Mitigation Assessment Team Report

Hurricane Ike in Texas and Louisiana

Building Performance Observations, Recommendations, and Technical Guidance

FEMA P-757 / April 2009

FEMA

MITIGATION ASSESSMENT TEAM REPORT

HURRICANE IKE IN TEXAS & LOUISIANA

In response to Hurricane Ike, 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 FEMA Headquarters and Regional Office engineers, representatives from other Federal agencies and academia, and experts from the design and construction industry. The conclusions and recommendations of this Report are intended to provide decisionmakers with information and technical guidance that can be used to reduce future hurricane damage.

In this photo taken by the MAT on September 19, 2008, a lone house in the Gilchrist neighborhood on the Bolivar Peninsula in Texas, survived Hurricane Ike.

MITIGATION ASSESSMENT TEAM REPORT

Hurricane Ike in Texas and Louisiana

Building Performance Observations, Recommendations, and Technical Guidance

FEMA P-757 / April 2009

THE AMERICAN INSTITUTE OF ARCHITECTS

APA

GHBA GREATER HOUSTON BUILDERS ASSOCIATION

Institute for Business & Home Safety

ICC INTERNATIONAL CODE COUNCIL

VINYL SIDING INSTITUTE VSI

U.S. DEPARTMENT OF HOMELAND SECURITY

FEMA

Members of the Mitigation Assessment Team

Chapter Leaders and Authors

Executive Summary
Eric Letvin

Chapter 1
Vassiliki Koumoudis
Chris Jones
Larry Tanner
Wallace Wilson

Chapter 2
Larry Tanner
Chris Jones
Dave Low
Wallace Wilson

Chapter 3
Chris Jones
Larry Tanner
David Johnston
Dave Low
Mark Matulik
Tom Smith
Wallace Wilson

Chapter 4
Tom Smith
David Conrad
Dave Low
Mark Matulik
Wallace Wilson

Chapter 5
Tom Smith
David Conrad

Chapter 6
All

Chapter 7
All

Chapter 8
Janice Olshesky

Team Members

Team Leader
Paul Tertell, PE, FEMA HQ

Team Manager
Eric Letvin, PE, Esq., CFM, URS Group, Inc.

Team Members
Kent Baxter, FEMA Region 6

David L. Conrad, PE, PBS&J

Claudette Fetterman, FEMA HQ

Lois Forster, FEMA HQ

Philip Grankowski, International Code Council

David S. Johnston, Vinyl Siding Institute, Inc.

Christopher P. Jones, PE

Vassiliki Koumoudis, URS Group, Inc.

Emanuel Lain, Jr., MPA, FEMA LA TRO

Dave Low, PE, D.K. Low & Associates

CW Macomber, APA

Mark Matulik, CFM, MPA, Dewberry

Janice Olshesky, AIA, Olshesky Design Group LLC

Tim Reinhold, Institute for Business and Home Safety

Thomas L. Smith, AIA, RRC, TLSmith Consulting, Inc.

Larry J. Tanner, PE, MASCE, MAAWE, Wind Engineering Research Center, Texas Tech University

Charles Tobelman, FEMA LA TRO

Jonathan Westcott, PE, FEMA HQ

Brian Willsey, FEMA HQ

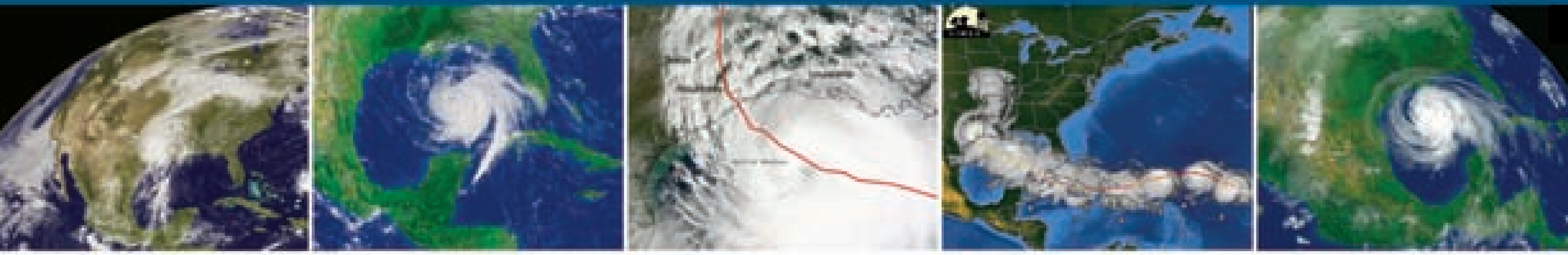
Wallace A. Wilson, PE, CFM, W.A. Wilson Consulting Services, LLC

Gary Zimmerer, PE, FEMA Region 6

Technical Editor: Susan Ide Patton, URS Group, Inc.

Publication Designer: Wanda Rizer, Consultant

Graphic Artist: Julie Liptak, Greenhorne & O'Mara, Inc.



Eric Letvin

HURRICANE
IKE
IN TEXAS & LOUISIANA

Executive Summary

Hurricane Ike made landfall over Galveston, TX, on September 13, 2008 at 2:10 a.m. Central Daylight Time (CDT). Hurricane Ike was the ninth named storm during the 2008 hurricane season and the most significant of the three that hit Texas in 2008. It was the seventh storm of the season to hit the United States mainland. At one point in time, the tropical-force winds spanned 600 miles across the Gulf of Mexico as the hurricane approached Texas. It is estimated that the storm surge generated by Hurricane Ike affected an area of approximately 310 miles along the Gulf of Mexico coastline.

Hurricane Ike is likely to be one of the costliest and most destructive hurricanes in U.S. history. Although Hurricane Ike was only a Category 2 hurricane when it made landfall near Galveston, TX, the large wind field of Hurricane Ike and the timing of when it struck, which included a period of increased tides, led to storm surge levels more typically associated with a Category 4 hurricane. This disparity is due to the fact that the Saffir-Simpson hurricane scale is based on typical storm characteristics, and Ike was atypical. Ike was a very large hurricane (tropical-storm-force and hurricane-force winds extended approximately 275 miles and 120 miles from the storm center, respectively). A proposed new storm classification system (Integrated Kinetic Energy classification) would place Ike as high as 5.2 on a scale of 1 to 6.

The combination of surge and high waves was particularly destructive in areas along the Gulf of Mexico coast and parts of the Galveston Bay shoreline, particularly the Bolivar Peninsula, where preliminary numbers show that out of 5,900 buildings standing before Ike, approximately 3,600 were destroyed, 400 sustained major damage (substantially damaged), 1,800 sustained some damage but were not substantially damaged, and 100 were undamaged or sustained only minimal damage. Flooding also damaged many homes and businesses in the City of Galveston; in communities surrounding Galveston Bay; in the Bridge City, TX, area; and in low-lying southwest Louisiana.

In January 2009, the Property Claim Services (PCS) of the Insurance Services Office revised its estimated insured losses to $10.655 billion from its original estimates of $8.1 billion. Based on the revised estimated insured losses, total losses are estimated at $21.3 billion, which would make Hurricane Ike one of the top five costliest U.S. hurricanes of all time.

Mitigation Assessment Team (MAT)

For the past 25 years, the Federal Emergency Management Agency (FEMA) has studied the performance of buildings affected by disasters of national significance. Disasters of national significance provide opportunities for research on how hazards affect the built environment and also an opportunity to research the performance of current building codes and practices. This work is accomplished by the FEMA Mitigation Assessment Team (MAT). Often, recommendations from these findings have been adopted as statutes in model building codes, or just as importantly, as guidance for better and stronger construction practices.

These broad-minded studies are driven by a core mission of FEMA's Mitigation Directorate: to reduce damages from future disasters. They support an integral part of the Stafford Act, which is to reduce the loss of life and property that can occur from disasters. The ongoing study of the effects of these significant disasters and the documentation of findings will help in developing recommendations to enhance building performance. Improving building performance will reduce the vulnerability of population centers and critical infrastructure to natural hazards. This can be accomplished by exploiting the science and technology developed today, and imparting this knowledge to local communities through guidance and education.

In response to a request for technical support from FEMA's Joint Field Office in Austin, TX, and the Transitional Recovery Office in New Orleans, LA, FEMA's Mitigation Directorate deployed a MAT to Texas and Louisiana in October 2008 to evaluate both building performance during Hurricane Ike and the adequacy of current building codes, other construction requirements, and building practices and materials. The MAT set out to investigate the following issues and make appropriate conclusions and recommendations based on their observations of Hurricane Ike damage:

- Performance of new construction, especially foundation performance and performance against floodborne debris
- Performance of critical facilities (e.g., schools, hospitals, and first responder facilities)
- Performance of high-rise buildings in downtown Houston
- Performance of hurricane-resistant homes on Bolivar Peninsula
- Performance of beach nourishment and reinforced dune projects in reducing flood damage
- Performance of FEMA-funded mitigation projects
- Sustainable design considerations in hurricane-prone areas

Assessment Observations

In localized areas in Texas, the flood levels for Hurricane Ike exceeded the current design flood event (i.e., 100-year base flood event) illustrated on the FEMA Flood Insurance Rate Maps (FIRMs). The wind speeds from Hurricane Ike were less than the design speeds prescribed in American Society of Civil Engineers (ASCE) 7-05, *Minimum Design Loads for Buildings and Other Structures*.

Flood Damage

All the Texas and Louisiana communities visited by the MAT participate in the National Flood Insurance Program (NFIP) and have adopted floodplain management regulations that meet or exceed minimum NFIP requirements. Most of the communities have also adopted model building codes. However, unincorporated areas of Texas are not required to complete plan review, residential building design review, or building inspection by a State or county building official. One of the goals of the MAT was to investigate building failures in mapped flood zones. The MAT determined that some of the communities visited have adopted design and construction requirements more stringent than required by the NFIP for these zones, and that structural damage to newer buildings in these communities was generally less than in communities that have not adopted higher standards.

Compliance with NFIP design and construction provisions was lacking at some buildings and in some Louisiana communities. Problems were observed at residential and commercial buildings, and at critical facilities. Compliance issues seemed to be more frequent at older structures, but some problems were also noted at newer structures.

A preliminary review of pre- and post-Ike aerial photographs suggests that 100 to 200 feet of dunes and vegetation were lost during Ike along much of the Gulf of Mexico shoreline. This loss occurred in areas with natural dunes and in areas where eroded dunes had been rebuilt and reinforced with geotextile tubes. The MAT observed significant levels of erosion and scour around buildings situated near the Gulf. Erosion was widespread along the Gulf shoreline of Follets Island, Galveston Island, Bolivar Peninsula, and portions of southwest Louisiana. The MAT did not observe any significant erosion and scour along the bay shorelines, although there may have been some locations where such erosion and scour occurred.

Overall, the damage observed by the MAT was consistent with typical wave damage patterns: damage to properly designed and constructed elevated homes was generally minor until the waves reached above the elevated floor system, at which point the damage increased dramatically with increasing water level and wave height. Performance of residential building foundations to coastal and near-coastal hazards depended primarily on the residence having adequate elevation, proper construction, and proper foundation selection. If any of these criteria were not satisfied, performance suffered. Several of the houses the MAT evaluated performed well, particularly where the foundations elevated the houses above flood levels, where the foundations were adequately constructed to resist the imposed forces, and where the foundations were founded deeply enough to resist scour and erosion.

Wind Damage

Though Hurricane Ike's estimated wind speeds were less than the design wind speeds given in the current building code, the MAT observed widespread wind damage in the areas that were investigated. Although a very large number of buildings (including residential, commercial, and critical facilities) were damaged, much of the damage was light to moderate. Most of the wind damage was to building envelopes (primarily roof coverings, rooftop equipment, and wall coverings). Wind damage was most pronounced along the Bolivar Peninsula, the eastern portion of Galveston Island, and the areas bordering Galveston Bay.

The MAT observed various types of building envelope damage at several buildings in downtown Houston. A few high-rise buildings in downtown Houston had extensive glazing damage. According to the current building code, the basic wind speed for downtown Houston is approximately 108 mph. The estimated maximum speed during Hurricane Ike was approximately 94 mph. Several failure mechanisms were observed for building envelopes, specifically glazing damage.

The wind speeds in Louisiana were even less than those in Texas, and were also less than the design wind speeds given in the current building codes. Estimated wind speeds ranged from 80 mph near the Texas/Louisiana border, to 50 mph in Vermilion Parish. East of Vermilion Parish, estimated wind speeds were less than 50 mph. Although wind damage did occur in Louisiana, it was not as significant as the damage in Texas. As is frequently observed during MAT investigations, damage to buildings and other structures is routinely produced by less than design wind speeds due to the following: lack of understanding and execution of basic wind-resistant design and construction practices; insufficient codes and standards at the time of construction; insufficient or lack of design guides and/or test methods at the time of construction; and improper or non-compliant building modifications or lack of maintenance by the property owners.

Critical Facilities Damage

Several critical facilities, such as Emergency Operations Centers (EOCs), fire and police stations, hospitals, nursing homes, and schools were evaluated by the MAT in order to document building performance, as well as loss of function from Hurricane Ike. Critical facilities generally performed as expected. Those that were elevated higher and on stronger foundations sustained less damage. Those that were constructed in a manner similar to nearby, minimally compliant residential and commercial buildings sustained more damage.

Critical facilities with equipment and utilities in basements or at ground level tended to sustain flood damage to these support systems that either prohibited post-Ike resumption of operations, or delayed or reduced operational capabilities. At least one critical facility destroyed by Hurricane Rita and rebuilt prior to Ike appeared to have insufficient elevation, and will likely be flooded again. While Ike flooding did not enter the building, the below-floor utilities were damaged by Ike, and facility function was lost for a period of time. Critical facilities such as this should be elevated several feet above the base flood elevation (BFE) to reduce the likelihood of future flood damage.

All of the critical facilities exposed to Hurricane Ike were subjected to wind speeds that were less than the design wind speeds given in the current building codes. Hence, while most of the critical facilities observed by the MAT experienced relatively little or no wind damage, the MAT observed issues indicating that if Hurricane Ike had delivered code design wind speeds, damage from poor wind performance would have been expected at many of these facilities.

Recommendations

A few of the main recommendations based on observed building performance related to Hurricane Ike are provided below, as well as specific recommendations for improving wind- and flood-resistance of critical facilities.

Flood

a. Until new flood maps are available and adopted, require the following freeboard above the Effective BFEs for new construction, substantial improvements, and repair of substantial damage: freeboard specified by the ASCE 24-05, *Flood Resistant Design and Construction*, plus 3 feet. Once new flood maps are available and adopted, require new construction, substantial improvements, and repair of substantial damage to be elevated to or above the freeboard elevation specified by ASCE 24-05.

b. Enforce ASCE 24-05's Zone A design and construction standards in the area between the Effective Special Flood Hazard Area (SFHA) landward limit and a ground elevation equal to the adjacent Zone A Effective BFE plus freeboard.

c. Enforce ASCE 24-05's Coastal A Zone design and construction requirements in areas presently mapped as Zone A on the Effective FIRM.

d. FEMA should review its lowest floor elevation requirements for consistency with the requirements contained in the national consensus standard ASCE-24, *Flood Resistant Design and Construction*, and in light of the recommendations contained in the *Evaluation of NFIP Building Standards* (American Institutes for Research, 2006). Specifically, FEMA should consider requiring freeboard such that the entire floor system is at or above the BFE for all flood hazard zones.

e. State and local governments should encourage siting away from eroding shorelines; employ coastal restoration, where justified, to mitigate erosion effects; and acquire erosion-damaged properties and prohibit reconstruction on those properties.

f. All new and replacement manufactured homes should be elevated to or above the BFE using wind- and flood-resistant foundations, such as those specified in the National Fire Protection Association 225-09, and installation of new manufactured homes should follow the guidance provided in FEMA 85, *Manufactured Home Installation in Flood Hazard Areas* (1985). (Note that FEMA 85 is currently under revision and is tentatively scheduled for release later in 2009.)

Figure ES-1 illustrates the recommendations outlined in bullets a, b, and c above.

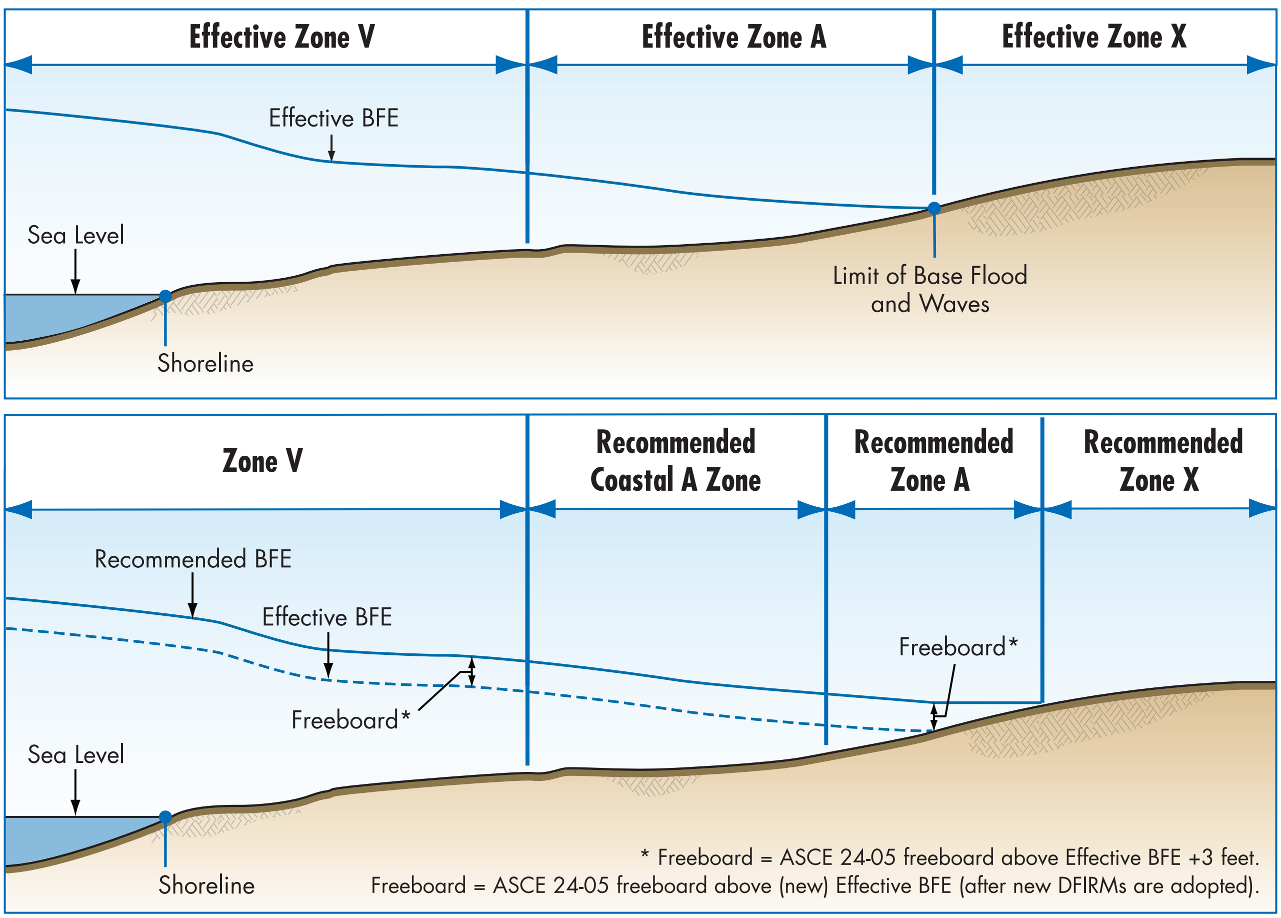


Figure ES-1. Comparison of Effective BFEs and flood hazard zones (upper figure), with MAT-recommended freeboard and flood hazard zones (lower figure)

Wind

a. An extensive amount of envelope wall covering, primarily vinyl siding and fiber cement siding, was damaged by Hurricane Ike. Municipalities with building code authorities, along with the Texas Department of Insurance (TDI) and their inspection program, should require that the installed products are on their approved and tested list and are installed in accordance with industry and manufacturer's recommendations for high-wind-zone installations.

b. Vinyl soffits and attic ventilation systems frequently failed, thereby allowing water infiltration into the homes, causing damage. The TDI and Building Inspection Program should ensure that vinyl soffits are installed in accordance with industry and manufacturer's recommendations for high-wind-zone installations.

c. Few impact-resistant laminated glass window units were observed by the MAT, with homeowners and builders opting to use shutters to provide windborne debris impact protection for glazed openings. TDI currently requires homes located in the Seaward Zone and the Inland (I) to be protected by impact-resistant glazing or shutters. The MAT recommends that opening protection by TDI include Inland (II [110 mph]) within 1 mile of the coastal mean high water line where the basic wind speed is equal to or greater than 110 mph, which is consistent with ASCE 7-05 and International Residential Code (IRC) 2003 recommendations.

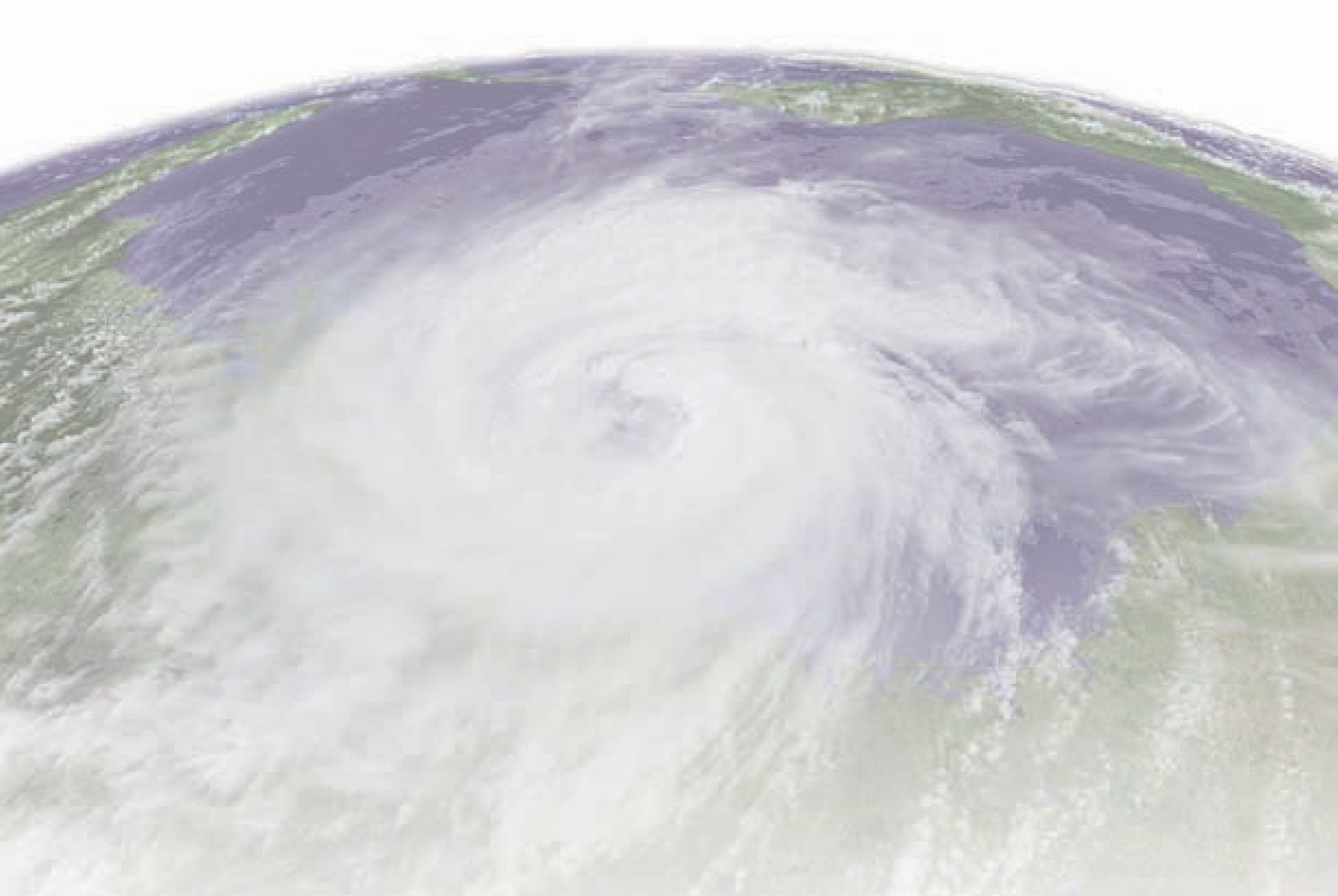
Critical Facilities

a. New and replacement critical facilities should be sited outside the 500-year f oodplain, where possible; where not possible, the critical facilities should be elevated higher than the residential and commercial building elevations called for in the f ood recommendations. At a minimum, critical facilities should be elevated above the 500-year f ood level or the freeboard requirements of ASCE 24-05, whichever offers more protection to the facility.

b. Do not locate equipment and utilities in the basements or ground levels of critical facilities; locate these above the BFE-plus-freeboard elevation. If elevation of these components is not feasible for existing critical facilities in Zone A, evaluate dry-f oodproofing of these areas to an elevation several feet above the BFE; if the building structure cannot accommodate f ood loads associated with dry-f oodproofing to this elevation, consider relocation of the critical facility or replacement with a new critical facility.

c. Perform a comprehensive vulnerability assessment of the Main Wind Force Resisting Systems and building envelope. As part of the evaluation process, prioritize the identified vulnerabilities. FEMA 543, *Design Guide for Improving Critical Facility Safety from Flooding and High Winds: Providing Protection to People and Buildings* (2007) and FEMA 577, *Design Guide for Improving Hospital Safety in Earthquakes, Floods, and High Winds: Providing Protection to People and Buildings* (2007) recommend such an evaluation, regardless of building age, for critical facilities located in hurricane-prone regions.

d. Before a critical facility receives a grant from either the Hazard Mitigation Grant Program or the Pre-Disaster Mitigation Grant Program, the MAT recommends that a comprehensive vulnerability assessment be conducted. All significant wind vulnerabilities (including those related to interruption of municipal utilities) should be mitigated as part of the grant work, and for those that are not, the remaining residual risk should be recognized and documented.



