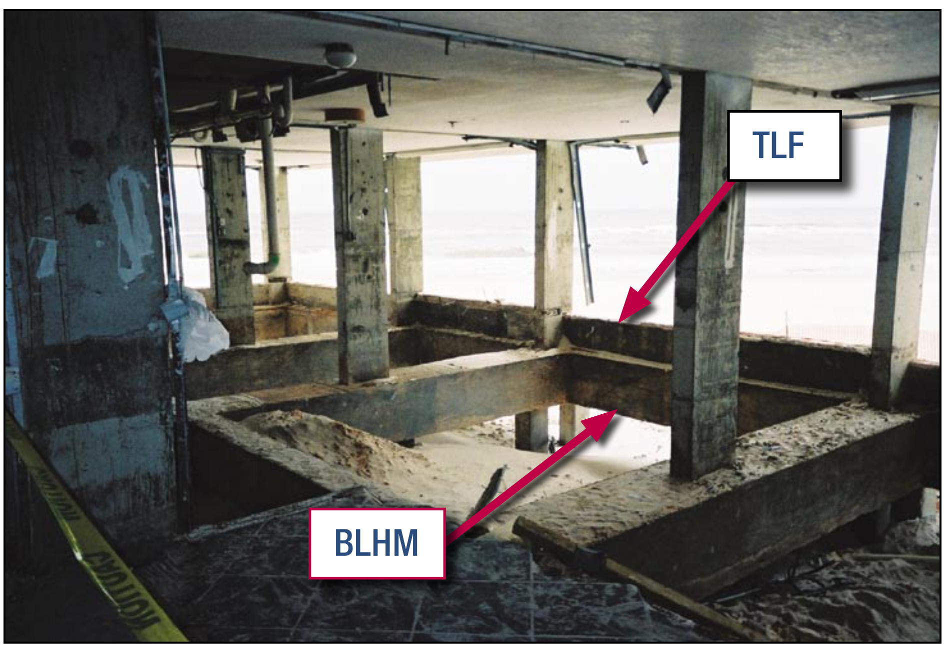


Figure F-7.
Floor destroyed, wall destroyed damage state

Building Damage versus Lowest Floor Elevation

Building damage states were compared against lowest floor elevations. Not surprisingly, buildings with the lowest floor elevations had more wall and floor destruction than buildings with higher floor elevations (see Table F-5, Figure F-8 and Figure F-9).

Note that even though the number of lowest floor living units above elevation 19.6 feet was less than 10 percent of the total number of lowest floor living units (see Figure F-4), these units accounted for 75 percent of the total number of undamaged lowest floor living units – units at higher floor elevations had a better survival rate.

Similarly, 69 percent of the totally destroyed lowest floor living units were below elevation 16.5 feet NGVD, even though only 52 percent of the total number of lowest floor living units were below this elevation – units at lower elevations had a greater likelihood of being destroyed.

Review of Hurricane Ivan water levels at Orange Beach (see Table 1-2 and Figure 1-10) show that water levels reached elevations of approximately 12 to 15 feet NGVD, which exceeded the BFEs there. The Ivan water levels may have included wave setup and some wave effects, but probably did not reflect the true wave crest elevation, which could have been several feet higher than the measured water levels. The fact that lowest floor living units survived intact only when the floor elevation exceeded 19 feet NGVD is consistent with this, and reinforces the importance of adding freeboard – designing and constructing buildings above the minimum elevations required by the NFIP.

Table F-5. Damage States versus Top of Lowest Floor Elevation*

Damage State	Number of Buildings (n)	Average Top of Lowest Floor Elevation (ft NGVD)
Floor Intact, Wall Intact	6	19
Floor Intact, Wall Destroyed	21	17.4
Floor Destroyed, Wall Destroyed	15	15.9