HURRICANE IKE IN TEXAS & LOUISIANA

Table of Contents

Appendices

List of Figures

Chapter 1

Chapter 2

Chapter 3

Chapter 4

Chapter 5

Chapter 6

Chapter 7

Chapter 8

List of Tables

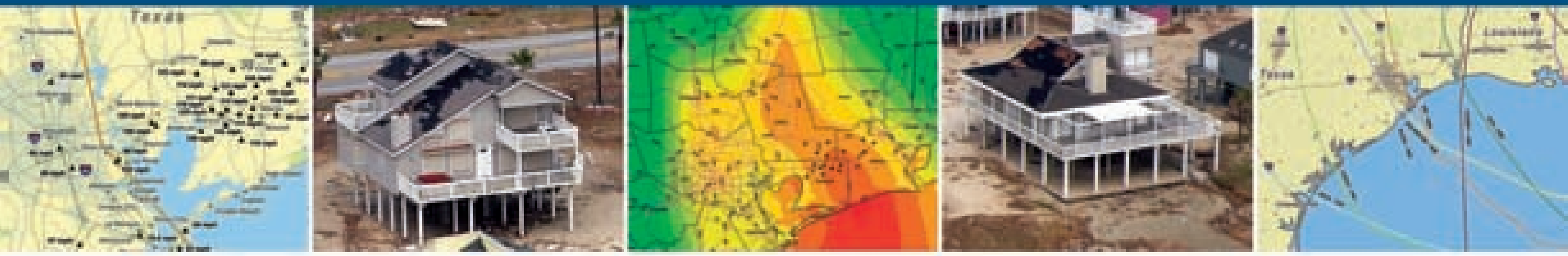
Chapter 1

Chapter 2

Chapter 3

Chapter 4

Chapter 8



Vassiliki Koumoudis
Chris Jones
Larry Tanner
Wallace Wilson

HURRICANE IKE IN TEXAS & LOUISIANA

1 Introduction

On October 15, 2008, the Mitigation Division of the Department of Homeland Security's (DHS) Federal Emergency Management Agency (FEMA) deployed a Mitigation Assessment Team (MAT) to the States of Texas and Louisiana to assess damage caused by the floodwaters and winds of Hurricane Ike. This report presents the MAT's observations, conclusions, and recommendations in response to those field investigations.

This chapter provides an introduction, a discussion of the event, historical information, and background on the MAT process. Floodplain management regulations and building codes and standards that affect construction in Texas and Louisiana are discussed in Chapter 2. Chapter 3 provides a basic assessment and characterization of the structural and envelope performance of residential buildings, including FEMA-funded mitigation projects in areas affected by Hurricane Ike. Chapter 4 presents damage to, and functional loss of, critical and essential facilities affected by Hurricane Ike. Chapter 5 presents damage to buildings in Houston's Central Building

District. Chapters 6 and 7 present the MAT's conclusions and recommendations, respectively, intended to help guide the reconstruction for hurricane-resistant communities in Texas and Louisiana, and other hurricane-prone regions susceptible to future hurricanes. Chapter 8 presents information on sustainable building practices, which are those practices that promote the longevity of buildings and the ecosystem. Although not generally part of a MAT report, this information is provided because sustainability issues are in the forefront of building responsibly. This information is intended to support the significant reconstruction effort that will follow Hurricane Ike. Over the past few decades, FEMA has provided guidance on hazard-resistance building practices. FEMA highly recommends that designers, architects, and planning officials in hurricane-prone areas refer to these publications. Relevant FEMA publications are provided in Appendix B. In addition, the following appendices are presented herein:

Appendix A: Acknowledgments

Appendix B: References and FEMA Publication List

Appendix C: Acronyms and Glossary of Terms

Appendix D: FEMA Recovery Advisories

- Attachment of Brick Veneer in High-Wind Regions (December, 2005; revised 2009)
- Design and Construction in Coastal A Zones (December, 2005; revised 2009)
- Designing for Flood Levels above the BFE (July, 2006; revised 2009)
- Enclosures and Breakaway Walls
- Erosion, Scour, and Foundation Design
- Minimizing Water Intrusion Through Roof Vents in High-Wind Regions
- Metal Roof Systems in High-Wind Regions
- Siding Installation in High-Wind Regions

Appendix E: FEMA High Water Marks for Hurricane Ike

1.1 Hurricane Ike – The Event

Hurricane Ike made landfall over Galveston, TX, on September 13, 2008, at 2:10 a.m. Central Daylight Time (CDT) as a large Category 2 hurricane. Hurricane Ike was the ninth named storm during the 2008 hurricane season and the seventh of the season's storms to hit the U.S. mainland. It was the most significant of the three that hit Texas in 2008 and the second to hit Louisiana in a matter of weeks, with Gustav having hit southwestern Louisiana on September 1, 2008. Hurricane Ike made landfall over Galveston, TX, on September 13, 2008, at 2:10 a.m. as a large Category 2 hurricane. Even though damages were still being tallied as of February 2009, Hurricane Ike is likely to be one of the costliest and most destructive hurricanes in U.S. history; the total damage is estimated to be $21.3 billion, making it the fourth costliest hurricane in history behind Hurricanes Katrina (2005), Andrew (1992), and Wilma (2005) (National Hurricane Center [NHC], 2007).

Although Hurricane Ike was a Category 2 hurricane when it made landfall near Galveston, TX, the large wind field of Hurricane Ike led to storm surge levels more typically associated with a Category 4 hurricane. This disparity is due to the fact that the Saffir-Simpson hurricane scale (Table 1-1), the scale currently used to measure hurricane intensity, is based on typical storm characteristics, and Ike was atypical. Ike was a very large hurricane; tropical-storm-force and hurricane-force winds associated with Ike at the time of its landfall extended approximately 275 miles and 120 miles from the storm center, respectively. A proposed new storm classification system, called the Integrated Kinetic Energy classification (Powell and Reinhold, 2007), would place Ike's storm Surge/Wave Destructive Potential (SDP) as high as a 5.2 (on a scale of 1 to 6) at mid-day on September 11, 2008 (refer to text box for additional information). Figure 1-1 provides a satellite image of Hurricane Ike that illustrates the size of the storm as it approached Galveston, TX.

Table 1-1. Saffir-Simpson Hurricane Scale Wind Speeds and Pressures

Strength	Sustained Wind Speed[1] (mph)	Gust Wind Speed[2] (mph)	Pressure (mb[3])
Category 1	74-95	89-116	>980
Category 2	96-110	117-134	965-979
Category 3	111-130	135-159	945-964
Category 4	131-155	160-189	920-944
Category 5	>155	>189	<920

[1] 1-minute sustained over open water [2] 3-second gust over open water [3] mb = millibars

SOURCE: http://www.nhc.noaa.gov/aboutsshs.shtml

INTEGRATED KINETIC ENERGY

The kinetic energy in a hurricane or any windstorm is proportional to the wind velocity squared. The Integrated Kinetic Energy (IKE) is calculated for a 1-meter deep layer of the storm centered at about a height of 10 meters and can be produced using any appropriate wind field that provides a map of sustained 1-minute winds. The IKE values reported are based on the H*Wind wind field produced by the Hurricane Research Division (HRD) of the National Oceanographic and Atmospheric Administration (NOAA) as an experimental product. The H*Wind wind field is used to produce contours of areas where the wind speeds are greater than tropical storm force, greater than hurricane force, and greater than very strong hurricane force winds (>123 mph sustained winds). These estimates of IKE for areas experiencing wind speeds above certain thresholds are used to produce an SDP and a Wind Destructive Potential (WDP). The SDP is based on the total IKE for all areas where sustained wind speeds are greater than or equal to tropical storm force. The resulting IKE is expressed in terrajoules and is converted to a decimal value between 0 and 6.

What it is:

- A number between 0 and 6 that gives a relative measure of the wind field forcing over the ocean that can lead to high surge and wave damage
- The higher the number, the greater the potential for extensive along-shore inundation and damage from surge and waves
- Independent of bottom slope, coastline shape or properties at risk

What it is not:

- An accurate estimate of actual surge levels or damage since these depend on characteristics of the storm throughout its life cycle as it approaches the coast, and local effects including bottom slope, coastline shape, track of the storm, the roughness of the land surface, and property at risk.

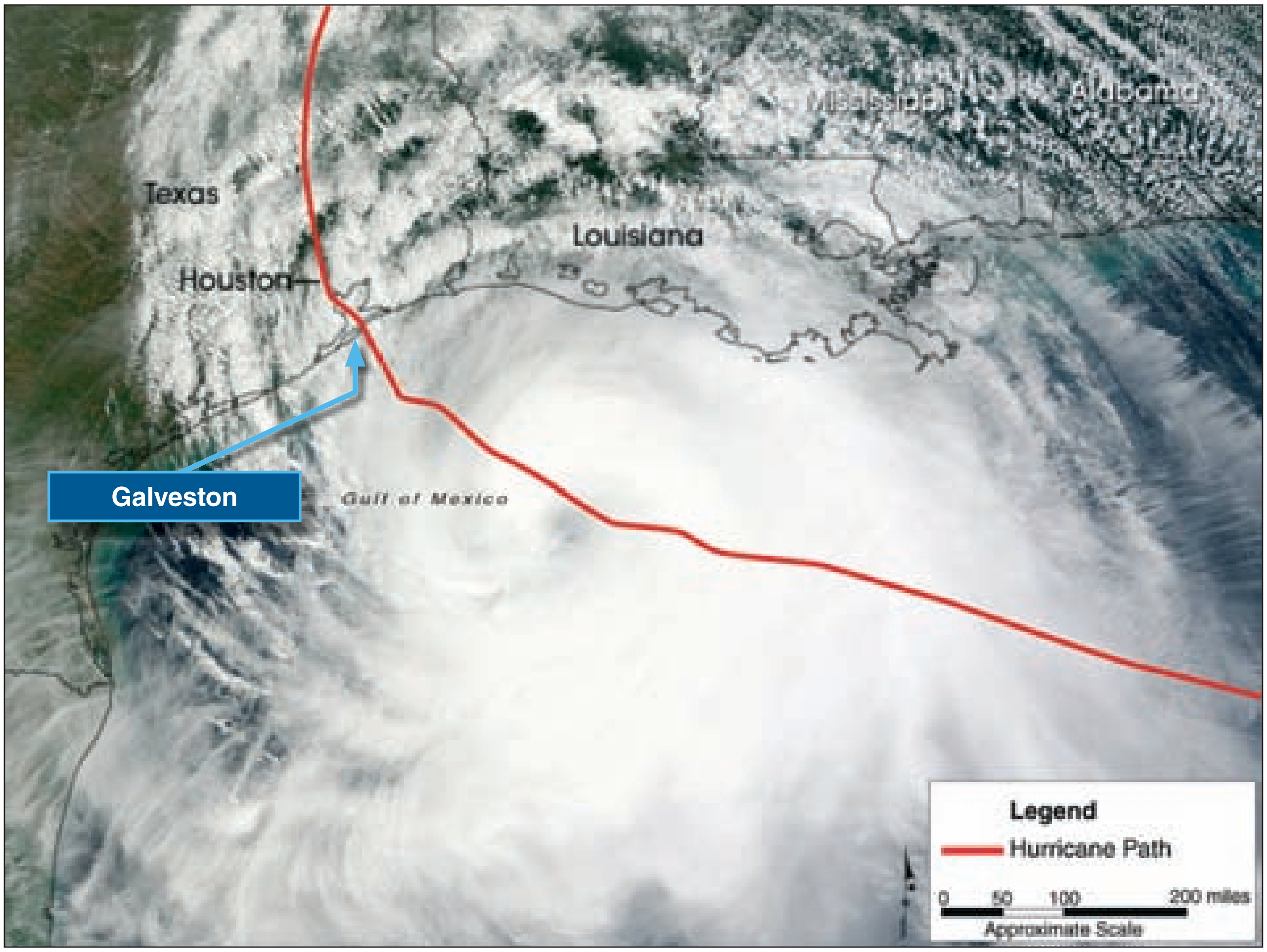


Figure 1-1. Satellite image of Hurricane Ike as it moved toward Texas and Louisiana

SOURCE: http://www.srh.noaa.gov/hgx/projects/ike08.htm

The Saffir-Simpson Scale consists of five separate categories. The NHC reserves the term "major hurricane" for hurricanes that reach maximum 1-minute sustained surface winds of at least 111 miles per hour (mph) over open water. Therefore, Category 3, 4, and 5 hurricanes are all considered major hurricanes.

Hurricane Ike's significant storm surge caused damage to a widespread area across the upper Texas and southwestern Louisiana coast. Some of the hardest hit areas include the communities of Crystal Beach, Gilchrist, and High Island on the Bolivar Peninsula, TX (Figure 1-2). Parts of Galveston Island, TX, were also hit hard by the storm surge, although the seawall protected much of the City of Galveston from the direct impact by storm surge and wave action from the Gulf of Mexico. However, the seawall did not protect Galveston from flooding when water rose on the north side of the island from Galveston Bay. In Louisiana, storm surge caused flooding in Lake Charles in Calcasieu Parish, which is 30 miles inland. The storm surge also inundated areas in parts of Cameron, Vermilion, St. Mary, Terrebonne, Lafourche, Iberia, Jefferson, Plaquemines, St. Bernard, Orleans, St. Charles, St. John the Baptist, St. Tammany, Tangipahoa, Livingston, Ascension, and St. James Parishes.

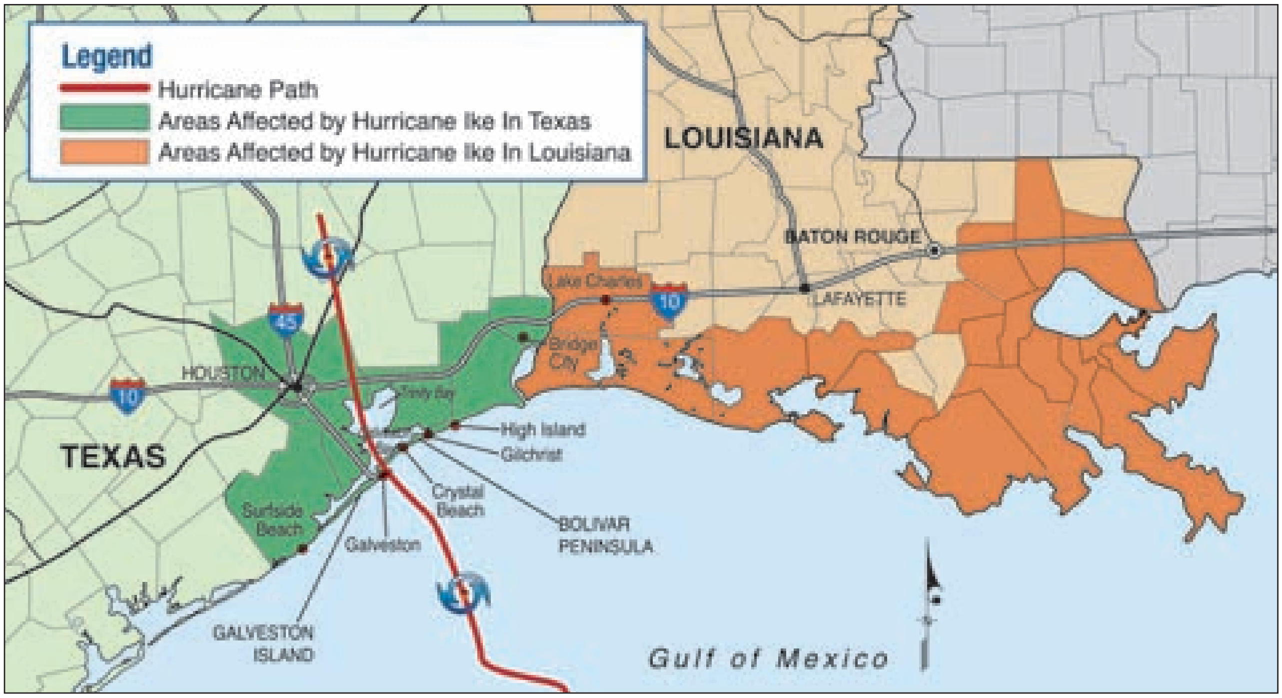


Figure 1-2. Areas affected by Hurricane Ike

Hurricane Ike became extratropical as it moved inland over Arkansas. It continued through the Midwest and into the Ohio Valley, dumping between 6 and 8 inches of rain in parts of Indiana, Illinois, and Missouri (Minnesota Public Radio, 2008). Twenty-nine tornadoes were reported in association with Hurricane Ike. Luckily there were no deaths reported from the tornadoes.

The Tropical Cyclone Report for Hurricane Ike published by the NHC on January 23, 2009 (Berg, 2009) indicated that Hurricane Ike is directly responsible for 103 deaths across Hispaniola, Cuba, and parts of the U.S. Gulf Coast. The report also states that the latest official counts and media reports indicate that 20 people died in Texas, Louisiana, and Arkansas as a direct result of Hurricane Ike, and at least 64 indirect deaths were reported in Texas. According to the Laura Recovery Center,[1] 33 people were still missing in Texas as of February 12, 2009.

1.1.1 Summary of Damage and Economic Loss

The combination of surge and high waves were particularly destructive in areas along the Gulf of Mexico coast and parts of the Galveston Bay shoreline, particularly Bolivar Peninsula, TX. Preliminary numbers show that of the 5,900 buildings standing on Bolivar Peninsula before Ike, approximately 3,600 were destroyed, 400 sustained major damage (likely substantially damaged),

1 NWS Houston/Galveston office, http://www.srh.noaa.gov/hgx/projects/ike08/wind_analysis.htm

1,800 sustained some damage but were not substantially damaged, and only 100 were undamaged or sustained only minimal damage (Halff Associates, 2008). Eastern areas of Trinity and Galveston Bays were inundated with floodwaters. In Bridge City, TX, 3,380 of the 3,400 residences in the city were inundated. Flooding also damaged many homes and businesses in the City of Galveston, on west Galveston Island and Follet's Island, in communities surrounding Galveston Bay, and in low-lying southwest Louisiana. Final estimates on the total number of homes and businesses damaged in the affected areas were not available at the time of the publication of this report.

Ports from Corpus Christi to Lake Charles were closed in advance of Ike. Damage to the Ports of Galveston and Houston, as well as debris in Galveston Bay and the Houston Ship Channel, kept those ports closed after the storm for several days, leaving almost 150 tankers, cargo vessels, and container ships waiting offshore. The U.S. Department of Energy said that 14 oil refineries were closed by the storm, as well as two Texas strategic petroleum reserve sites, causing rising gas prices and gas shortages across parts of the United States. In addition, the storm destroyed at least 10 offshore oil rigs and damaged several large pipelines. Before Ike reached the coast, a Cypriot freighter carrying petroleum coke, the 580-foot *Antalina,* lost propulsion about 90 miles southeast of Galveston with its 22-man crew. The U.S. Coast Guard could not rescue the crew during the storm due to the hazardous weather conditions, but the ship rode out the storm without casualties.

In January 2009, the Property Claim Services (PCS) of the Insurance Services Office revised its estimated insured losses to $10.655 billion from its original estimates of $8.1 billion. Based on the revised estimated insured losses, total losses are estimated at $21.3 billion. PCS may increase its estimates again because it is considering including offshore properties in its catastrophe estimates, which it currently does not (Berg, 2009; Hays, 2009).

The Louisiana Economic Development agency reported on September 18, 2008, that "conservative preliminary estimates suggest the total physical damage in Louisiana as a result of Gustav and Ike combined amounts to roughly $8 to $20 billion, including insured and uninsured losses."[2] This amount includes only physical damage and does not include losses due to economic activity; as of the publication of this report, Louisiana Economic Development had not yet estimated that amount for Hurricane Ike alone.

The U.S. Department of Energy estimated that 2.6 million customers lost power in Texas and Louisiana (NHC, 2009). Power outages were also experienced along Ike's path as it moved northward through the United States. Ohio experienced the same level of power interruption as Texas and Louisiana combined, with almost 2.6 million people losing power. The Cincinnati, Columbus, and Dayton areas experienced significant wind damage from the remnants of Hurricane Ike. PCS estimates that the post-tropical remnants of Ike produced $2.3 billion in non-flooding related insured losses—this value equates to approximately $4.7 billion in damages. Insured losses in Ohio alone are estimated at $1.1 billion (Berg, 2009).

2 http://www.ledlouisiana.com/news--multimedia/news-releases/led-releases-hurricane-gustav-and-hurricane-ike-economic-impact-assessment.aspx

1.1.2 Timeline and History of Hurricane Ike

According to the NHC, Hurricane Ike originated as a well-defined tropical wave off the coast of West Africa on August 28, 2008. Tropical Storm Ike developed from a tropical depression west of the Cape Verde Islands on September 1, 2008. On September 3, 2008, the tropical storm had intensified and strengthened into a hurricane. Hurricane Ike continued its path west toward the Caribbean. On September 4, Hurricane Ike had strengthened to a Category 4 hurricane on the Saffir-Simpson scale, with maximum sustained winds of 145 mph.[3]

On September 7, Hurricane Ike made landfall over the Turks and Caicos Islands, with the eye of the storm coming directly over Grand Turk Island and over Great Inagua Island in the southeastern Bahamas. The hurricane continued on its westward path and made its first of two landfalls in Cuba as a strong Category 3 hurricane near Cabo Lucrecia. Hurricane Ike emerged over the ocean south of Cuba during September 8. The hurricane moved northwest through the night and made its second landfall in Cuba on Pinar del Rio on September 9. The storm entered the Gulf of Mexico as a Category 2 hurricane and continued its course toward Galveston Island, TX. Hurricane Ike produced tropical force winds over portions of the Florida Keys, but did not make landfall. The path of the hurricane is shown in Figure 1-3.

According to the National Weather Service,[4] the storm continued its track northwest making its way to the Texas coastline. As it made its way across the Gulf of Mexico, a few unique characteristics associated with this storm started to take place. The central pressure slowly fell from 968 millibars (mb) upon entering the Gulf of Mexico to 944 mb by late on September 10. Although the decrease in central pressure generally indicates that the storm is intensifying, Hurricane Ike had unusually low sustained winds of 110 mph at that time. Another unique aspect was the large envelope of winds associated with Hurricane Ike. The hurricane continued to grow in diameter overnight. By 10 a.m. CDT on September 11, aircraft reconnaissance measured Ike's tropical storm wind swath to be approximately 450 miles wide, with a hurricane force wind swath of 180 miles. At that point, the National Oceanic and Atmospheric Administration (NOAA) issued a hurricane warning for the area between Morgan City, LA, and Baffin Bay, TX.

3 NWS Houston/Galveston office, http://www.srh.noaa.gov/hgx/projects/ike08/wind_analysis.htm

4 NWS Forecast Office, Lake Charles, LA, http://www.srh.noaa.gov/lch/ike/ikemain.php

Figure 1-3. Hurricane Ike storm track

On September 13 at 2:10 a.m. CDT, Hurricane Ike made landfall as a Category 2 hurricane on Galveston Island, TX, with reported sustained winds of 110 mph. Hurricane Ike made its final landfall at about 4:00 a.m. CDT near Baytown, TX.[5]

Hurricane Ike continued to move in a north and ultimately northeastern direction. By the afternoon of September 13, the hurricane was downgraded to a tropical storm by the NHC; it continued to weaken into a tropical depression before the center reached southwestern Arkansas later that evening. The storm continued its northeastern path, passing near St. Louis, MO, before it merged with a large cold front moving east across central United States. Hurricane Ike spawned a major wind event in the lower and middle Ohio Valley with strong wind gusts reported across parts of Kentucky, Indiana, Ohio, and Pennsylvania. Wind gusts of 75 mph were recorded in Columbus, OH.[6] According to American Society of Civil Engineers (ASCE) 7-05, *Minimum Design Loads for Buildings and Other Structures,* the design wind speed for the Ohio Valley is 90 mph (3-second gust).

5 NWS Houston/Galveston office, http://www.srh.noaa.gov/hgx/projects/ike08/wind_analysis.htm

6 Ibid.

1.2 Coastal Flooding

The area affected by Hurricane Ike is a low-lying region susceptible to flooding by hurricane storm surge and freshwater flooding during heavy rain events (e.g., Tropical Storm Allison, 2001). Flood Insurance Studies (FISs) and Flood Insurance Rate Maps (FIRMs) have been prepared for communities in the area since the 1970s and 1980s. A study is currently underway to update coastal flood hazard analysis and maps (the study was already in progress when Hurricane Ike struck).

1.2.1 Shoreline Characteristics

The region most directly affected by Hurricane Ike was from Brazoria County, TX, to Plaquemines Parish, LA, and adjacent inland areas. The eastern portion of the affected area, coastal Louisiana, is a low-lying chenier plain—intermittent sand ridges atop Mississippi River delta sediments, cut by tidal channels and embayments fringed with marsh. This plain extends west into eastern Texas, to the salt dome upon which the community of High Island sits. The shoreline from High Island, TX, to Freeport, TX, is composed of barrier islands of varying widths. The region landward of Galveston Island and Bolivar Peninsula is a large estuary known as Galveston Bay.

1.2.2 Subsidence

One factor that increases the vulnerability of the coastal region to hurricane storm surge is land subsidence—a lowering of the ground surface with respect to a fixed reference elevation. It can occur for a number of reasons, which vary geographically and over time (e.g., extraction of groundwater and hydrocarbon, tilt of underlying geologic strata, compaction of surface sediments, and interruption of natural delta sedimentation processes). Subsidence affects the entire region visited by the Ike MAT, from the Houston-Galveston region to coastal Louisiana. In portions of Texas, subsidence has been measured for over 100 years, and subsidence of several feet has been measured over a wide area; some land areas in Texas have dropped 10 feet in elevation since 1906 (see Figure 1-4). Subsidence rates in coastal Louisiana are also high, reaching 0.8 foot/decade in places.[7] Subsidence also complicates flood hazard mapping and can render some flood hazard maps obsolete before they would otherwise need to be updated.

7 Hurricane Katrina Flood Recovery (Louisiana), Questions and Answers about the Advisory Flood Elevations and the Katrina Recovery Maps. http://www.fema.gov/hazard/f ood/recoverydata/katrina/katrina_la_faqs.shtm

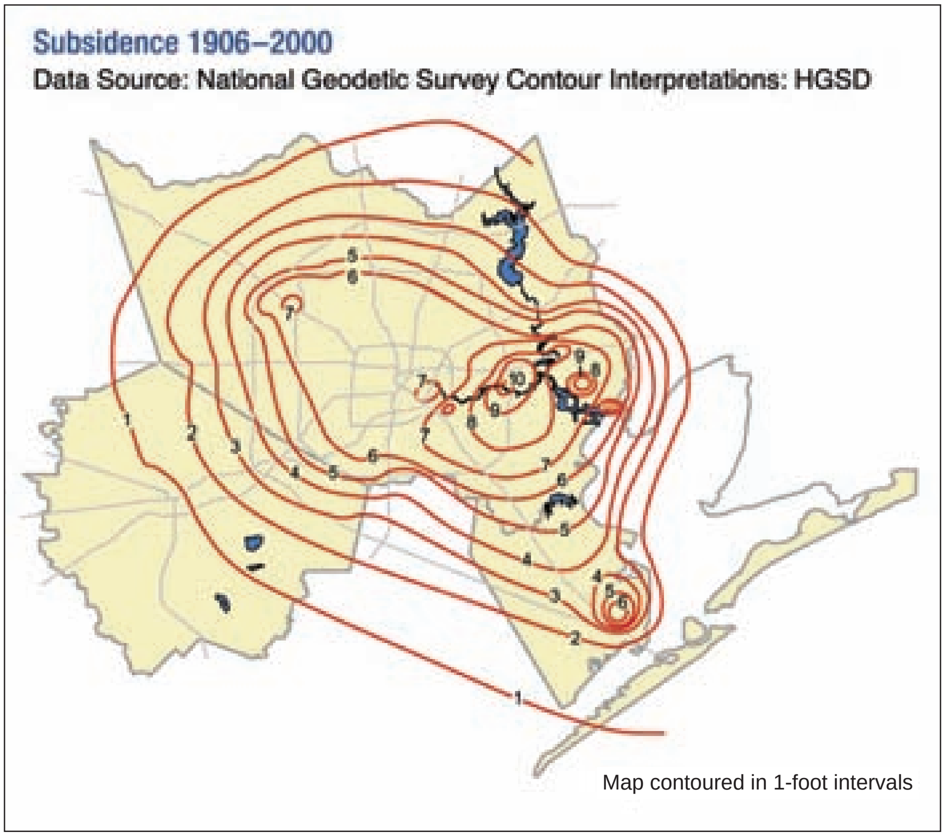


Figure 1-4. Land subsidence in the Houston-Galveston area, 1906–2000 (Harris-Galveston Subsidence District [HGSD], retrieved January 2009)

SOURCE: http://www.hgsubsidence.org/assets/pdfdocuments/HGSD%20Subsidence%20Map%201906-2000.pdf

1.2.3 Hurricane Ike High Water Marks

A total of 380 high water marks (HWMs) were surveyed by FEMA in Texas and Louisiana after Hurricane Ike. Figure 1-5 shows the locations of surveyed HWM in Texas, identifies each by type (stillwater, wave height, wave runup), and provides the elevation (grouped, in feet North American Vertical Datum [NAVD]).[8] Figure 1-6 provides HWM data for Louisiana. Appendix E of the report provides additional FEMA HWM maps and relevant data for Texas and Louisiana.

Based on the preliminary HWM survey data, some areas of southeast Galveston Bay may have been affected by water levels over 20 feet NAVD. The stillwater level is estimated to have been in the range of 17 feet NAVD in areas of Chambers County, TX, and averaged about 15 feet NAVD near the Bolivar Peninsula, TX.

IKE FLOOD LEVELS

Although data reviewed by the MAT indicated that the area f ooded by Ike exceeded the Effective Special Flood Hazard Area (SFHA), and Ike wave crest levels exceeded the Effective Base Flood Elevations (BFEs) by up to approximately 5 feet in east Texas and southwest Louisiana, Ike f ooding should not be considered a rare event. A new f ood study begun before Ike will likely show Ike f ood levels to be below the new BFEs for much of the affected area.

8 For this report, the FEMA and Harris County Flood Control District HWM elevations are in NAVD of 1988, 2001 adjustment. The U.S. Geological Survey (USGS) HWM elevations are in NAVD of 1988.

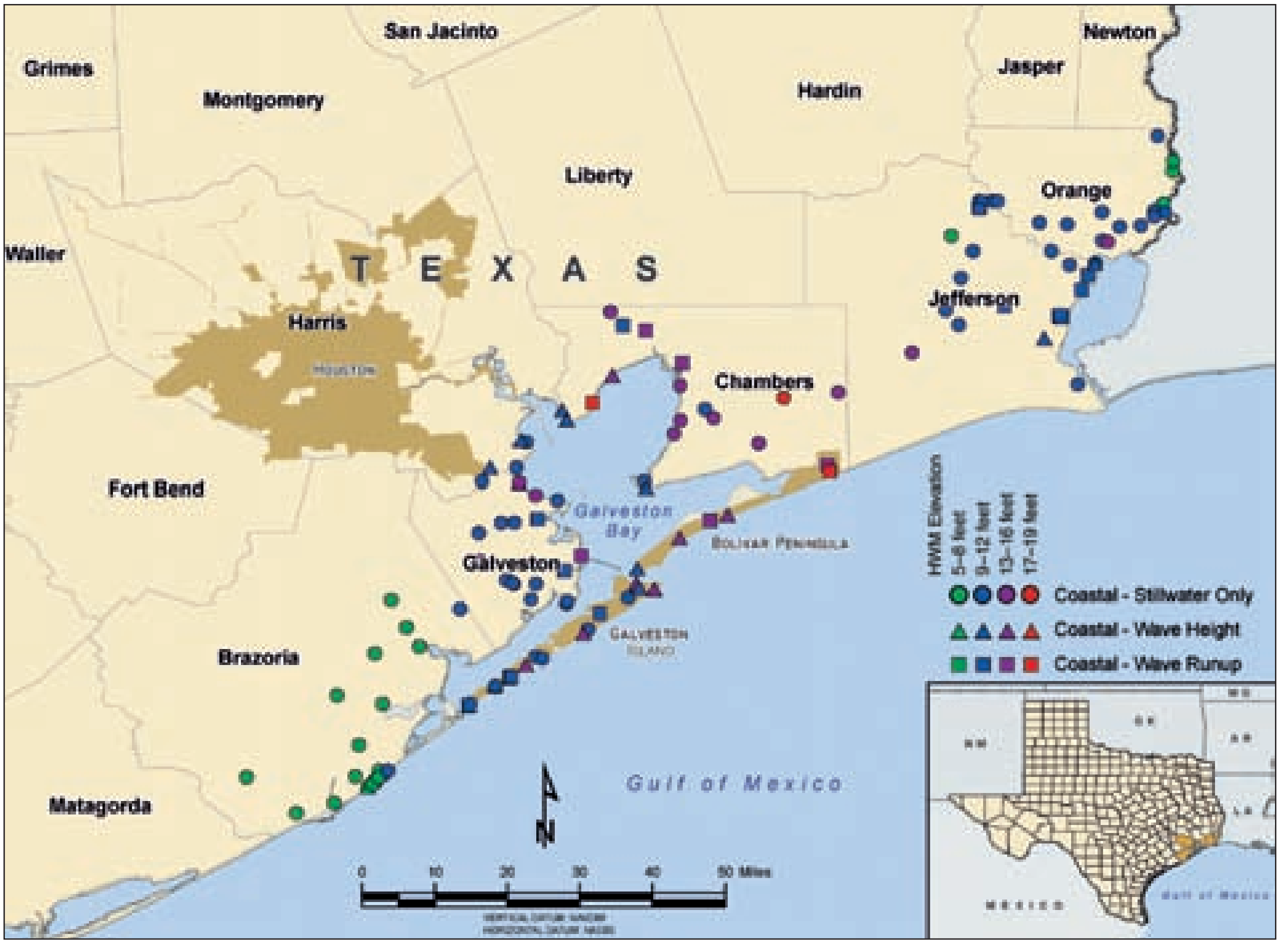


Figure 1-5. FEMA's surveyed locations of Hurricane Ike's HWMs in Texas

Based on preliminary results from the HWM surveys, southwestern areas of Cameron Parish, LA, may have been affected by water levels in the range of 12 feet. The stillwater level is estimated to have reached over 9 feet in the Lake Charles area of Calcasieu Parish.

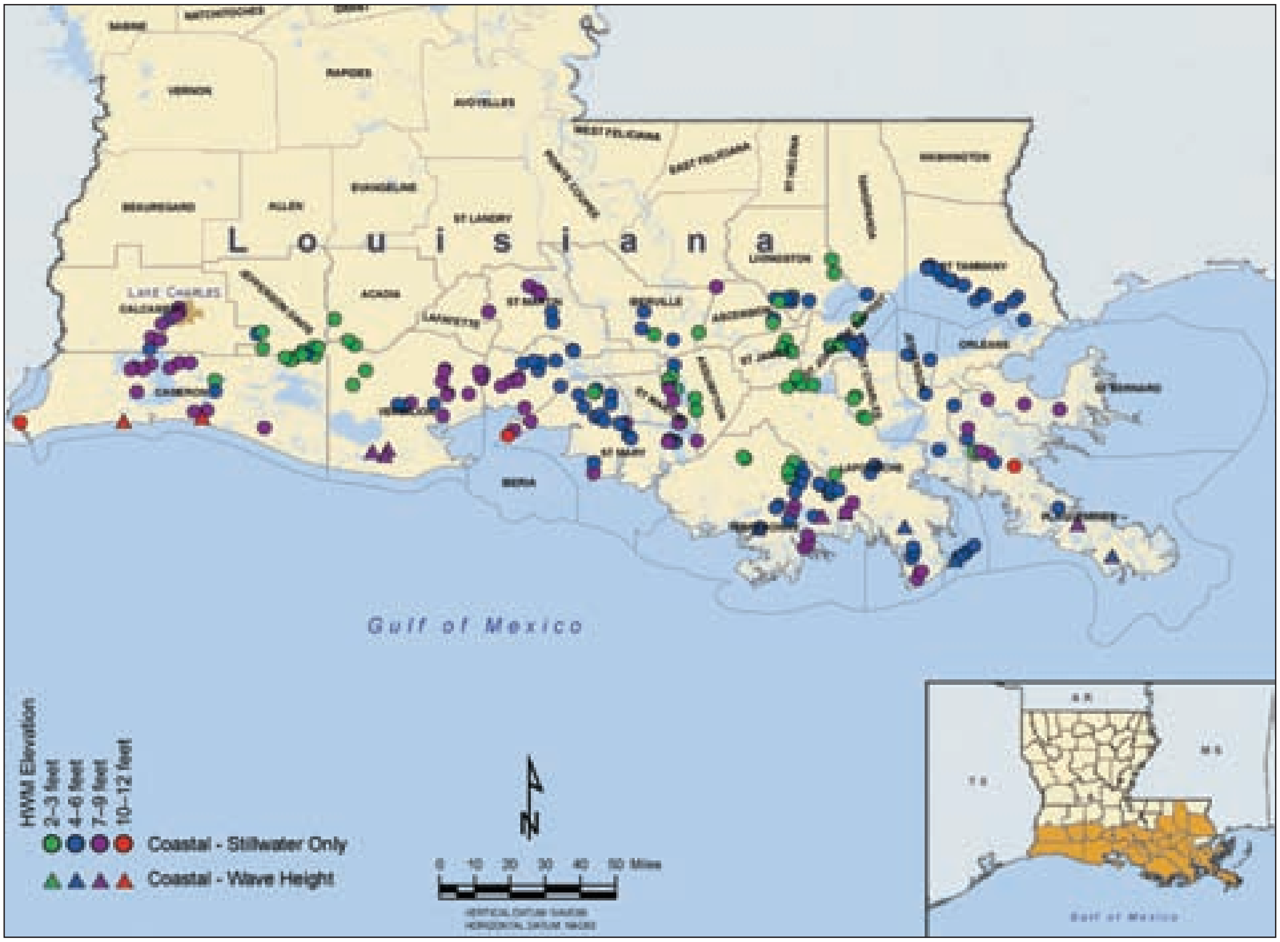


Figure 1-6. FEMA's surveyed locations of Hurricane Ike's HWMs in Louisiana

1.3 Wind Hazard Analysis and Discussion

Hurricane Ike came ashore along Galveston Island and the Bolivar Peninsula early morning on September 13, 2008, as a Category 2 storm with 1-minute sustained winds of 110 mph, according to the NWS October 5, 2008, report.[9] The NHC Tropical Cyclone Report states that the landfall intensity of 110 mph was determined from three different sources: 1) flight level winds of 120 mph using the standard 90 percent reduction to get the 10-meter, 1-minute average; 2) stepped Frequency Microwave Radiometer (SFMR) on the Hurricane Hunter Aircraft indicating 104 mph; and 3) Weather Surveillance Radar 88 Doppler System radar wind velocities from the NWS Houston/Galveston radar site that measured 130 mph at 6,500 feet above the ground

> Wind speed weather reporting stations include Automated Surface Observing Systems (ASOS), Coastal-Marine Automated Network (C-MAN), and portable meteorological towers deployed by universities or other agencies.

9 NWS Houston/Galveston office, http://www.srh.noaa.gov/hgx/projects/ike08/wind_analysis.htm

(Berg, 2009). Although the NHC Report does not specify where this wind speed was measured, it is likely to have been close to a point over the Gulf southeast of High Island, TX.

On land, reporting Automated Surface Observation System (ASOS) towers nearest the eye of the storm included Houston Hobby Airport and Bush Intercontinental Airport. Houston Hobby reported winds of 75 mph with gusts of 92 mph. Bush Intercontinental did not report hurricane-force winds despite the eye of Hurricane Ike passing reasonably close to the airport. Galveston Scholes Field stopped reporting prior to the passage of the hurricane's eye due to storm surge. Other reporting stations included Coastal Marine (C-MAN) stations located at lighthouses, piers, and offshore navigation platforms.

NOAA's Office of Atmospheric Research (OAR) uses a 1-minute averaging time for reporting sustained winds. The maximum sustained wind referenced in National Hurricane Advisories for tropical storms and hurricanes is the highest 1-minute surface wind occurring within the circulation of the system. The ASOS stations average and report their wind data over a 2-minute period, but no conversion factor is required to change a 2-minute average wind into a 1-minute average wind, since they are virtually the same speed. The "surface" winds are those observed or estimated to occur at the standard meteorological height of 33 feet (10 meters) in an unobstructed exposure (i.e., not blocked by buildings or trees).[10] Refer to the inset for the definition of wind exposure zones.

DEFINITION OF WIND EXPOSURE ZONES

Exposure B. Urban, suburban, wooded areas

Exposure C. Open terrain, f at open country, grasslands, all water surfaces in hurricane-prone regions

Normally, gusts are only a few seconds (3 to 5 seconds) of peak wind. Typically, in a hurricane environment, the value of the maximum 3-second gust over a 1-minute period is on the order of 1.3 times (or 30 percent higher than) the 1-minute sustained wind. ASCE 7-05 requires buildings to be designed using 3-second gust wind speeds (ASCE, 2005b).

In addition to aircraft, radar, and official monitoring stations, wind speeds were also obtained from portable land-based anemometers positioned along the storm's path. Portable units included five 10-meter towers operated by the Florida Coastal Monitoring Program (FCMP) and 18 towers (2.25-meter instrumented probes) provided by Texas Tech University (TTU). The highest land-based wind speed recorded by FCMP for Hurricane Ike was 116 mph, 3-second gust, recorded near Sea Breeze, TX, approximately 18 miles east of Anahuac, which is near the northeast corner of Galveston Bay. The highest speed recorded by TTU was also 116 mph, 3-second gust, recorded near Monroe City, which is approximately halfway between Anahuac and Sea Breeze, TX. The map in Figure 1-7 shows all of the stations and portable towers that reported data in Texas during Hurricane Ike. Table 1-2 provides a summary of the notable maximum recorded wind speeds. These data have been converted to 3-second gust wind speeds. Data has been adjusted for a 10-meter instrument elevation and Exposure C.

10 NOAA, "H*Wind Swath Hurricane Ike," http://www.atmo.ttu.edu/TTUHRT/HWindSwath.png

Figure 1-7. Locations of monitoring stations and portable towers that reported data in Texas during Hurricane Ike

Table 1-2. Notable Wind Speeds Recorded in Texas for Hurricane Ike

Data Collector	Location (Station type)	Wind Speed
Official Locations	FreePort (C-MAN)	93 mph
	Galveston Island east end (C-MAN)	93 mph
	Houston Hobby International Airport (ASOS)	98 mph
	Houston George Bush International Airport (ASOS)	95 mph
Universities deploying portable meteorological towers at various locations	LaPorte (FCMP T4)	102 mph
	Winnie (FCMP T5)	116 mph
	Baytown (FCMP T2 & T3)	110 mph
	Beaumont (TTU 108B)	103 mph
	Anahuac (TTU 103A)	106 mph
	Port Bolivar (TTU 110A)	94 mph
	Monroe City (TTU 104B)	116 mph

Note: Wind speeds provided are 3-second peak gusts measured at 33 feet (10 meters), Exposure C.

HURRICANE IKE'S WIND SPEEDS RELATIVE TO DESIGN WIND SPEEDS

Texas. Though Hurricane Ike's estimated wind speeds were less than design wind speeds given in the 2006 International Building Code (IBC 2006)/ASCE 7-05, the MAT observed widespread wind damage in the areas that were investigated. Most of the wind damage was to building envelopes (primarily roof coverings, rooftop equipment, and wall coverings). A few high-rise buildings in downtown Houston had extensive glazing damage.

Although a very large number of buildings (including residential, commercial, and critical facilities) were damaged, the damage was light to moderate at many of the damaged buildings. Wind damage was most pronounced along the Bolivar Peninsula, the eastern portion of Galveston Island, and areas bordering Galveston Bay.

Louisiana. Wind speeds in Louisiana were also less than the design wind speeds given in IBC 2006/ASCE 7-05, and they were much less than those in Texas. Estimated wind speeds ranged from 80 mph near the Texas-Louisiana border to 50 mph in Vermilion Parish. East of Vermilion Parish, estimated wind speeds were less than 50 mph. Although wind damage did occur in Louisiana, it was not as significant as the damage in Texas.

1.3.1 H*Wind

As a result of both non-functioning wind-measuring instruments and a lack of instruments in the hurricane's path (ASOS, C-MAN, and portable towers), few wind speed measurements reflect the actual strength of the storm. Thus, damage investigators and weather scientists estimate wind speeds based on a variety of methods, the most reliable being scientifically based wind models. The best known model in the public domain for estimating wind variations is H*Wind from NOAA's Hurricane Research Division (HRD). Based on past experience of comparing modeled estimates with actual recorded wind speeds, the H*Wind model provides reasonably accurate estimates of maximum wind speeds over significant areas impacted by a storm. Contours of the 1-minute sustained wind speeds from H*Wind analysis are shown in Figure 1-8. All wind speeds have been adjusted for a 10-meter instrument height and marine exposure over water or open terrain (Exposure C) over land.