* damage states not included in table for small n

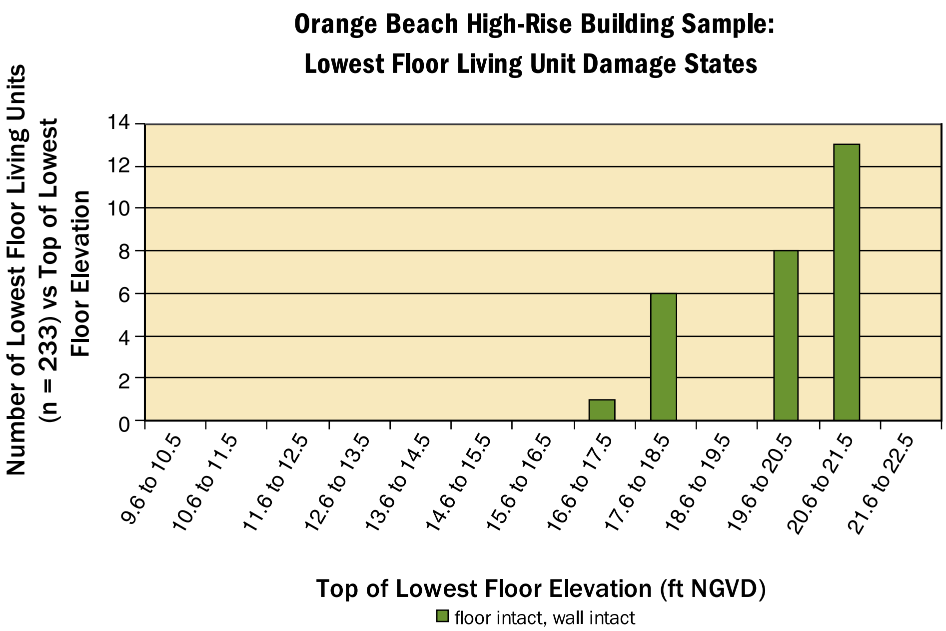


Figure F-8.
Floor intact, wall intact damage state versus top of lowest floor elevation

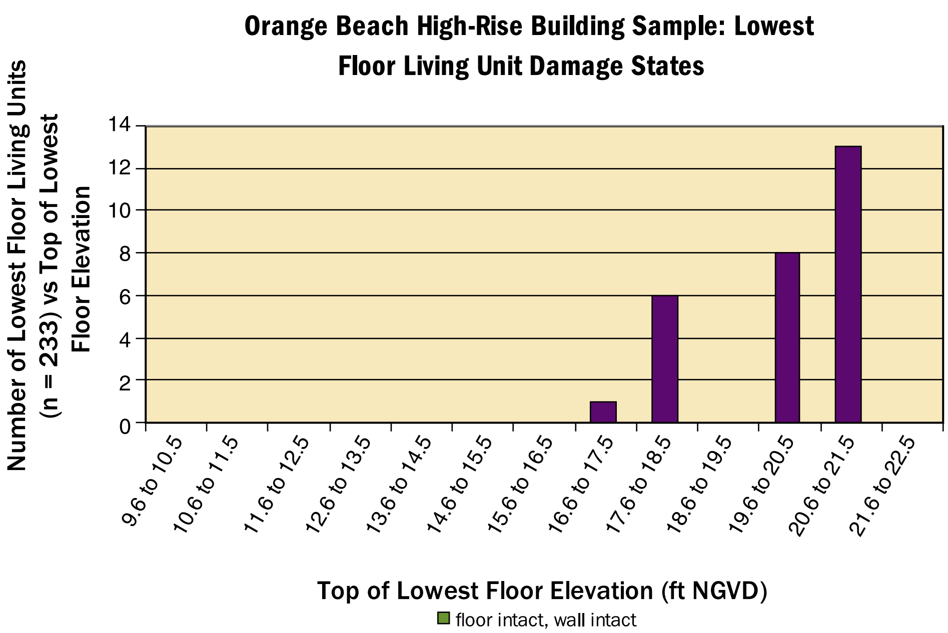


Figure F-9.
Floor destroyed, wall destroyed damage state versus top of lowest floor elevation

Building Damage versus Erosion Depth

Building damage states were also compared against erosion depth at the building foundations. Not surprisingly, buildings with the greatest erosion depths had more wall and floor destruction than buildings with lower erosion depths (see Table F-6). Low erosion depths were associated with buildings sited farther from the shoreline, and buildings near the east end of Orange Beach, where sand trapped against the East Pass jetty produced a wide beach seaward of the buildings.

Table F-6. Damage States versus Average Erosion Depth*

Damage State	Number of Buildings (n)	Average Erosion Depth (ft)
Floor Intact, Wall Intact	6	1.3
Floor Intact, Wall Destroyed	20	7
Floor Destroyed, Wall Destroyed	15	6

* damage states not included in table for small n

Summary of Findings

- While the exact construction requirements for each building (i.e., the effective flood hazard zones and BFEs at the time of construction) are not certain, all but two of the high-rise structures examined were constructed with pile foundations – which prevented total collapse of the structures.
- The buildings, as a whole, performed well structurally, although a high percentage of the lowest floor living units and common areas were damaged or destroyed by Ivan's flood effects and erosion. Lowest floor damage could have been prevented or reduced by adherence to current VE zone construction standards and use of freeboard to elevate the lowest floors several feet above the BFE.
- Elevating the lowest floor one story above the BFE and using the space below the BFE for parking would be the most appropriate means of reducing lowest floor living unit damage to new high-rise buildings in the area.