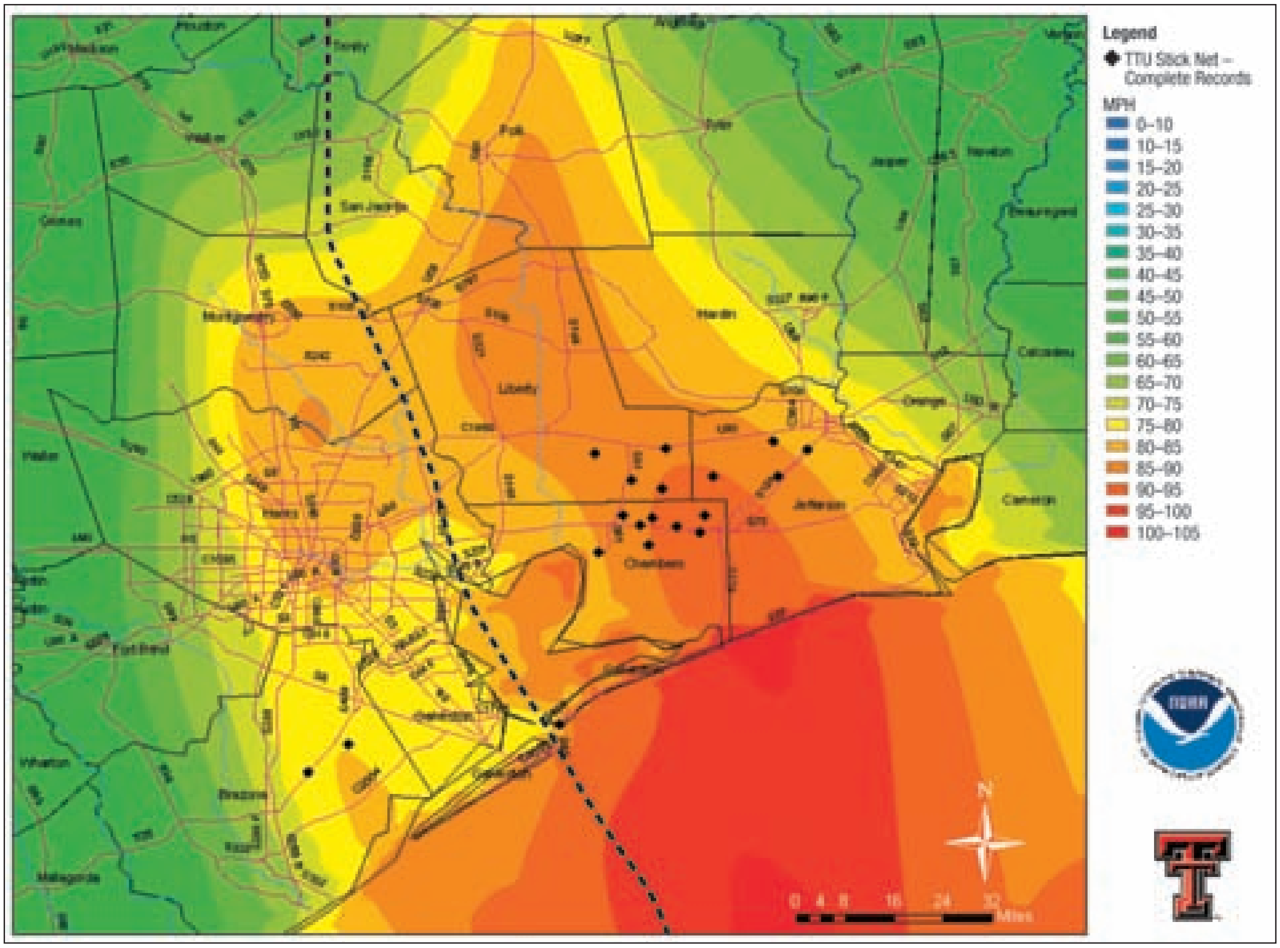


Figure 1-8.
Wind swath contour plot based on H*Wind analysis; wind speeds given in mph with contours of the 1-minute sustained wind speed
SOURCE: http://www.atmo.ttu.edu/TTUHRT/Ike.htm

1.3.2 HAZUS-MH

Another model for estimating wind speeds is FEMA's HAZUS-MH (Hazards United States-Multi-Hazard) loss estimation model, which produces reasonable estimates of maximum speed and lateral distribution of wind. Figure 1-9 is a wind swath contour plot of maximum 3-second gust wind speeds in mph at a height of 33 feet (10 meters) above ground (over land wind speeds are representative of open terrain conditions; over water wind speeds are representative of marine conditions) produced by Hurricane Ike in Texas and Louisiana based on HAZUS-MH wind field methodology and modeled by Applied Research Associates (ARA, 2008). Figure 1-10 portrays the estimated maximum peak gust winds nearest the eye of Hurricane Ike, radius of maximum winds.

The HAZUS-MH model for Hurricane Ike used weather data collected from the five FCMP portable towers, three C-MAN stations, and nine ASOS stations. The locations of these reporting stations are shown in Figures 1-9 and 1-10. The data are weighted and aggregated to develop a plot of the wind fields. The data collected from towers are influenced by ground exposure around the towers, which may differ from tower to tower. Given these conditions, the data from the towers are normalized for exposure and proximity to the storm path. Historically, these data have compared favorably with other modeled data.

Table 1-3 provides a summary of maximum recorded and modeled wind speeds for the sites investigated by the MAT. These data are 3-second gust wind speeds and have been standardized for 10-meter instrument heights and Exposure C. The conversion from Exposure B to Exposure C was made using an equivalent wind pressure calculation equation contained in ASCE 7-05.

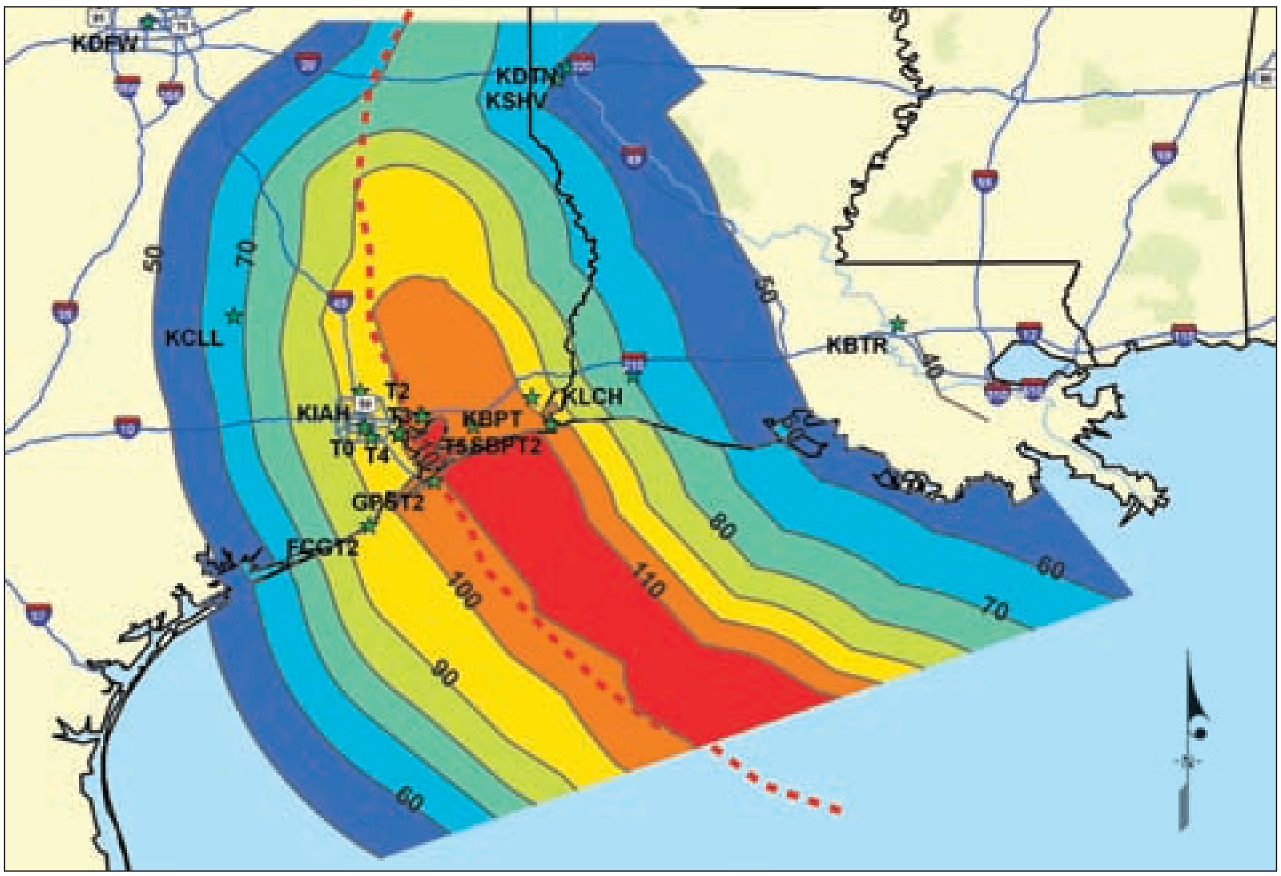


Figure 1-9.
Wind swath contour plot (3-second gust at 10-meter elevation [33 feet above ground level]) at Texas and Louisiana based on HAZUS-MH wind field methodology. Anemometer locations used in model verification are indicated by the stars.
SOURCE: ARA, 2008

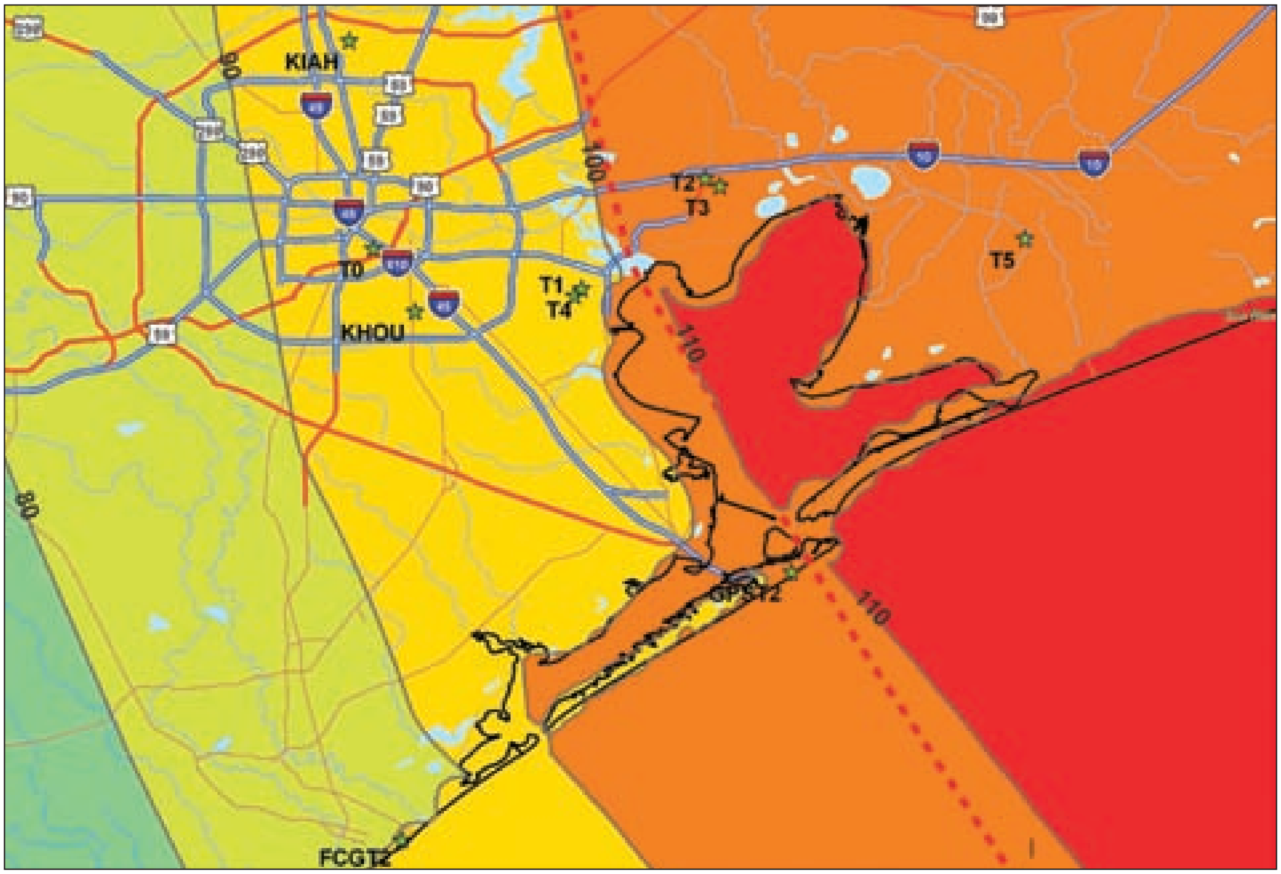


Figure 1-10.
HAZUS-MH-estimated maximum peak gust wind speeds near radius of maximum winds. Stars indicate anemometer locations used in model verification.
SOURCE: ARA, 2008

Table 1-3.
Estimated Maximum 3-Second Gust Wind Speeds for MAT Investigation Sites in Texas Based on Reporting Stations and HAZUS-MH Wind Model

Data Source	MAT Investigation Site	3-Second Gust Speed Estimate for Exposure C (Open Terrain)	3-Second Gust Speed* Estimate for Exposure B (Suburban Terrain)
Universities deploying portable meteorological towers at various locations	Anahuac	106 mph	90 mph
	Baytown	100 mph	85 mph
	Houston (City)	88 mph	75 mph
	Jamaica Beach	90–95 mph*	75–80 mph*
	LaPorte	102 mph	85 mph
	Port Bolivar	94 mph	80 mph
	Surfside	90 mph*	75 mph*
	Winnie	110 mph	95 mph
HAZUS-MH modeled data	Audubon Village**	110 mph	95 mph
	Beachtown	108 mph	93 mph
	Crystal Beach**	110 mph	95 mph
	Deer Park	95 mph	80 mph
	Galveston (City)	100–105 mph	85–90 mph
	High Island**	110 mph	95 mph
	Houston Central Business District	90–94 mph	75–80 mph
	Port Neches	90 mph	75 mph
	Texas City	105 mph	90 mph
	Tiki Island	103 mph	88 mph

* Calculated wind speeds, Exposure B—calculated from wind pressure conversions for components and cladding for buildings with a mean roof height of 33 feet (see ASCE 7-05, Table 6-3)

** Located on Bolivar Peninsula, TX

According to the HRD analysis, much of east Texas felt the brunt of hurricane force winds from the east side of the storm moving through Chambers and Jefferson Counties approximately 2 hours after Ike made landfall. Maximum sustained winds on the east side of the storm were between 92 and 98 mph. Three hours later, at 5:30 a.m. CDT (1030 Universal Time Coordinated [UTC]), Hurricane Ike had continued to push north and begun to weaken. Even though the maximum sustained winds decreased to 80 to 85 mph, hurricane force winds still covered much of Galveston Bay and Chambers County through the southern part of Hurricane Ike (Figure 1-11). Figure 1-11 also shows that Hurricane Ike still had hurricane force winds in the southern part of its core as shown by the red arrows, all of which contributed to the Galveston West Bay surge along the west end of the island and the wind damage noted on the north and western exposures of the building structures, as seen in Figure 1-12. Though the east side of a hurricane produces the highest wind speeds and surge levels, these graphics illustrate that damaging forces exist on the weaker west side of a storm.

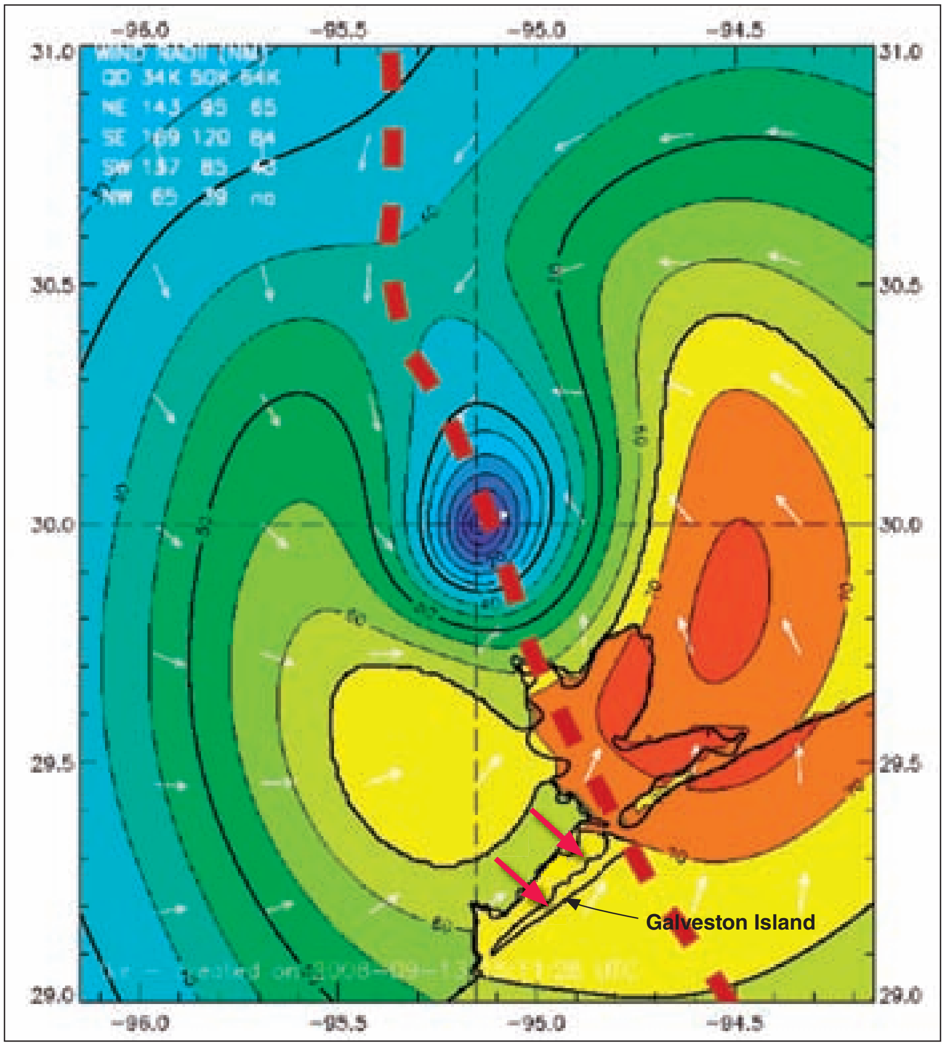


Figure 1-11.
Map showing 1-minute sustained winds 3 hours after Galveston landfall with continued high back bay winds
SOURCE: NWS, 2008

Hurricane Ike Tornadoes

According to the NHC Tropical Cyclone Report for Hurricane Ike, a total of 29 tornadoes associated with Hurricane Ike were reported in Arkansas, Florida, Louisiana, and Texas (Berg, 2009). Tornadoes spawned by hurricanes are normally in the lower range of intensity, EF0 or EF1 on the Enhanced Fujita (EF) Scale (65–110 mph); however, they frequently produce significant damage and even deaths. In this instance, no deaths were reported from the tornadoes.

Figure 1-12.
Roofing damage to north and west exposures produced by Hurricane Ike backside winds

1.4 Historic Hurricanes

The Texas and Louisiana coastlines have experienced many destructive hurricanes, with Hurricane Katrina being the most notable. The following section describes significant hurricanes that have damaged the Texas-Louisiana coastline beginning with the most recent, Hurricane Rita, and ending with the deadliest hurricane to affect the Galveston area, the Great Galveston Hurricane of 1900 (unless otherwise stated, information from NHC-NOAA).[11] Figure 1-13 shows the paths of the Great Galveston Hurricane and Hurricanes Audrey, Carla, Betsy, Celia, Allen, Alicia, Andrew, Katrina, and Rita. Table 1-4 shows the total estimated damages for each hurricane discussed in this section.

11 http://www.nhc.noaa.gov/HAW2/english/history.shtml and Tropical Cyclone Reports for specific hurricanes found at http://www.nhc.noaa.gov/pastall.shtml#tcr

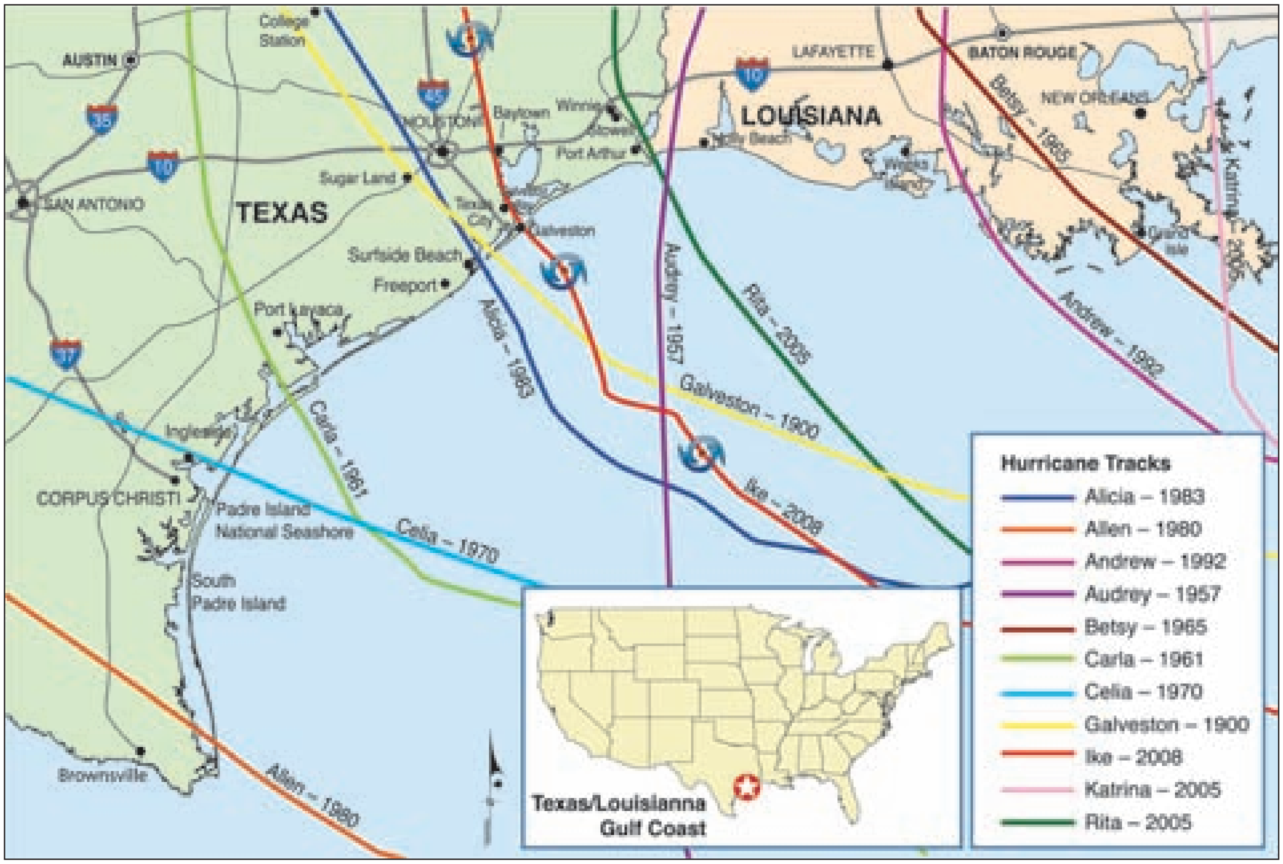


Figure 1-13. Hurricane tracks of significant historic hurricanes in Texas and Louisiana

Table 1-4. Damage Costs of Historic Hurricanes—Original and 2009 Dollars

Hurricane	Year	Original Cost of Damages ($ Million)	Cost of Damages in 2009 Dollars ($ Million)
Rita[1,2]	2005	16,000	18,000
Katrina[1,2]	2005	125,000	139,000
Andrew[1,2]	1992	27,000	41,000
Alicia[1,2]	1983	3,000	6,000
Allen[1]	1980	600	1,500
Celia[1]	1970	453	2,220
Betsy[1]	1965	1,400	8,300
Carla[1]	1961	325	2,020
Audrey[1]	1957	147	970
Galveston[3]	1900	30	770

Notes:

1 Conversion factor used is from Consumer Price Index Conversion Factors to Convert to 2007 Dollars Table from Oregon State, http://oregonstate.edu/cla/polisci/faculty-research/sahr/cv2007rs.pdf

2 Estimated cost from NOAA paper, Billion Dollar U.S. Disasters, 1980–2008 (January 2009), http://www.ncdc.noaa.gov/img/reports/billion/billionz-2008.pdf

3 Conversion factor used is from Consumer Price Index Conversion Factors 1774 to estimated 2018 to Convert to 2006 Dollars Table from Oregon State, http://oregonstate.edu/cla/polisci/faculty-research/sahr/cv2006.pdf

Hurricane Rita

Hurricane Rita struck the east side of the Texas-Louisiana border on September 24, 2005, as a Category 3 hurricane with 1-minute sustained winds of 115 mph. It produced storm surges 10 to15 feet above normal tide levels. The storm surge devastated coastal communities in southwestern Louisiana. Coastal areas of southeastern Louisiana were flooded by 4 to 7 feet of storm surge, including some areas that had already been impacted by the surge from Hurricane Katrina about 1 month earlier. Portions of the Florida Keys were inundated from the storm surge as well. Its winds, rain, and tornadoes caused fatalities and damages from eastern Texas to Alabama. A total of seven deaths and $16 billion worth of damage resulted from this storm.

Hurricane Katrina

Hurricane Katrina, which struck the U.S. coast on August 25, 2005, now ranks as one of the most destructive hurricanes in U.S. history for cost (No. 1), deaths (No. 3), and intensity (No. 3). Hurricane Katrina made its first U.S. landfall near Miami, FL, on August 25. The hurricane moved into the eastern Gulf of Mexico, and over the next 2 days it significantly strengthened to become a Category 5 hurricane. Hurricane Katrina made a second landfall on the Louisiana-Mississippi border as a Category 3 hurricane with 1-minute sustained winds of 127 mph at the Louisiana landfall and 120 mph 1-minute sustained winds at the Mississippi landfall. Storm surge flooding of 25 to 28 feet above normal tide level occurred along portions of the Mississippi coast and storm surge flooding of 10 to 20 feet above normal tide levels occurred along the southeastern Louisiana coast. This resulted in over 1,700 deaths and $125 billion in damages. It is ranked as the costliest hurricane in U.S. history.

Hurricane Andrew

Hurricane Andrew struck Florida and Louisiana in August 1992. With total damage estimates at $27 billion, Hurricane Andrew is the second costliest hurricane in the United States. It is also ranked as one of the 10 most intense hurricanes in the United States, with a minimum pressure of 922 mb (27.23 inches) (NOAA, 2007). On August 24, Hurricane Andrew made landfall over south Florida as a Category 5 hurricane with peak gusts of 164 mph. The hurricane continued westward into the Gulf of Mexico where it made its second U.S. landfall on August 26 on the central Louisiana coast as a Category 3 hurricane. Andrew produced a storm tide of at least 8 feet and inundated portions of the Louisiana coast. The total death toll was 65 people.

Hurricane Alicia

Hurricane Alicia, a Category 3 hurricane, struck southwest Galveston Island on August 17, 1983. Alicia had sustained winds over 96 mph with gusts of up to 125 mph along the coast. Hobby Airport at Houston reported 94 mph sustained winds with gusts to 107 mph. Hurricane Alicia is notable because it resulted in extensive glazing damage in high-rise buildings in downtown Houston (for further discussion of the glazing damage, see Chapter 5). Storm surges of 12.1 feet were recorded at Morgan Point along Galveston Bay. It is believed that a total of 17 people lost their lives in this storm.

Hurricane Allen

Hurricane Allen is one of the top five most intense storms in history. The storm became a hurricane on August 3, 1980, about 120 miles east of Barbados as it made its way westward across the Atlantic. On August 7, 1980, the storm became the strongest hurricane recorded at that time, with sustained winds of 185 mph and higher gusts and a central pressure of 899 mb (26.55 inches). Hurricane Allen made landfall as a Category 3 hurricane near Port Mansfield, TX, on August 10. The highest wind gust reported was from Port Mansfield, registering 138 mph. Storm surges reached 12 feet at Port Mansfield. A total of 34 tornadoes from this hurricane were known to have touched down across south Texas. About 300,000 people were evacuated. Seven died in Texas and 17 in Louisiana, with the majority of the deaths in Louisiana having occurred when a helicopter crashed trying to evacuate people from an offshore platform. Estimated damages in Texas and Louisiana were over $600 million at the time.

Hurricane Celia

On August 3, 1970, Hurricane Celia made landfall in Texas midway between Corpus Christi and Aransas Pass. Hurricane Celia had strong wind gusts estimated as high as 180 mph that far exceeded the hurricane sustained winds of 130 mph. The hurricane did not produce torrential rains and massive flooding over a large area as storms of this magnitude typically do. The heaviest storm rainfall was in the immediate Corpus Christi area, where 6 to 6.5 inches fell. Rains of 3 to 4 inches or less accompanied the hurricane along its path across south Texas. The major cause of destruction from this storm was from the extreme winds. The final estimate of damage was placed at $453 million. Nine deaths and 466 injuries were a direct result of the storm.

Hurricane Betsy

Hurricane Betsy was a major hurricane of the 1965 hurricane season tracking through the Bahamas and Florida before making landfall on September 9, 1965, as a Category 3 hurricane at Grand Isle, LA. Hurricane Betsy brought 160 mph gusts and a 16-foot storm surge that flooded the entire island. Winds gusted to 125 mph in New Orleans and a 10-foot storm surge caused major flooding. Winds in most of southeast Louisiana reached 100 mph and, in areas as far inland as Monroe, winds exceeded 60 mph. Offshore oil rigs, public utilities, and commercial boats all suffered severe damage, resulting in approximately $1.4 billion in damage in 1965 dollars. Seventy-six people lost their lives as a direct result of Hurricane Betsy, the first storm to cause $1 billion in damage.

Hurricane Betsy caused surge effects in Lake Pontchartrain that caused a section of the levee to fail, resulting in flooding within New Orleans in the Ninth Ward and in the Chalmette area of St. Bernard Parish. In most low-lying areas of the city, floodwaters reached to the roofs of houses, resulting in drowning deaths of some of those who had sought refuge from the floodwaters in their attics. Water levels receded after approximately 10 days. It is estimated that approximately 164,000 homes were flooded in Louisiana as a result of Hurricane Betsy. A new levee system, both higher and stronger than the former system, was constructed by the U.S. Army Corps of Engineers (USACE) and protected New Orleans from Hurricane Camille's storm surge in 1969.

Hurricane Carla

Hurricane Carla hit Texas on September 11, 1961. Carla ranks among the top 30 costliest and most intense hurricanes on record (NHC, 2007). A Category 5 hurricane at its peak, it was a Category 4 when it struck Port O'Connor and Port Lavaca, TX. The highest maximum sustained winds for Hurricane Carla were recorded at 175 mph, 1-minute sustained; the hurricane had storm surges of 22 feet. Approximately 250,000 people evacuated Texas. This hurricane also spawned 26 tornadoes through its path. Damages at the time were estimated at $325 million. Because of the large, effective evacuation, there were only 43 deaths due to this hurricane.

Hurricane Audrey

Hurricane Audrey, a Category 4 hurricane, hit Louisiana and eastern Texas with winds of 145 mph, 1-minute fastest-mile and storm surges of 6 feet on June 27, 1957. The highest surge was measured at 12.4 feet west of Cameron, LA. Two tornadoes in New Orleans and Ardaudville, LA, were reported. Audrey also spawned 23 tornadoes in Mississippi and Alabama. Its destruction continued through the Ohio Valley, Pennsylvania, New York, and Canada with severe rainfall, flooding, and winds of up to 80 mph, 1-minute fastest-mile. Audrey caused approximately 600 casualties and $147 million of damage.

Great Galveston Hurricane

The deadliest hurricane in U.S. history was the Great Galveston Hurricane that occurred September 7 to 8 in the year 1900. This hurricane claimed approximately 8,000 lives. The population of Galveston in 1900 was approximately 37,000. This hurricane traveled the Caribbean as a tropical storm before making landfall across the southern United States where it hit Florida, Mississippi, Louisiana, and Texas. The hurricane then traveled through central United States and up through the Great Lakes making its way through Canada. The Great Galveston Hurricane was classified as a Category 4 at landfall, with sustained winds of 100 mph and gusts over 125 mph. The minimum central pressure was 931 mb or 27.49 inches of mercury. The monument shown in Figure 1-14 commemorates the Great Galveston Hurricane; plaques around the statue were destroyed by Hurricane Ike.

The storm surge and high water level from the Great Galveston Hurricane washed out the four bridges linking Galveston to the mainland and downed telephone lines, cutting off the island from the mainland. The highest land elevation on Galveston Island in 1900 was 8.7 feet; the storm surge reached 15 feet. The damage to property was about $30 million. The horrific devastation of the hurricane propelled the people of Galveston to find a way to protect themselves against another disaster of this magnitude. Construction of a 17-foot-high seawall began in 1902 to protect 3 miles of oceanfront and raise the city portion of the island by 8 feet. Sand was dredged from Galveston Bay to elevate the island. A memorial to the construction of seawall was erected after construction was completed; the monument was damaged by Hurricane Ike (Figure 1-15).

Figure 1-14.
Plaques near the Great Galveston Hurricane Memorial were destroyed by Ike

Future Hurricanes

Based on the history of hurricanes in this area, hurricanes of at least the same intensity can be expected to occur in the future. However, subsidence, shoreline retreat, and sea-level rise may increase the damaging effects of future hurricanes in some areas.

Figure 1-15.
The memorial capstone was moved off center by Ike

1.5 FEMA Mitigation Assessment Teams

Along with responding to disasters and providing assistance to people and communities affected by disasters, FEMA conducts building performance studies after disasters in order to better understand how natural and manmade events affect the built environment. The intent of the studies is to reduce the number of lives lost to these events and minimize the economic impact on the communities where these events occur. Also, lessons learned are applied to the rebuilding effort after disasters to enhance the disaster-resistance of new construction and building repairs using recommendations provided in the MAT report. The MAT studies the adequacy of current building codes, other construction requirements, and building practices and materials.

Following a Presidentially declared disaster, FEMA determines the potential need to deploy one or more MATs to observe and assess damage to buildings and structures, as caused by wind, rain, and flooding associated with the storm. FEMA bases this need on estimates from preliminary information of the potential type and severity of damage in the affected area(s) and the magnitude of the expected hazards. These teams are deployed only when FEMA believes the findings and recommendations derived from field observations will provide design and construction guidance that will not only improve the disaster resistance of the built environment in the impacted State or region, but will also be of national significance to all disaster-prone regions.

1.5.1 Purpose of the MAT

In response to a request for technical support from FEMA's Joint Field Office in Austin, TX, and the Transitional Recovery Office in New Orleans, FEMA's Mitigation Division deployed a MAT to Texas and Louisiana on October 15, 2008, to evaluate both building performance during Hurricane Ike and the adequacy of current building codes, other construction requirements, and building practices and materials. One of the major objectives of the MAT is to provide recommendations that can help reduce future damage from natural disasters.

The flood levels for Hurricane Ike exceeded the current design flood event (i.e., 100-year base flood event) in localized areas in Texas and Louisiana, as illustrated on the FEMA FIRMs. The wind speeds from Hurricane Ike were less than the design speeds prescribed in IBC 2006/ASCE 7-05.

FEMA was interested in the performance of new construction, hurricane-resistant homes on the Bolivar Peninsula, and residential structures and critical facilities that received FEMA mitigation funding, as well as houses in communities requiring freeboard. Of particular interest was the issue of sustainability and how it relates to rebuilding efforts. The MAT was also tasked with evaluating the performance of approximately 40 buildings on Galveston Island that were previously evaluated by TTU.

1.5.2 Team Composition

The MAT included FEMA Headquarters and Regional Office engineers and experts, technical consultants, and construction industry experts. Team members from FEMA's database of national experts included structural engineers, architects, wind engineers, civil engineers, and coastal scientists. In addition, there were representatives from the American Institute of Architects (AIA), the American Planning Association (APA), the Institute for Business and Home Safety (IBHS), the International Code Council (ICC), the National Association of Home Builders (NAHB), the Texas Association of Builders, the Vinyl Siding Institute (VSI), and TTU. In response to the unique situation presented by the substantial flooding in both Texas and Louisiana, a separate flood team was deployed for each State.

The MAT received invaluable support from independent Texas and Louisiana home builders and guides that assisted the MAT. They accompanied the MAT through many of the affected areas, providing valuable insights regarding local construction practices.

1.5.3 Methodology

Five days after Hurricane Ike struck the Texas/Louisiana Gulf Coasts (September 18 and 19), preliminary field investigations were performed by MAT members to assess overall building damage in limited areas of Texas. This investigation was tasked to observe and record perishable damage data and to locate damaged areas requiring further investigation. This survey included ground surveillance and aerial reconnaissance in the areas shown in Figure 1-16. The initial leg of the aerial reconnaissance focused on downtown Houston to look at window breakage in high-rise buildings (such as the JP Morgan Chase Building) and the Galleria area to observe roof and glazing damage. From the downtown area, the reconnaissance proceeded to the coastal areas starting at Surfside Beach and continuing along the beach side of Galveston Island, across the channel and up the Bolivar Peninsula to High Island. The return leg included observation of the bayside damage of the Bolivar Peninsula, San Leon, Seabrook, and LaPorte.

Figure 1-16. Flight plan for pre-MAT aerial reconnaissance

Based on findings from the preliminary field investigation, FEMA decided to deploy the full MAT. Consequently, the MAT was deployed on October 15 for 1 week. The MAT was separated into three teams: a flood team for Texas, a wind team for Texas, and a flood team for Louisiana.

The Texas MATs conducted extensive ground observations from October 16 through October 21, 2008, in the following locations:

- Brazoria County: Surfside Beach
- Galveston County: Galveston Island, Bolivar Peninsula, and cities and towns along Galveston Bay on the mainland
- Harris County, including downtown Houston
- Chambers County
- Orange County

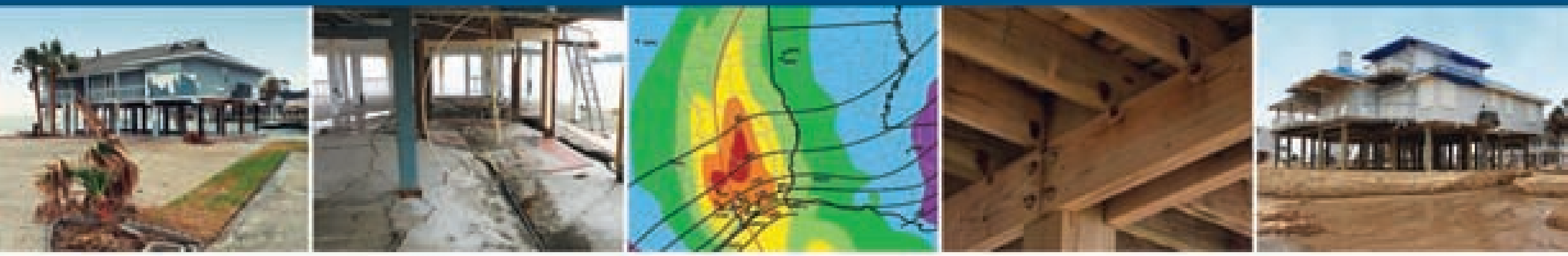
The Louisiana MAT conducted observations from October 15 through October 20, 2008, in the following parishes:

- Calcasieu
- Cameron
- Vermilion
- Iberia
- St. Mary's
- Terrebonne
- Lafourche
- Jefferson

Figure 1-17 provides details on the locations visited by the MAT in Texas and Louisiana.

Figure 1-17. Locations visited by the MAT in Texas and Louisiana

Damage was observed to single- and multi-family buildings, manufactured housing, commercial buildings, and historic buildings. In addition, critical facilities, such as Emergency Operations Centers (EOCs), fire and police stations, hospitals, nursing homes, and schools were also evaluated in order to document building performance as well as loss of function from Hurricane Ike. Documentation of observations is presented in this report. Photographs and figures are included to illustrate building performance in the wind field and surge areas produced by Hurricane Ike. The conclusions and recommendations of the MAT's findings will assist in minimizing damages from future hurricanes.



Larry Tanner
Chris Jones
Dave Low
Wallace Wilson

HURRICANE IKE IN TEXAS & LOUISIANA

2 Floodplain Management Regulations, Building Codes, and Standards

Floodplain management regulations, building codes, and standards are adopted and enforced to regulate construction in at-risk areas.

The floodplain management regulations applicable to the areas affected by Hurricane Ike are discussed in Section 2.1. Section 2.2 presents the building codes and standards specific to floods and wind used to regulate construction. Section 2.3 discusses the Texas Windstorm Program. Section 2.4 discusses enhanced code construction.

2.1 Floodplain Management Regulations

National Flood Insurance Program regulations form the basis of a community's efforts to guide development in flood hazard areas. These regulations are incorporated into a community's floodplain management ordinance, and have been integrated into national consensus standards

(ASCE 7 and ASCE 24) and model building codes that are adopted by communities. Figure 2-1 illustrates the process by which NFIP regulations flow to an individual building.

All the Texas and Louisiana communities visited by the MAT participate in the NFIP, have adopted floodplain management regulations that meet or exceed minimum NFIP requirements, and are governed by minimum building and performance standards or a model building code (see Section 2.2), so the process outlined in Figure 2-1 applies. These communities have two avenues for enforcing flood-resistant design and construction practices: the floodplain management ordinance and the minimum standards/building code. To address the flood coordination issues between the floodplain management ordinance and the building standards/code, communities may wish to refer to FEMA 9-0372, *Reducing Flood Losses Through the International Codes: Meeting the Requirements of the National Flood Insurance Program* (December 2008).

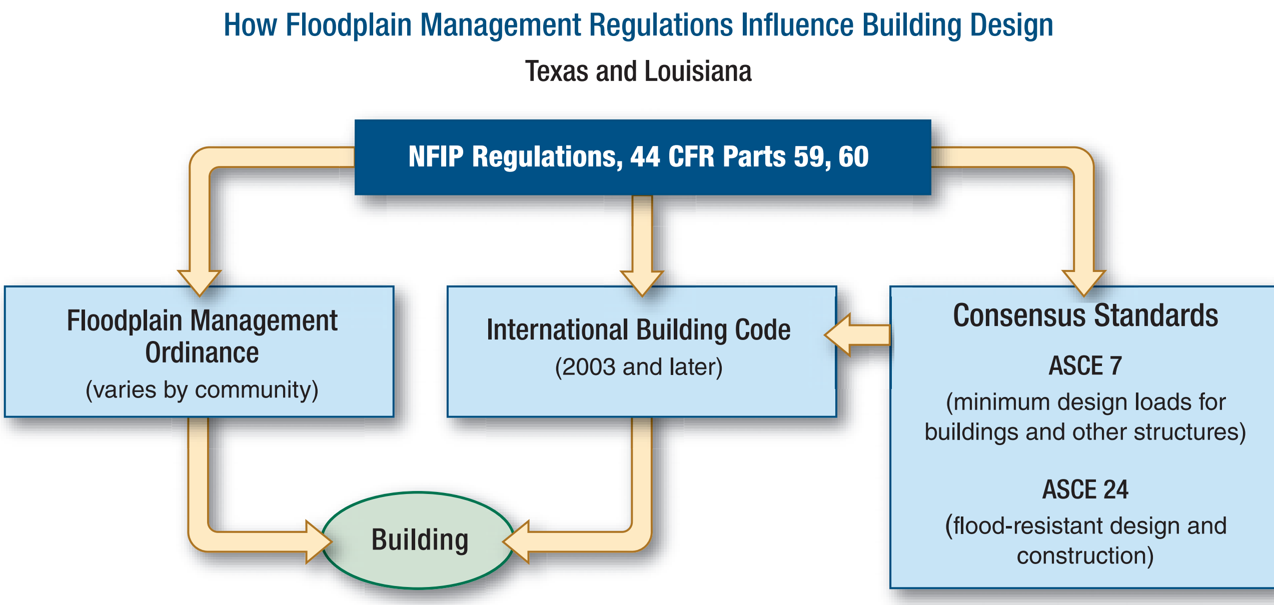


Figure 2-1. Floodplain management regulations and building design in communities with adopted building codes

2.1.1 Flood Studies and Flood Maps

FEMA and its mapping partners conduct FISs to create and update FIRMs. FIRMs identify areas of varying flood hazard as flood zones. Zones A and V comprise the area known as the SFHA. Locations designated as SFHAs have a 1-percent annual chance, or greater, of being inundated by flooding in any given year. The 1-percent annual chance flood is also referred to as the "base flood" or the "100-year flood." Areas that flood less frequently than the SFHA are also shown on FIRMs. The Shaded Zone X (old map designation Zone B) indicates the area that has between a 1-percent and 0.2-percent annual chance of flooding (this is commonly described as the area subject to flooding between the 100-year and 500-year floods). The Unshaded Zone X (old map designation Zone C) indicates the area that has less than a 0.2-percent annual chance of flooding.

FIRMs show BFEs in Zone V, and Advisory Base Flood Elevations (ABFEs) represent the minimum elevation to which the lowest floors of buildings must be elevated. When a community joins the NFIP and adopts its FIRM, the community is also adopting minimum building floor elevations and other floodplain standards required by the NFIP. Figure 2-2 shows the relationship between stillwater elevations, BFEs, and wave effects.

The FIRM zone designation and the BFE are critical factors in determining which requirements apply to a building and, as a result, how it is built. For example, the NFIP minimum requirements for buildings built in Zone V (Coastal High Hazard Areas) are:

1. Building must be elevated on pile, post, pier, or column foundations (refer to Section 3.1.1.1)
2. Building must be adequately anchored to the foundation (refer to Section 3.1.1.3)
3. Building must have the bottom of the lowest horizontal structural member supporting the lowest floor at or above the BFE (Figure 2-3)
4. Building design and method of construction must be certified by a design professional
5. The area below the BFE must be either free of obstructions or have breakaway construction in the form of non-supporting breakaway walls, lightweight open lattice or louvers, or insect screening (refer to Section 3.3.1)

In Zone A, the NFIP only requires that the top of the lowest floor of a building be at or above the BFE. There are no standards for foundations other than the general performance standard that the building be anchored to resist floatation, collapse, and lateral movement; any type of foundation that meets this performance standard is permitted by the NFIP. Also, in Zone A, the NFIP permits non-residential buildings to be floodproofed, with their walls made substantially impermeable to the passage of floodwater.

DESCRIPTION OF FLOOD ZONES

Zone V. 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 (3 feet and higher) from storms or seismic sources. The FIRMs use Zones VE and V1-30 to designate these Coastal High Hazard Areas.

Zone A. The portion of the SFHA not mapped as Zone V. Although FIRMs depict Zone A 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, Zone A is subject to wave heights less than 3 feet and wave runup depths less than 3 feet.

Coastal A Zone. The Coastal A Zone is an area within Zone A that is shown as an advisory layer on newer digital FIRMs (DFIRMs) using the Limit of Moderate Wave Action (LiMWA) line. Flood forces in the Coastal A Zone are not as severe as in Zone V, but are still capable of damaging or destroying buildings on shallow foundations. During base flood conditions, the potential for wave heights is greater than or equal to 1.5 feet, but less than 3.0 feet. For this reason, different design and construction standards are recommended (by the MAT and others) in the Coastal A Zone than in the riverine Zone A. Coastal A Zone provisions are included in ASCE 24-05 and ASCE 7-05, which are referenced by model building codes.

Shaded Zone X. Areas having between a 1-percent and 0.2-percent annual chance of flooding.

Unshaded Zone X. Areas with less than 0.2-percent annual chance of flooding.

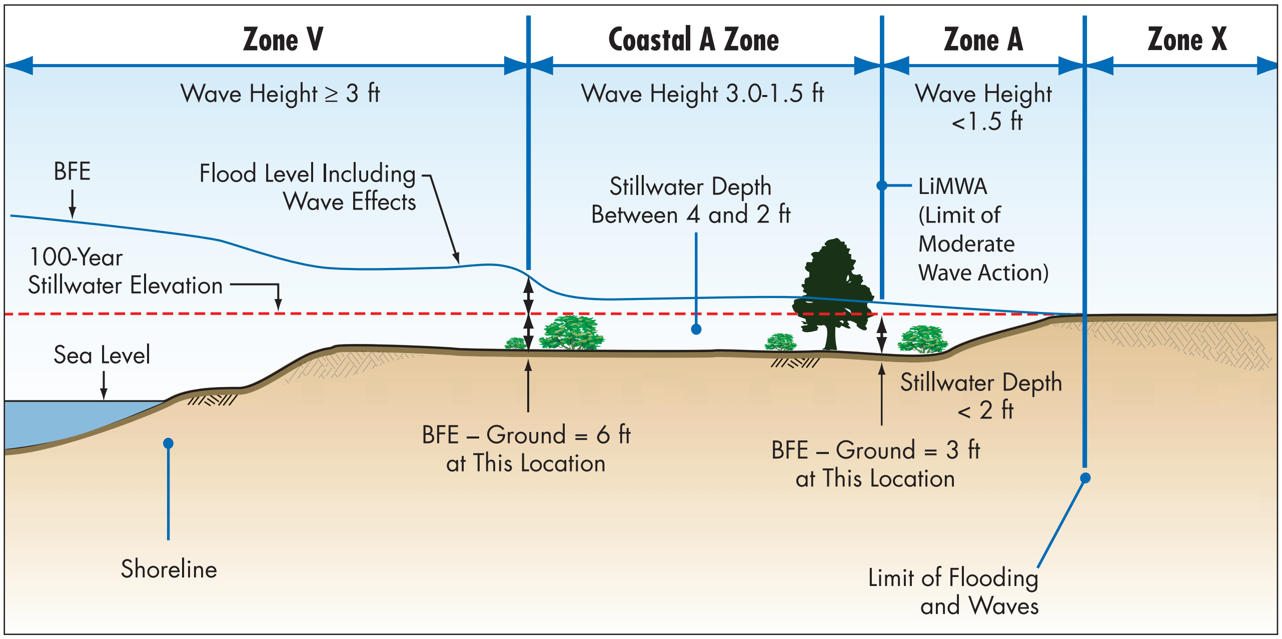
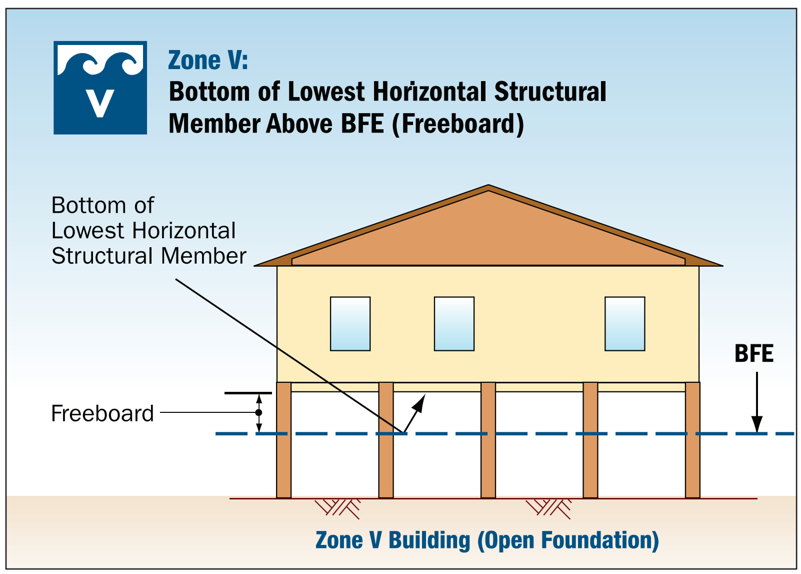


Figure 2-2. Relationship between the stillwater elevations, BFE, wave effects, and flood hazard zones

Figure 2-3.
Elevation of residential structures to the BFE is required in Zone V. The MAT recommends elevating higher, or adding freeboard (see Sections 2.1.1.3, 3.1.3, and 7.1.1).



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 the SFHA.

2.1.1.1 Accuracy of Flood Insurance Studies and Flood Insurance Rate Maps

It is important to note that the limits of the SFHA, the area over which floodplain management regulations apply, have changed over the past three decades as new FISs have been completed, BFEs have been changed, and new FIRMs have been issued. These changes affect the lowest building floor elevations mandated within the SFHA.

Any SFHA and BFE changes are generally the result of one or more of the following:

- **Changed conditions on the ground**
  - FISs and resulting FIRMs are based on physical, hydrologic, and hydraulic conditions existing at the time of the study. They do not anticipate or account for future changes in conditions (e.g., shoreline erosion, land subsidence, changed drainage patterns, etc.). Thus, as conditions change over time, the lateral and vertical extents of the base flood will deviate from those shown on the FIRM, and the FIRMs may no longer represent the best estimate of the SFHA and BFE.

> FEMA's *Community Status Book* provides the date of the effective FIS and FIRM for all mapped communities (http://www.fema.gov/fema/csb.shtm).
>
> The FIS and FIRMs can be viewed through the *Product Catalog* at FEMA's Map Service Center site. (http://msc.fema.gov/).

- **A longer period of record with which to characterize regional hurricane characteristics**
  - FISs and resulting FIRMs are based on the record of hurricanes at the time the study is conducted. Statistical distributions of important storm parameters (e.g., central pressure, radius to maximum winds, forward speed, direction, etc.) are developed from the record and are used as inputs to storm surge models. As time passes, more and more hurricanes occur that may not be represented in our statistics, and the FIRM becomes a less accurate predictor of the base flood.

- **New flood study models and procedures**
  - All FIRMs are generated using available topographic and land use data, and FEMA-approved study procedures and models. Those data, procedures, and models, however, are imperfect. They approximate the terrain and the physical processes that occur during a flood event. In an effort to improve map accuracy, FEMA, States, and communities now gather more accurate topographic and land use data than in years past. Also, FEMA has updated study procedures and models over the years to improve their ability to represent dune erosion, storm surge propagation, and wave effects. Taken together, improved terrain data and study methods used now yield more accurate BFE and SFHA estimates than in years past. However, even newer maps created with improved models and procedures have some uncertainty. This uncertainty can be addressed by adopting beyond-minimum flood-resistant design and construction practices, such as requiring freeboard (ASCE 24 is one source for guidance on freeboard).

> A new FIS for southwest Louisiana was just completed using the latest data, procedures, and models, and preliminary DFIRMs were released between January and November 2008 (see http://www.la-mappingproject.com/).
> A new FIS for coastal Texas is now underway, and preliminary DFIRMs are expected to be released within a year.

2.1.1.2 Implication of FIRMs on Rebuilding and Building Safety

It is important to understand the limitations of FIRMs when considering reconstruction or new construction after a storm. The information described in Section 2.1.1.1 has the following implications for communities and homeowners:

- Since BFEs shown on future FIRMs may be higher, buildings constructed to elevations shown on Effective FIRMs may be constructed at elevations below those future BFEs.
- Buildings originally constructed outside the SFHA may be located within future SFHAs, but without the benefit of flood-resistant construction techniques.
- Even if the FIRM predicted flood levels perfectly, buildings constructed to the elevations shown on the FIRM will offer protection only against the 1-percent annual chance flood level (BFE). Some coastal storms will result in flood levels that exceed the BFE, and buildings constructed to the minimum elevation could sustain flood damage.

2.1.1.3 Higher Regulatory Standards

One of the most effective ways to compensate for future conditions, changed flood hazards, and floods exceeding the 1-percent annual chance flood level is to elevate buildings above the BFE shown on the FIRM at the time of construction. This practice is called "adding freeboard," and it not only reduces future flood damage, but results in significantly lower flood insurance premiums.

FREEBOARD

Some communities visited by the MAT require freeboard above the BFEs

- Texas Floodplain Management Association's freeboard survey is available at http://www.tfma.org/.
- The eight Louisiana parishes visited by the MAT have adopted freeboard consistent with Rita or Katrina Flood Recovery and ABFE maps (http://www.lamappingproject.com/).

A comprehensive study of freeboard (American Institutes for Research, 2006) demonstrated that adding freeboard at the time of house construction is cost-effective. Reduced flood damage yields a benefit-cost ratio greater than 1 over a wide range of scenarios, and flood insurance premium reductions make adding freeboard even more beneficial to the homeowner. Reduced flood insurance premiums will pay for the cost of incorporating freeboard in a Zone V house in 1 to 3 years; in a Zone A house, the payback period is approximately 6 years.

2.2 Building Codes and Standards

Model building codes have long included requirements for designers to identify anticipated environmental loads and load combinations, including wind loads, seismic loads, snow loads, and soil conditions. The 2000, 2003, and 2006 editions of the IBC and the International Residential Code (IRC), and the 2003 and 2006 editions of the National Fire Protection Association's (NFPA) *Building Construction and Safety Code* (NFPA 5000) are the first model codes to include comprehensive provisions that address flood hazards. These codes are consistent with the minimum provisions of the NFIP that pertain to the design and construction of buildings.

> **NOTE**
>
> The 2009 edition of the IRC will require 1 foot of freeboard in Zone V and the Coastal A Zone.

International Building Code

The IBC is a performance and prescriptive code that, for the most part, requires buildings and structures to be individually designed to meet the requirements of the code and various referenced standards. The two referenced standards (ASCE 7-05 and ASCE 24-05) that include provisions pertaining to flood hazards are briefly described in Sections 2.2.1.2 and 2.2.1.3. According to Mehta et al., (2007, pg. 32), in a performance code, the performance criteria of a component are specified instead of the material or the construction system. The performance criteria are based on the function of the component. The older and traditional types of building codes are prescriptive codes. Such codes give the prescription for construction systems, types of materials, and the devices to be used without permitting any alternatives.

International Residential Code

The IRC addresses environmental loads in a more prescriptive approach so that many one- and two-family houses can be built without individual designs prepared by architects and engineers.

Texas Statewide Residential Building Code

The statewide residential building codes in Texas are the 2000 IRC and the 1999 National Electrical Code (NEC). These, however, may be amended in local jurisdictions if they have updated the code provisions. The code that applies to an unincorporated area is the same code adopted by the county seat. If the county seat has not adopted an updated version of the code, then the 2000 IRC applies and code enforcement falls under the jurisdiction of the Texas Residential Construction Commission (TRCC).

Texas Residential Construction Commission

The TRCC develops and maintains building and performance standards for residential construction in Texas. These standards are not the same as a building code. A building code dictates how a builder must build a house. The building and performance standards apply to how a house must perform after it is built. The commission-adopted building and performance standards apply to residential construction that began in Texas on or after June 1, 2005. Residential construction completed before June 1, 2005, is governed by the standards applicable to the project at the time of the construction. The commission-adopted standards include compliance with the 2000 IRC and the 1999 NEC (TRCC, 2005).

In August 2008, the Texas Sunset Advisory Commission, which was created in 1977 by the Legislature to identify and eliminate waste, duplication, and inefficiency in government agencies, called for the TRCC to be abolished and stated that its "current regulation of the residential construction industry is fundamentally flawed and does more harm than good" (Dallas Business

Journal, 2008). On September 1, 2008, in response to the Sunset Advisory Commission, the TRCC began enforcing an amendment to the Texas Register that had been previously approved in February 2008. This amendment requires the enforcement of the IRC for residential construction completed by builders and remodelers in unincorporated areas or in areas not subject to municipal inspections to have a minimum of three inspections: 1) a foundation inspection; 2) a framing, mechanical, and delivery systems inspection; and 3) a final inspection.[1] This three-step process provides inspection by a qualified third-party architect, engineer, or building official and is intended to ensure compliance with the requirements of the IRC. However, unincorporated areas of Texas are not required to complete plan review, residential building design review, or building inspection by a State or county building official.

Louisiana Statewide Uniform Construction Code

The Louisiana Legislature enacted Act 12 of the 2005 First Extraordinary Session to provide for a State uniform construction code to govern new construction, reconstruction, and additions to previously constructed homes in 11 coastal parishes. Act 12 mandated adoption of the latest editions of the IBC and IRC (subject to some amendments by the State) and created the Louisiana Statewide Uniform Construction Code Council (LSUCCC) to update statewide code as new editions of the IBC and IRC are published.[2]

2.2.1 Flood Requirements

The following discussion provides information regarding flood requirements in building codes and the national consensus standards that are incorporated into the codes. The flood-related code provisions discussed generally apply in Louisiana and Texas.

2.2.1.1 Flood Requirements in the IBC and IRC

IBC. The IBC applies to multi-family buildings (with a few exceptions) and to non-residential buildings. In the terminology of the NFIP, the IBC is used for engineered structures. The 2006 IBC addresses flood loads and flood-resistant construction primarily in Section 1612, Flood Loads, which refers to the consensus standards ASCE 7-05 and ASCE 24-05 (refer to Section 2.2.1.2 and 2.2.1.3 for information on ASCE). Most of the mandatory flood provisions are contained in Section 1612, but others occur in the code related to the lowest floor elevation inspection, flood-resistant materials, accessibility, ventilation, and elevators (IBC 2006). Flood loads and load combinations are specified in Section 1605, Load Combinations (IBC 2006). The designer must identify the pertinent, site-specific characteristics and then use ASCE 7-05 to determine the pertinent specific loads and load combinations. In effect, it is similar to a local floodplain ordinance that requires determination of the environmental conditions (location of building with respect to mapped flood hazard area, effective BFE, and flood depth) and then specifies certain conditions that must be met during design and construction. The body of the IBC, together with Appendix G, Flood-Resistant Construction, addresses all of the key building and development requirements of the NFIP. If communities participate in the NFIP, they should

1 http://www.trcc.state.tx.us/policy/FAQs_2.asp#countyinspections

2 See http://www.dps.louisiana.gov/lsuccc/codes.html for the latest Louisiana code information

coordinate their floodplain ordinances with the I-Codes (both IBC and IRC) to ensure that all requirements are addressed.

IRC. The scope of the IRC is more limited than the IBC. The IRC applies to one- and two-family dwellings and to some townhouses. In the terminology of the NFIP, the IRC is used for residential structures. The IRC addresses flood-resistant construction primarily in Section R324, Flood-Resistant Construction, although provisions for mechanical and plumbing installations are included in other pertinent sections of the 2006 IRC.

It is important that communities coordinate their ordinances with the I-Codes (both IBC and IRC) to ensure that all requirements are addressed. A crosswalk of the NFIP regulations and the I-Code provisions is provided in FEMA 9-0372.

IBC/IRC Commonalities. There are some commonalities between the IBC and the IRC as they relate to NFIP:

- **Both** specify information related to SFHAs that are to be included in permit applications and shown on plans.
- **Both** specify that an inspection is required upon placement of the lowest floor, including basement, and prior to further vertical construction, at which time the building official is to require submission of documentation, prepared and sealed by a registered design professional or surveyor, of the elevation of the lowest floor, including the basement.

2.2.1.2 Flood Requirements in ASCE 7-05

The ASCE develops and maintains the consensus standard for ASCE 7-05 (2005b). Since the 1995 edition, ASCE has included flood load provisions. The provisions have changed with each succeeding edition. ASCE 7-98 is a referenced standard in the 2000 and 2003 editions of the IBC, and the 2006 edition of the codes refers to ASCE 7-05.

Design loads used by the 2003 IBC are taken from ASCE 7-02. The following sections of ASCE 7-05 deal with flood:

- Section 2.3, Combining Factored Loads Using Strength Design, and Section 2.4, Combining Nominal Loads Using Allowable Stress Design, include load combinations for Zone V and Coastal A Zone.
- Chapter 5, Flood Loads, covers hydrostatic, hydrodynamic, wave, and impact loads. Load criteria for breakaway walls are included in Section 5.3.3.

The standard requires designers to determine if a site is susceptible to erosion (general lowering of the ground surface) or scour (localized lowering due to interaction of waves and currents with a building element).

In recognition of the growing awareness that wave heights between 1.5 feet and 3.0 feet (the latter being the lower cutoff used to delineate FEMA's Zone V) cause considerable damage, ASCE 7-05 incorporates the concept of the Coastal A Zone.

The 2006 edition of the IRC does not refer to ASCE 7-05 for flood loads because the code is a prescriptive code that, for the most part, does not require individual designs for buildings that are built in compliance with the provisions of the code. However, for buildings located in Zone V, individual designs for buildings must be prepared and sealed by a registered design professional.

2.2.1.3 Flood Requirements in ASCE 24-05

The ASCE develops and maintains the consensus standard for ASCE 24-05, *Flood Resistant Design and Construction* (2005a). The first edition of ASCE 24 was published in 1998 and is referenced in the 2000 and 2003 editions of the IBC. The 2005 edition of ASCE 24 is a major revision and expansion of the standard, and is referenced by the 2006 IBC.

ASCE 24-05 specifies minimum requirements for flood-resistant design and construction of buildings and structures located in flood hazard areas, including floodways, Coastal High Hazard Areas, and other high-risk flood hazard areas, such as alluvial fans, flash flood areas, mudslide areas, erosion-prone areas, and high velocity areas. It applies to new structures and substantial repair or improvement of existing structures that are not designated as historic structures. Basic design requirements address flood loads and load combinations, elevation of the lowest floor, foundation requirements and geotechnical considerations, use of fill, and anchoring and connections. As a function of the type of flood hazard area, enclosures are to have breakaway walls or meet requirements for flood openings (prescriptive or engineered).

For buildings in coastal high hazard areas (Zone V) and Coastal A Zone, ASCE 24-05 includes specifications for the design of pile, post, pier, column, and shear wall foundations. Considerable detail is specified for pilings as a function of pile types and connections.

Additional sections of ASCE 24-05 include the following elements: materials, dry and wet floodproofing, utility installations, building access, and miscellaneous construction (decks, porches, patios, garages, chimneys and fireplaces, pools, and above- and below-ground storage tanks).

Section 1612.4 of the 2006 IBC states, “The design and construction of buildings and structures located in flood hazard areas, including flood hazard areas subject to high velocity wave action, shall be in accordance with ASCE 24.”

The 2006 IRC does not refer to ASCE 24-05 because the code is a prescriptive code that, for the most part, does not require individual designs for buildings that are built in compliance with the provisions of the code. The exceptions for Zone V buildings (which do require design) were listed above. Communities must, therefore, reference ASCE 24-05 directly to apply its provisions to residential buildings. However, Section R324 of the 2006 IRC, Flood-Resistant Construction, states that buildings in floodways shall be designed in accordance with the IBC, thereby mandating use of ASCE 24-05 for buildings in floodways as shown on the FIRMs. Also, the 2009 IRC will allow use of ASCE 24-05 as an alternative to certain provisions of the IRC.

2.2.1.4 Flood Requirements in Texas

Flood requirements in Texas are specified at the community level. There are no additional State-mandated flood standards. The Texas Water Development Board[3] is the State coordinating agency for the NFIP.

2.2.1.5 Flood Requirements in Louisiana

Flood requirements in Louisiana are specified at the community level. There are no additional State-mandated flood standards. The Louisiana Department of Transportation and Development (LADOTD)[4] is the State coordinating agency for the NFIP, and produced a *Louisiana Floodplain Management Desk Reference* summarizing floodplain management in the State (LADOTD, 2008).

2.2.2 Wind Requirements

Wind speeds and wind damage were more significant in Texas than Louisiana. The wind investigation and analysis was primarily limited to Texas. The following discussion provides information regarding wind requirements in codes and information about code adoptions in Texas and Louisiana.

2.2.2.1 Wind Requirements in the IBC

The methodology required for calculating wind loads in the 2006 IBC is that prescribed in Chapter 6 of ASCE 7-05. Using ASCE 7-05 for determining wind loads ensures that designers are using state-of-the-art methodology to calculate wind loads. In addition to improved load computations, ASCE 7-05 also provides performance and testing requirements for windborne debris protection of glazing in compliance with ASTM E 1886, *Standard Test Method for Performance of Exterior Windows, Curtain Walls, Doors, and Impact Protective Systems Impacted by Missile(s) and Exposed to Cyclic Pressure Differentials*, and ASTM E 1996, *Standard Specification for Performance of Exterior Windows, Glazed Curtain Walls, Doors, and Storm Shutters Impacted by Windborne Debris in Hurricanes.*

2.2.2.2 Wind Requirements in Texas

Texas counties and municipalities have the authority to adopt a building code of their choosing. Historically, in the State of Texas, the codes of choice were the Standard Building Code (SBC) and the Uniform Building Code (UBC), with the SBC being the preferred code in the coastal counties. With the advent of the I-Codes in 2000, most counties had adopted the IRC and the IBC prior to Hurricane Ike. As of September 1, 2008, the TRCC requires unincorporated areas within counties to comply with the 2000 IRC, at a minimum. If a county seat has adopted an updated version of the IRC code, that code applies to the unincorporated areas within the county. Table 2-1 lists those counties affected by Ike and their adopted codes.

3 http://www.twdb.state.tx.us/wrpi/flood/nfip.htm
4 http://www8.dotd.la.gov/lafloods/

Table 2-1. Codes in Effect at the Time of Hurricane Ike for Impacted Counties and Cities in Texas

County	City	Building Codes*, **
Brazoria County		
	Surfside Beach	2003 IBC and IRC
Chambers County		
	Baytown	2006 IBC and IRC
Galveston County		
	Clear Lake Shores	2003 IBC and IRC
	City of Galveston	2003 IBC and IRC
	Jamaica Beach	2006 IBC and IRC
	Village of Tiki Island	2000 IBC and IRC
	Kemah	2003 IBC and IRC
	Texas City	2003 IBC and IRC
	League City	2000 IBC and IRC
Harris County		
	Houston	2000 IBC and IRC
	La Porte	2003 IBC and IRC
	Deer Park	2003 IBC and IRC
	Seabrook	2003 IBC and IRC
	Shoreacres	2000 IBC and IRC (2006 IBC and IRC adopted after Hurricane Ike)
Jefferson County		
	Beaumont	1997 SBCCI
	Port Arthur	2006 IBC and IRC
	Port Neches	2003 IBC and IRC
Orange County		
	Bridge City	2006 IBC
	Orange	2003 IBC and IRC

Notes:

* IBC – International Building Code
IRC – International Residential Code
SBCCI – Southern Building Code Congress International

** The current adopted code should be verified before construction or rebuilding activities commence.

All versions of IBC specify higher wind speeds for coastal Texas counties than any of the previous editions of the SBC. Therefore, variation exists in the design wind speeds for areas throughout those counties for buildings previously constructed to the SBC standard. The 1985 SBC modified the required speeds to match those in the American National Standards Institute (ANSI) A58.1-1982 standard, the predecessor to the ASCE 7, but rejected the inclusion of the new methods and coefficients for calculation pressures included in the ANSI standard. The wind speed map remained unchanged for all 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 gust wind speeds cited in the 2003 IBC for Galveston, Chambers, and Harris Counties increased significantly from those cited in the 1997 SBC. Table 2-2 summarizes the progression over time of the basic design wind speeds for those counties. The map shown in Figure 2-4 includes an overlay of design wind speed contours for the portion of the Texas and Louisiana coast affected by Hurricane Ike and was taken directly from the 2003 IBC/ASCE 7-05. The colored swaths provide a graphical representation of the percentage difference between Hurricane Ike's peak 3-second gusts compared to these design speeds. This map clearly indicates that Hurricane Ike's winds were less than the required design wind speeds for buildings in this region.

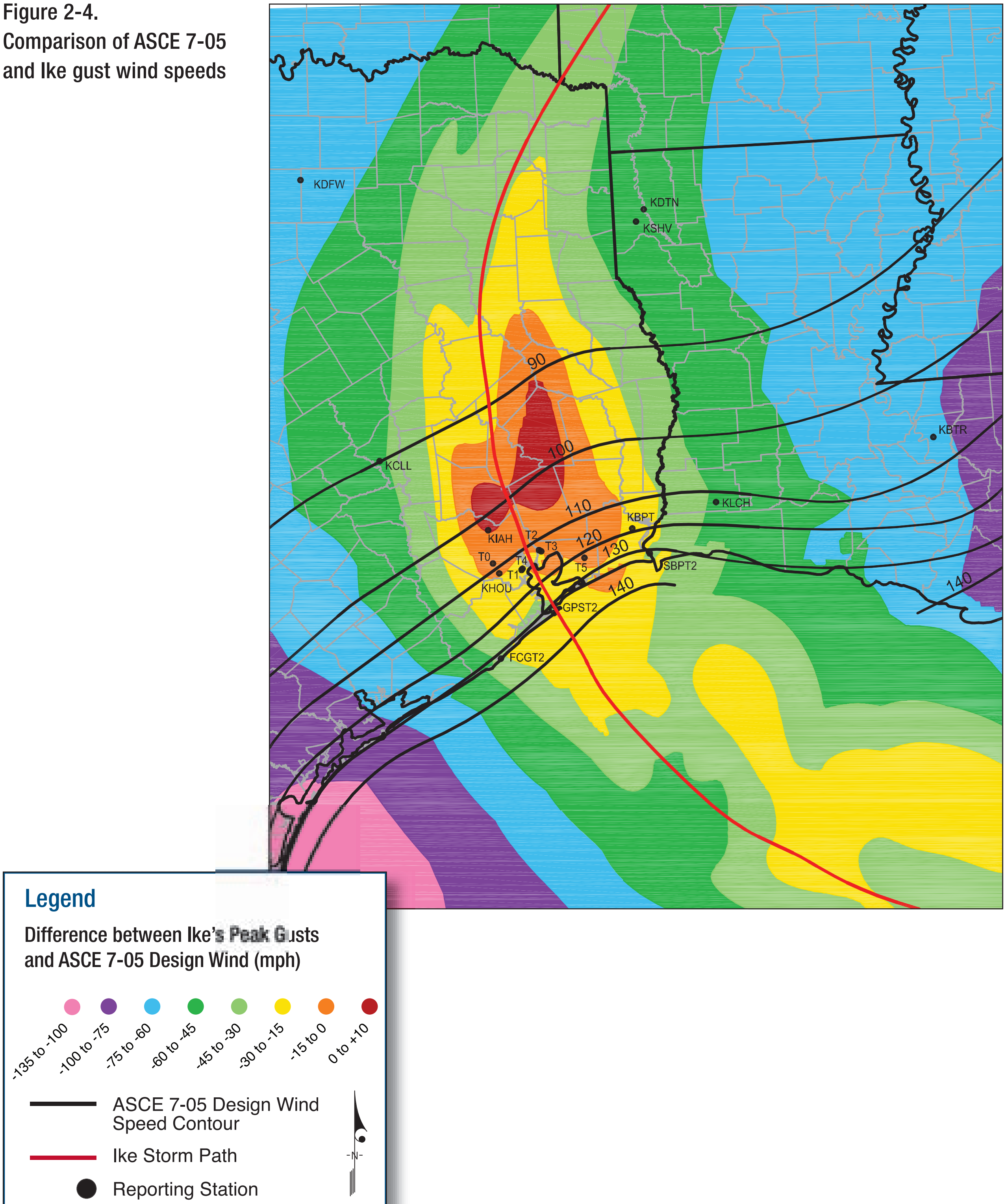
Table 2-2. Approximate Range of Basic Design Wind Speeds in the Coastal Counties Visited by the MAT (3-Second Gust, Exposure C, at 33 Feet Above Ground)

County	SBC 1985 Edition*	SBC 1997 Edition*	2006 IBC and ASCE 7-02 and Later
Galveston	115–120 mph	110–120 mph	120–130 mph
Chambers	110–115 mph	110–115 mph	110–125 mph
Harris	100–110 mph	100–110 mph	100–110 mph

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

IBC = International Building Code
ASCE = American Society of Civil Engineers

Figure 2-4.
Comparison of ASCE 7-05 and Ike gust wind speeds



Example of Design Load Changes Over Time

The SBC expressed wind speeds in terms of the "fastest mile," whereas the IBC and ASCE 7 measures maximum wind speeds as "3-second gusts" (refer to text box). Table 2-3 presents a summary of the design wind pressures on wall and roof areas for a typical residence in the City of Galveston, and compares the wind pressures with respect to the 1985 SBC fastest mile measurement, the 1997 SBC 3-second gust (converted from fastest mile) measurement using an ASCE 7-95 design solution and the current adopted 2006 IBC 3-second gust measurement. The IBC calculations are based on a home less than 33 feet tall and located near the water in Exposure C. The required design pressures are given for both a building's structure (referred to in codes and standards as the main wind force resisting system or MWFRS) and for a building's envelope (referred to as components and cladding, or C&C). The 1985 SBC uses the terminology of "Parts and Portions" (P&P) in lieu of the current ASCE 7 terminology of C&C. The 1985 SBC design coefficients did not address pressures for MWFRS corners or P&P coefficients for roof and corner edges. Though the 1985 SBC references and allows the use of the ANSI standard (ANSI A58.1-1982), the new design load standard and predecessor of ASCE 7 of that time, the City of Galveston did not adopt the ANSI standard.

COMPARING BASIC DESIGN WIND SPEEDS

Current codes and standards (2006 IBC and ASCE 7-05) standardize wind speed measurement as the 3-second gust. This differs from the fastest-mile wind speed measure that was previously used by the SBC, as well as the wind speed measure of 1-minute sustained that is used in the Saffir-Simpson Hurricane Scale and referenced by the NHC. The Saffir-Simpson Hurricane Scale was presented in Table 1-2. The table below provides a comparison of wind speeds for 3-second gust, fastest mile, and 1-minute sustained.

Wind Speed Comparison (in miles per hour)

*$V_{3\text{-second gust}}$	85	90	100	110	120	130	140	150
*$V_{\text{fastest-mile}}$	70	75	80	90	100	110	120	130
**$V_{\text{sustained}}$	67	71	79	87	95	102	110	118

* 3-second gust and fastest mile based on 2003 IBC table 1609.3.1.

** 1-minute sustained based on the Engineering Sciences Data Unit gust factor curve.

Table 2-3. Design Loads for a Typical Single-Family Residence in the City of Galveston, Galveston County, TX

Description	SBC 1985 Edition	SBC 1997 Edition (ASCE 7-95 Solution)	2006 IBC and ASCE 7-05
Basic Design Wind Speed	100 mph (fastest-mile, f_m)	120 mph (f_m converted to 3-second gust)	130 mph (3-second gust)
Wind Design Pressures on Exterior Walls (psf)			
As MWFRS:			
Windward	+19/+14	+29/+16	+30/+17
Leeward	-12/-7	-20/-8	-21/-9
Net Horizontal	+31	+37	+39
As C&C:			
Middle	+26/-26	+36/-41	+39/-43
Corner	*	+36/-49	+39/-51
Wind Design Pressures on Roof (4:12 slope) (psf)			
As MWFRS:			
Windward	-22/-18	-18/-5	-23/-10
Leeward	-17/-12	-20/-8	-23/-11
As C&C:			
Middle	*	+16/-53	+27/-64
Corner	*	+16/-55	+23/-80
Overhang Middle	-36	-73	-75
Overhang Corner	*	-83	-127

Definitions:

SBC = Standard Building Code
ASCE = American Society of Civil Engineers
IBC = International Building Code
mph = miles per hour
psf = pounds per square foot
MWFRS = Main Wind Force Resisting System
C&C = Components and Cladding

Notes:

The sampled residence is 40 feet by 40 feet, elevated on 10 pilings, with a total roof eave height of 20 feet. The roof is gable with the winds calculated normal to the roof ridge line. The roof slope is a 4:12 pitch. Calculations use the SBC and ASCE 7 method for buildings of all heights. Wind speeds were selected from the 50-year Mean Recurrence Maps from the respective code or standard. Calculations are based on Exposure C wind speeds measured at 33 feet (10 meters) above ground level.

* Load considerations and pressure coefficients not included in the SBC 1985 Edition.

1. The pressure calculations under each code for both MWFRS and C&C were calculated using building design coefficients that provide the maximum wind pressure for that area on the building surface.
2. Previous and current U.S. building codes and ASCE standards do not address pressures on the underside of floors for open elevated structures.
3. Positive pressure values indicate pressure acting inward toward building surfaces. Negative value pressures indicate pressures acting outward from building surfaces.
4. The building was considered to be an enclosed structure subject to positive and negative internal pressures and the values tabulated represent the maximums per evaluated area.
5. Numbers divided by a slash (/) represent the effect of positive and negative pressure coefficients.
6. The net horizontal pressures consider the addition of the positive windward pressures and negative leeward pressures with the internal pressures canceled.

2.2.2.3 Wind Requirements in Louisiana

Prior to Hurricane Katrina, Louisiana communities had various building and residential codes, and, in many communities, no codes at all. The State Uniform Construction Code, which took effect on January 1, 2004, required only that communities choosing to enforce a code use the 2000 IBC. Many larger cities and parishes adopted the IBC, but many other communities had not adopted the IBC, and were still enforcing various editions of the SBC. There were no State-level provisions relating to residential building codes. When adopted, the form and guidance provided by these residential codes varied widely, including various editions of the IRC, SBC, and Council of American Building Officials (CABO) codes. This lack of a residential code, or use of older versions of the residential codes, is often an indicator that the residential buildings in the areas were designed and constructed without the guidance and criteria of the newer hazard-resistant codes.

After Hurricane Katrina, the Louisiana State Legislature passed Act 12 on November 29, 2005, requiring enforcement of the IBC and IRC statewide. It also created the Louisiana State Uniform Construction Code Council, whose purpose is to "... review and adopt the state uniform construction code, provide for training and education of code officials, and to accept all requests for amendments to the code, except the Louisiana State Plumbing Code." The provisions of the newly revised State Uniform Construction Code were to be implemented in phases. The new law contained emergency provisions requiring Calcasieu, Cameron, Iberia, Jefferson, Lafourche, Orleans, Plaquemines, St. Bernard, St. Tammany, Terrebonne, and Vermilion Parishes to enforce all wind and flood mitigation requirements prescribed by the 2003 IBC and IRC, as modified and amended by Section 301.2.1.1(2) to replace SBCCI *Standard for Hurricane-Resistant Construction* (SBCCI SSTD 10-99) with the *Guidelines for Hurricane-Resistant Residential Construction* as published by the IBHS in 2005.

2.2.3 HUD Manufactured Housing Design Standards

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

Beginning in 1976, the Manufactured Home Construction and Safety Standards, Title 24 of the Code of Federal Regulations (CFR) Part 3280, established the minimum requirements for the construction, design, and performance of a manufactured home. HUD, rather than States or communities, determines the manufacturing standards for manufactured homes. However, States and communities determine where manufactured housing can be sited and what permits and inspections are required for installation and occupancy of manufactured housing.

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

In August 1992, when Hurricane Andrew hit southern Florida, over one-third of all site-built houses were substantially damaged and almost all manufactured homes were destroyed within the area affected by the hurricane. As a direct consequence, HUD developed improved wind-resistance requirements for the hurricane-prone coastal areas of the United States. Published as a Final Rule in the Federal Register (59 FR 2456 [1994]), these changes introduced more stringent requirements in high wind areas and defined three separate wind zones: Zone I, Zone II, and Zone III.

For wind Zones II and III, this rule also designates higher wind loads. Specifically, the updated HUD standard requires that the manufactured home, each of its wind-resisting parts, and its C&C materials be designed by a professional engineer or architect to resist either the design wind loads for Exposure C specified in ANSI/ASCE 7-88, *Minimum Design Loads for Buildings and Other Structures*, for a 50-year recurrence interval or those tabulated in 24 CFR Part 3280. Zone II homes must be designed to resist a fastest-mile wind speed of 100 mph; Zone III homes must be designed to resist a 110 mph fastest-mile wind speed. Zone I homes are not specifically associated with a design wind speed, but rather are designed to resist minimum horizontal and vertical wind pressures.

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

> Please note that the September 1985 edition of FEMA 85, *Manufactured Home Installation in Flood Hazard Areas*, is currently under revision and is tentatively scheduled to be released later in 2009.

Manufactured home regulations and standards are continuously being developed. The following list summarizes some of the more recent regulations and standards that have been passed or developed:

- The HUD Manufactured Housing Installation Standard, 24 CFR Part 3285, was issued in October 2007 and became effective October 20, 2008. This standard is part of an installation program that includes: (1) installation standards, (2) training and licensing manufactured home installers, and (3) inspecting manufactured home installations. The HUD program will be mandated for any State that does not have its own program that includes all three of the previously described components. To be exempted, a State must have adopted standards that equal or exceed the protection provided by HUD's program.[5]
- The NFPA currently maintains three documents on the subject of manufactured housing: (1) NFPA 501, *Standard on Manufactured Housing*, a consensus document on the design and construction of manufactured homes (NFPA, 2005b); (2) NFPA 501A, *Standard for Fire Safety Criteria for Manufactured Home Installations, Sites and Communities* (NFPA, 2009b); and (3) NFPA 225, *Model Manufactured Home Installation Standard*, a consensus document that governs the installation of manufactured homes (NFPA, 2009a). The 2005 edition of NFPA 501 has wind-related requirements based upon ASCE 7-02. The 2009 edition of

5 More information on the development of this new program can be found at http://www.hud.gov/offices/hsg/ramh/mhs/mhip.cfm

NFPA 225 has wind provisions consistent with ASCE 7-05 and flood provisions consistent with the NFIP. The latest edition of NFPA 225 also contains new prescriptive flood- and wind-resistant foundation designs.

2.2.3.1 Manufactured Housing in Texas

The Manufactured Housing Division of the Texas Department of Housing and Community Affairs adopted amendments to Texas Administrative Code (TAC), Chapter 80, Sections 80.2, 80.21, and 80.22, related to installation standards of the manufactured housing program. These amendments comply with the Federal Installation Standards (24 CFR Part 3485) that became effective January 1, 2009.

The Texas codes require that all new manufactured homes be installed by a licensed installer in accordance with the home manufacturer's approved installation instructions. The installer of a new manufactured home is responsible for the proper preparation of the site where the manufactured home will be installed.

The codes require that all used manufactured homes be installed by a licensed installer to resist overturning and lateral movement of the home and in accordance with instructions appropriate for the wind zone where the home is to be installed as per the home manufacturer's installation instructions; the State's generic standards set forth in Sections 80.22 through 80.25 of Chapter 80; the instructions for a stabilization system registered with the Department in accordance with Section 80.26 of Chapter 80; or the instructions for a special stabilization system.

2.2.3.2 Manufactured Housing in Louisiana

The State of Louisiana has adopted the Manufactured Home Installation Standards – Final Rule contained in 24 CFR Part 3285 for the installation of new manufactured homes. In the Final Rule, all new manufactured homes must be installed to the new standard at the initial installation. The manufacturer's instructions apply where the manufacturer's approved instructions meet or exceed this standard and do not take the home out of compliance.

Prior to initial installation of a new manufactured home, the installer is responsible for determining whether the manufactured home site lies wholly or partially within a flood hazard area (24 CFR 3285.102). If the property where the home is to be installed is located within a flood zone, 24 CFR Part 3285 requires the installation to satisfy the NFIP. The Final Rule at 24 CFR Part 3285 also requires that manufacturer's installation instructions specifically state whether they are appropriate for homes placed in SFHAs or not.

For existing homes, Louisiana follows the Louisiana Revised Statutes (R.S.) 51:912.21. In the absence of manufacturer's installation instructions, homes must be placed in accordance with R.S. 51:912.21 through 51:912.31. Louisiana statutes require the landowner to be responsible for proper site preparation. The statutes also require that the grade under the home be cleaned of all vegetation and organic material, and sloped to properly drain. All grass and organic material must be removed and the pier foundation placed on stable soil or compacted fill. The statutes also specify minimum requirements for the pads or footers supporting the piers. In floodprone areas, the foundation is required to comply with the requirements set forth in FEMA 85, M*anufactured Home Installation in Flood Hazard Areas* (FEMA, 1985).

2.2.4 Galveston Residential Hurricane Resistance Study, 1990

During the last decade, new information has been learned about the effects of hurricane wind and flooding, and this knowledge has been incorporated into building codes and construction practices. In 1990, a study titled *Effectiveness of Building Codes and Construction Practice in Reducing Hurricane Damage to Non-Engineered Construction* was conducted by James R. McDonald, PhD, P.E. of the TTU Institute for Disaster Research and Billy Manning, P.E. of SBCCI. The scope of work was to examine the history of the wind and flood design provisions of the City of Galveston, TX, building code and to determine the effectiveness of building codes and construction practices in reducing hurricane damage to non-engineered construction. Thirty-one single-family residences constructed under various eras of building code authority were examined. The information collected included terrain exposure, floor elevation, construction practices, quality of workmanship and materials, state of repair, insurance coverage, and damage from previous hurricanes. The MAT's review and investigation of some of the buildings analyzed in the 1990 Galveston study provides insight into an important question: whether the continued observed vulnerability of buildings from hurricanes results from an incomplete understanding of design or construction issues or the lack of incorporating these design and construction practices into new construction and retrofit buildings.

Ten code eras were identified, beginning with the first Galveston code adoption in 1914 and ending with the effective code at the time the study was conducted. The codes concurrent with the Galveston study were the SBC (1985 edition with the 1986 revisions, published by SBCCI) and the 1971 Texas Catastrophe Property Insurance Association (TCPIA) wind load provisions. The TCPIA wind code applied to the first two tiers of counties along the Gulf Coast of Texas, including Galveston (refer to Section 2.3.2 for more information). In order to obtain extended-coverage insurance, a building owner had to have certification that the property met the TCPIA requirements.

The locations of the houses investigated in the Galveston study are shown in Figure 2-5. The newest house, number 3289, was still under construction at that time, which allowed for a thorough investigation of building connections and construction quality. The remaining 30 houses had been constructed prior to the study, and the building connections could not be thoroughly examined. Attics were inspected and the type of rafter-to-wall connections noted, either toe-nailed or hurricane clips. Of the 31 houses, seven were observed to have hurricane clip connections. A roof uplift resistance analysis was run on each house based upon the observed quality of construction, the roof anchorage, rafter size and spacing, and the roof decking. Those results were then compared to the current Galveston code, SBC, and ASCE 7-88 uplift forces associated to the same assigned wind speed of 96 mph, fastest-mile (117 mph, 3-second gust).

The City of Galveston adopted the NFIP's FIRMs on May 7, 1971. Based on the results of a wave analysis that FEMA conducted for the City, the FIRMs were revised in 1983 and remained current

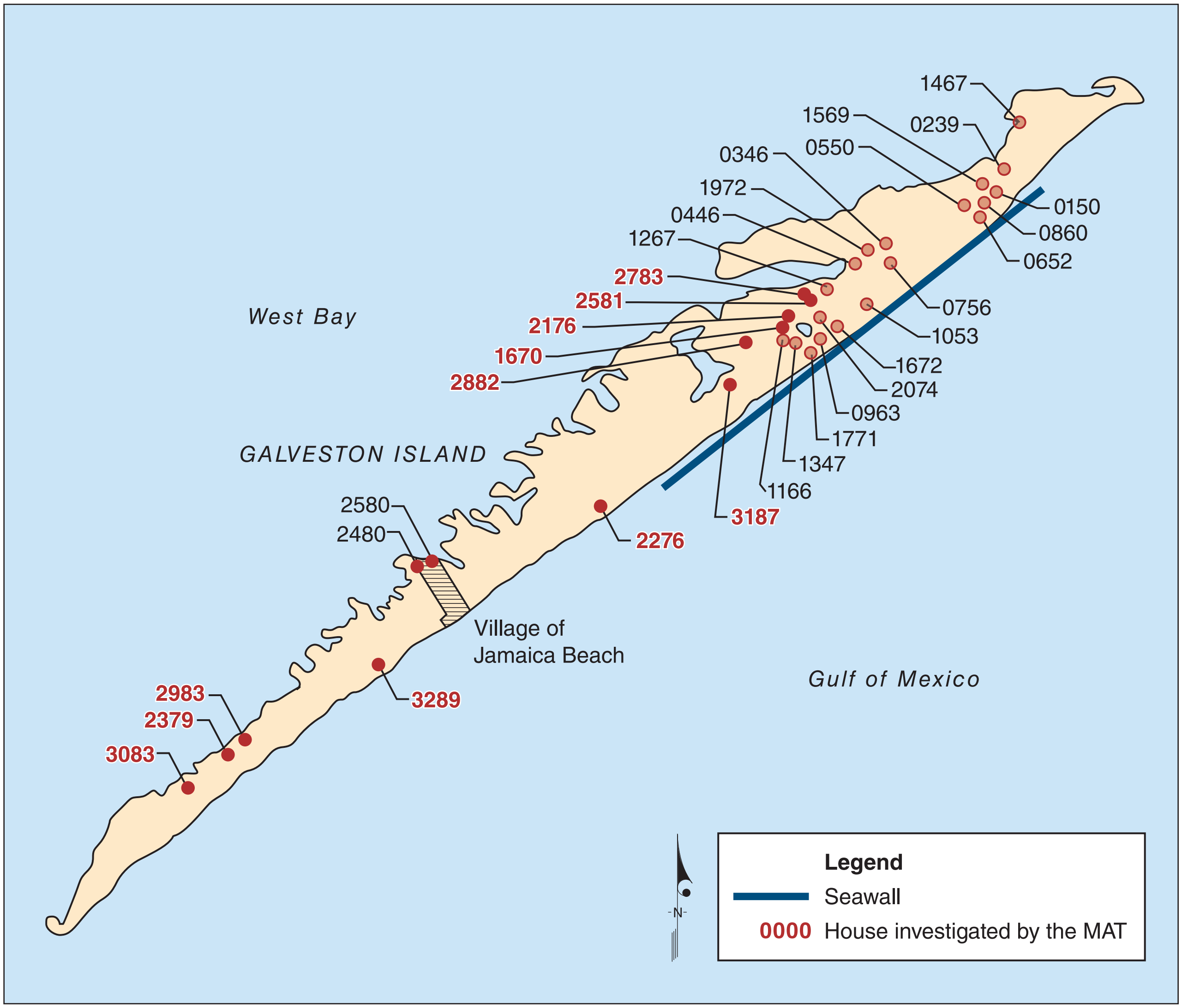


Figure 2-5.
Galveston Island houses investigated for the 1990 report that were visited by the MAT in 2008 after Hurricane Ike

at the date of the 1990 Galveston study. As a part of the investigation of susceptibility of the 31 houses for flooding and surge damage, the following information was recorded for each:

- Flood zone
- BFE
- Elevation of lowest floor
- Distance to water
- Closest body of water
- Foundation type
- Connections of elevated structure

PRE-FIRM AND POST-FIRM BUILDINGS

For insurance rating purposes, a pre-FIRM building was constructed or substantially improved on or before December 31, 1974, or before the effective date of the initial FIRM of a community, whichever is later. Most pre-FIRM buildings were constructed without taking the flood hazard into account.

A post-FIRM building was constructed or substantially improved after December 31, 1974, or after the effective date of the initial FIRM, whichever is later. For a community that participated in the NFIP when its initial FIRM was issued, post-FIRM buildings are the same as new construction and must meet the NFIP's minimum floodplain management standards.

The observations included in the Galveston study noted that many of the houses constructed pre-FIRM were constructed at or within 1 foot of the mapped BFE. All of the houses constructed post-FIRM were sited above the BFE and appeared to have more substantial pile foundations than the older residences, and had more substantial anchorage between the piles, girders, and floor joists.

The overwhelming conclusions of the Galveston study regarding wind resistance were that most wood-framed residences did not meet the performance criteria of building codes and roof-to-wall connections were not designed or analyzed for resistance to wind uplift forces. Other conclusions were that the practice of using toe-nailed connections is unsatisfactory, and that hurricane clips can provide the needed resistance, but their selection must be based upon the calculated forces. Other factors that contribute to large uplift forces include building width, eave height, roof angle, and overhang dimension.

Additionally, the Galveston study concluded that the wind load provisions of the building code current at the time of investigation failed to meet the then current criteria of ASCE 7-88. The study further concluded that houses constructed since the adoption of the NFIP in 1971 utilizing flood-resistant construction and BFE elevations should perform to NFIP expectations; however, the practice of installing non-breakaway walls below the BFE in Zones V and Coastal A Zones were in violation of the NFIP and jeopardized the houses' structural resistance to flood loads.

2.2.4.1 Ike MAT Observations of Houses in the 1990 Galveston Study

The MAT chose to investigate 12 of the 31 houses included in the 1990 Galveston study located nearest the coastline and not protected by the seawall. Eleven of these houses were still standing after Hurricane Ike, but suffered varying degrees of damage (Figure 2-5). Number 2276, located on the Gulf side of Bermuda Drive, had been washed away by the storm. Number 3289, located in Indian Beach in a Zone V, is approximately 200 feet from the Gulf (Figure 2-6). This house had been under construction during the preparation of the Galveston study, thereby allowing the investigators to survey the building construction and connections. The Galveston study reported deficiencies for this house, including non-breakaway elements below the BFE and a roof uplift resistance greater than the local building code, but less than ASCE requirements. The MAT observed that the first floor was 2 feet above the BFE (17 feet) with significant pilings (12-inch by 12-inch) to girder connections and hurricane clips; however, many clips were corroded and broken (Figure 2-6 inset), as would be expected in this location. Refer to NFIP Technical Bulletin 8-96, *Corrosion Protection for Metal Connectors in Coastal Areas* (August 1996).

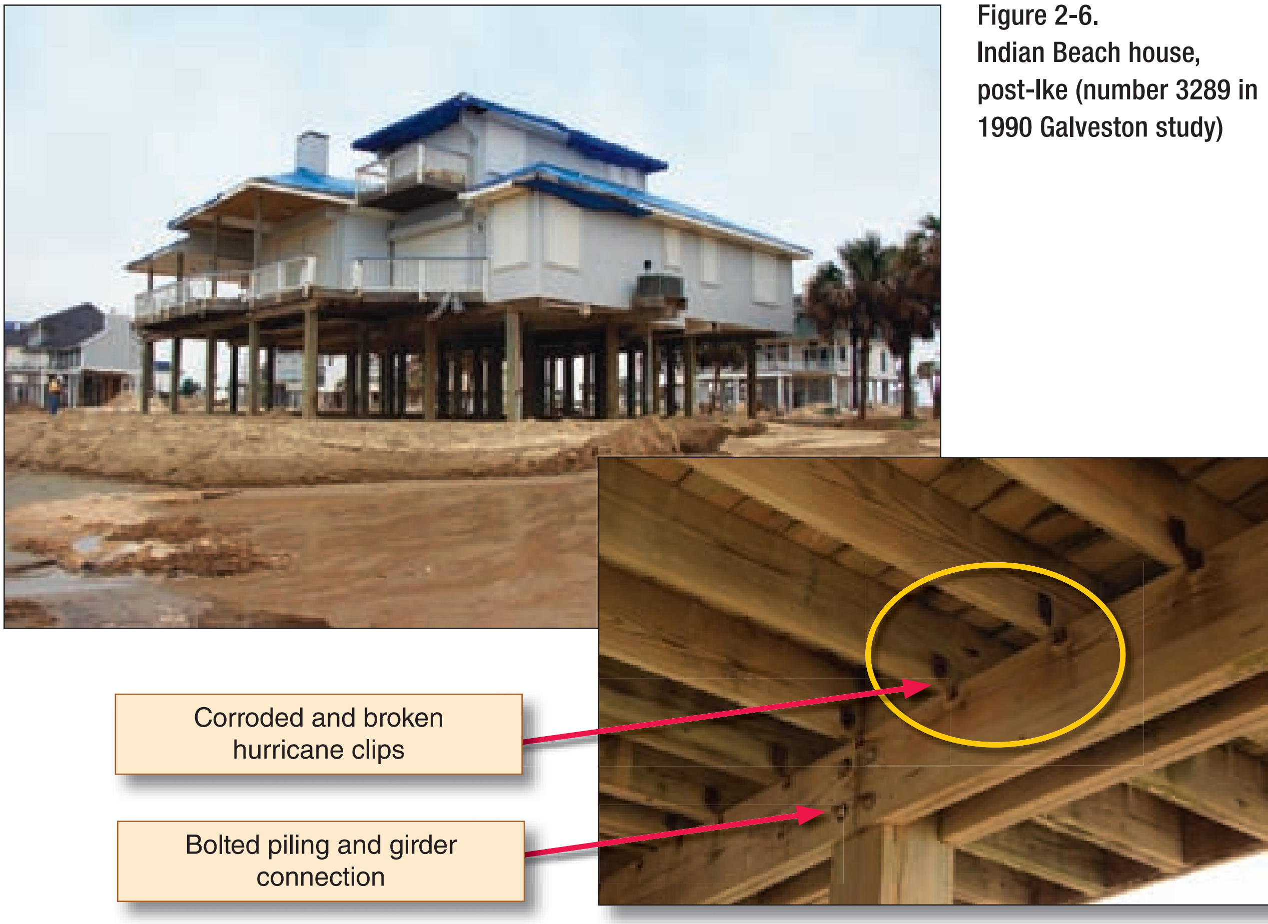


Figure 2-6.
Indian Beach house, post-Ike (number 3289 in 1990 Galveston study)

During Hurricane Ike, the house suffered substantial wind damage to the asphalt shingles, vinyl siding, and soffits. The Galveston study identified the lack of shuttering for the house openings as a weakness. At the time of Hurricane Ike, the house openings were fully shuttered.

Number 3083, constructed in 1983, is located in Zone A in Point San Luis on a canal that opens to the West Bay (Figure 2-7). According to the Galveston study, this house's identified weaknesses included overhangs greater than 4 feet, pile spacing greater than 12 feet, and walls or enclosures below the BFE that were not of breakaway construction. During Ike, the house was inundated by approximately 8 feet of water with waves that destroyed the majority of the first floor walls.

Number 2480 is located on the West Bay in Zone A in Jamaica Beach with a Category C wind exposure (Figure 2-8). The Galveston study identifies the hurricane clips and bolted structural connections as strengths and the non-breakaway wall structures as a primary weakness. The house experienced both wind and flood damage during Hurricane Ike. Wind damaged vinyl siding and roof shingles on the north and west exposure of the house, an indicator of "backside" (north-to-south) winds. Flooding and waves undermined the concrete paving below the house and tore out ceilings, stairs, and wall structures below the first floor (Figure 2-9).

Figure 2-7.
Point San Luis house (number 3083 in 1990 Galveston study)

Figure 2-8.
Jamaica Beach house on the West Bay with “backside” wind damage (number 2480 in 1990 Galveston study)

Figure 2-9.
First floor walls removed and floor slab undermined by flooding and waves at this Jamaica Beach house (number 2480 in 1990 Galveston study)

2.2.4.2 MAT Summary of Findings Regarding the Galveston Study

The Galveston study concludes that the wind load provisions of the building code current at the time of investigation failed to meet the then current provisions of ASCE 7-88. The study further concluded that houses constructed since the adoption of the NFIP in 1971 utilizing flood-resistant construction and BFE elevations should perform to NFIP expectations; however, the practice of installing non-breakaway walls below the BFE in Zones V and Coastal A Zones were in violation of the NFIP and jeopardized the houses' structural resistance to flood loads. The Galveston study rated each house for wind and water resistance based upon the collected data.

The Galveston study assigned ratings to each house regarding performance for wind resistance and flood/wave resistance. The average rating in the study for the 12 houses sampled by the MAT was an "expected Poor Performance for wind resistance and a Good Performance for resistance to flood and wave loads." Hurricane Ike was not a design wind speed event and wind damage to the houses was relegated to loss of asphalt shingles, siding, and soffit materials; therefore, a reasonable comparison of the Galveston study wind expectations could not be measured.

Of the 12 houses visited by the MAT, Numbers 3289 and 2276 were the only houses located in Zone V. Number 3289 lost non-breakaway walls and Number 2276 was washed away by the storm. The other 10 houses were Zone A units with first floors located at or above the BFE. Four of these houses were slabs-on-grade and experienced flooding, while the other six houses were elevated and experienced breakaway and non-breakaway wall damage below the BFE, along with the loss of garage doors and ceiling finishes. The MAT's observations of the resistance of the sampled houses to flood and wave loads indicate a "Poor Rating" in comparison to the Galveston study's "Expected Good Performance."

2.3 Texas Windstorm Program

Hurricanes periodically strike the Texas Gulf coast. The City of Galveston was flattened in 1900 by the Great Galveston Hurricane, the deadliest ever recorded in the State, killing approximately 8,000 people. Another massive storm, Hurricane Carla, killed 43 people and caused approximately $2 billion in property damage (in 2009 dollars) when it came ashore near Galveston in August of 1961. Hail storms, tornadoes, and floods subject other parts of the State to catastrophe, but only hurricanes have caused levels of devastation that demanded action by the State legislature. Because of the level of devastation caused along the Texas coast by previous hurricanes and prompted by Hurricane Celia (which caused significant damage to coastal areas near Corpus Christi in 1970), the TCPIA—a "Cat Pool" of insurers—was created by the Texas Legislature in 1971. The Cat Pool was renamed the Texas Windstorm Insurance Association (TWIA) in 1997. All insurers that write property insurance in Texas are required to become members of TWIA. Excess funds collected from premiums and investments are deposited in the Texas Catastrophe Reserve Trust Fund (CRTF) to pay for excess losses. According to a report on the TWIA, prepared by the Texas Department of Insurance (TDI) in October 2008, the current balance of the CRTF is zero as a result of losses from Hurricanes Rita (2005), Dolly (2008), and Ike (2008) (Insurance, 2008).

TWIA operates under the authority of Chapter 2210 of the Texas Insurance Code. TWIA is a pool intended to serve as an "insurer of last resort" for individuals needing windstorm and hail insurance on buildings that are located in the first tier of coastal counties along the 367-mile Texas Gulf Coast; see Table 2-4 and Section 2.3.3.

Table 2-4. Texas Counties covered by TWIA

Aransas	Brazoria	Calhoun
Cameron	Chambers	Galveston
Jefferson	Kenedy	Kleberg
Matagorda	Nueces	Refugio
San Patricio	Willacy	

Along with those counties indicated, TWIA also provides windstorm and hail coverage in certain specifically designated communities in Harris County that are east of State Highway 146. These communities include Pasadena, Morgan's Point, Shoreacres, Seabrook, and La Porte.

2.3.1 Texas Department of Insurance

When the TCPIA was established in 1971, the Texas Legislature adopted the TCPIA Building Code for Windstorm Resistant Construction, which was based on the wind load provisions of the 1971 SBC. The damage caused by Hurricane Alicia in 1983 revealed that applicable building codes were not being enforced. As a result, the Windstorm Inspection Program at the TDI was created by the Texas Legislature, effective January 1, 1988. The TDI was charged with the following responsibilities:

- Certify to TWIA that buildings are constructed to the adopted windstorm code and therefore insurable against windstorm and hail losses

- Provide inspection services and process windstorm forms
- Though not part of the original charge, but as an integral part of the windstorm program, evaluate and list building products for compliance with the building specifications adopted by the TDI

2.3.2 Basic Tenets of the Texas Windstorm Code

In 1989, the TDI began using the Windstorm Resistant Construction Guide, which was based on the SBC, as amended May 8, 1973, in addition to using the 1971 TCPIA Building Code for Windstorm Resistant Construction. In 1998, the TDI began using the TWIA (formerly TCPIA) Building Code for Windstorm Resistant Construction, which was updated to be based on ASCE 7-93. In 2003, the TDI adopted the 2000 IRC and the 2000 IBC. This was followed by the adoption of the 2003 IRC and 2003 IBC in 2005, and most recently, the adoption of the 2006 IRC and 2006 IBC in 2008.

Since 1998, the first tier counties, referred to as Designated Catastrophe areas, have been divided into three zones, referred to as Inland (II), Inland (I), and Seaward, by the TDI. The delineation between Inland (II) and Inland (I) is primarily roadways, city limits, and county lines. The delineation between Inland (I) and Seaward is the Intracoastal Waterway. The TDI also adopts wind speed requirements for each of the three zones. Figure 2-10 illustrates the three zones, as well as the current wind speed requirements adopted for each zone. The TDI has adopted amendments, called Texas Revisions, for each edition of the IRC and the IBC that have been adopted by the TDI. The Texas Revisions to the 2006 IRC and 2006 IBC include the following:

- Defines requirements for windborne debris protection as follows:
  - Inland (II) – no protection required
  - Inland (I) – all glazed openings to be protected
  - Seaward – all exterior openings (windows, doors, skylights, and garage doors) to be protected
- In accordance with IRC Section R301, Design Criteria, and IBC Section 1609, Wind Loads, the provisions of the IBHS *Guidelines for Hurricane Resistant Residential Construction* (IBHS, 2005) were added as an option for the designer and builder.
  - Regarding asphalt roof shingles, in accordance with Sections R905.2, Requirements for Roof Coverings, of the 2006 IRC and Section 1504, Performance Requirements, of the 2006 IBC, the TDI allows for shingles that have passed the ASTM D 3161, *Standard Test Method for Wind-Resistance of Asphalt Shingles*, Class F to be installed on roofs

NOTE

For more information about the Texas Department of Insurance, visit http://www.tdi.state.tx.us/wind/.

located in the Inland (II), the Inland (I), and the Seaward zones. In addition, the TDI permits the use of asphalt shingles that have passed ASTM D 7158, *Standard Test Method for Wind Resistance of Sealed Asphalt Shingles*, Class H to be installed in the Inland (I) and the Seaward zones. The TDI maintains a list of asphalt shingle products that have passed these criteria on their Windstorm Program Web.[6]

- The TDI requires building products to be tested to and comply with the test standards and criteria specified in the IRC, the IBC, and the Texas Revisions. Products that meet these criteria are evaluated by the TDI and listed on their Windstorm Program Web site. The TDI also evaluates and lists some types of building products that have passed test criteria used by Dade County, FL.

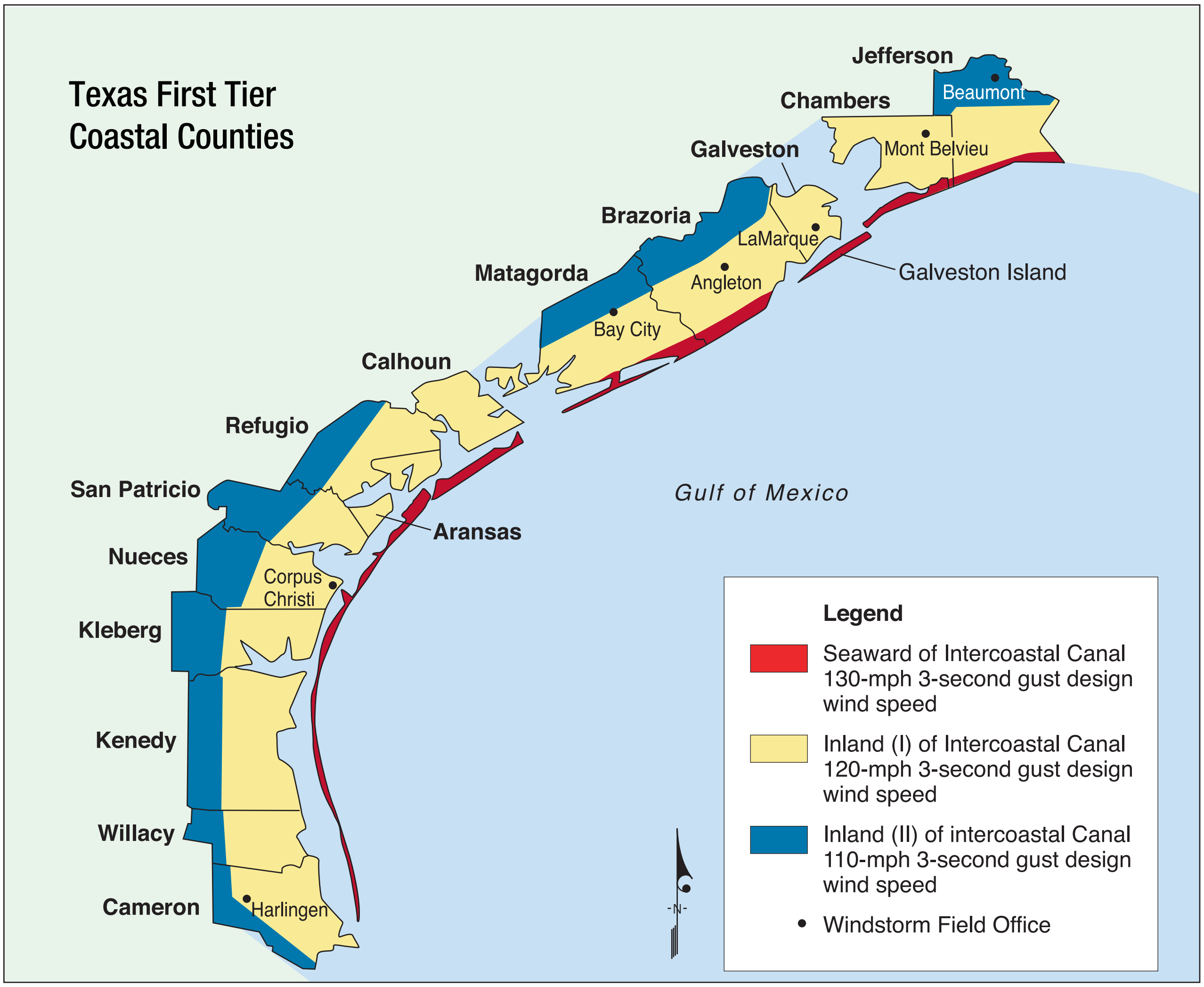


Figure 2-10. Texas Windstorm Designated Catastrophe Areas

SOURCE: http://www.tdi.state.tx.us/wind

6 www.tdi.state.tx.us/wind/geninfo.html

2.3.3 Texas Windstorm Program – Insights and Opinions

The TDI Windstorm Program has evolved from using prescriptive codes and construction criteria with minimal requirements for high wind construction to adopting nationally recognized codes, such as the IRC and IBC. Properties that are constructed in accordance with the building specifications adopted by the TDI are eligible for insurability against wind hazards. However, numerous challenges continue for the windstorm program to remain solvent and for buildings to reliably resist hurricane wind forces. Some of these challenges and concerns include:

- TWIA losses in excess of a certain threshold will negatively impact the general revenue of the State of Texas. Numerous proposals are currently before the State Legislature to address this problem.
- The windborne debris criteria adopted by TDI address the opening protection for residences in the Seaward and Inland I zones, 130 mph and 120 mph wind zones, respectively. Ike's winds were less than design levels, and therefore windborne debris was basically relegated to flying asphalt shingles, roof aggregate, and wall cladding materials. However, MAT observations from other hurricane events have found that windborne debris frequently perforates windows, doors, garage doors, as well as the building envelope (walls and roof), thereby allowing the entrance of water that damages home finishes and contents. Furthermore, debris impacts on large openings can allow wind to enter the home, thereby producing internal pressurization failures. The MAT observed that some homeowners shuttered the windward facing seaward side of their home and left the leeward side unprotected. The TDI should consider adopting windborne debris protection for all zones in the Designated Catastrophe Area, including the Inland II zone (110 mph), in accordance with the ASCE 7-05/IRC 2003 guidelines that require opening protection within 1 mile of the coastal mean high water line where the basic wind speed is equal to or greater than 110 mph. Glazing or opening protection should be compliant with ASTM E 1886 and ASTM E 1996 as the impact testing criteria. This opening protection should be provided for all sides of the home, irrespective of the predominant wind direction or the expected direction of threat.
- Although Hurricane Ike was not a design wind event, significant losses of asphalt shingles (which were the predominate type of residential roof covering in the areas impacted by Hurricane Ike) were observed by the MAT (see Section 3.2.1.1). Asphalt shingles are affordable and available for use in areas with design wind speeds of 90, 120, and 150 mph. When asphalt shingles are used, TDI should consider requiring the use of shingles complying with ASTM D 7158 Class G shingles in Inland (I) and Inland (II) zones, and Class H shingles in the Seaward zone.

2.4 Enhanced Code Construction

Several terms have been used to describe construction that exceeds minimum building code requirements, with two of the more common terms being “Code-Plus” and “Fortified.”

- The Federal Alliance for Safe Homes (FLASH), Blueprint for Safety™ program, has published a *Contractors Field Manual*, whose glossary[7] defines “Code-Plus” as: “Additional measures are taken to build to higher standards or loads than the minimum required by code requirements. This adds strength and protection to the building” (FLASH, 2002).
- The IBHS has developed a *Fortified . . . for safer living®* program that specifies design, construction, and landscaping guidelines to increase a new house’s resistance to natural catastrophes, including hurricanes. After completing certain documentation, verification, and inspection steps, a builder is permitted to advertise a house as a “Fortified” house (IBHS, 2008).[8]
- Many FEMA documents, such as FEMA 55, *Coastal Construction Manual: Principles and Practices of Planning, Siting, Designing, Constructing, and Maintaining Residential Buildings in Coastal Areas* (June 2000) and FEMA 499, *Home Builders Guide to Coastal Construction* Technical Fact Sheet Series (August 2005), recommend best practices for design and construction that exceed minimum requirements of the NFIP and/or building code. These best practices include elevating a house to an elevation higher than the FIRM specifies (this practice is called “adding freeboard”); using an open foundation where a solid foundation may be permitted; and using different, additional, or stronger building components than the code calls for.

This Hurricane Ike MAT report refers to the above types of construction collectively as *enhanced code construction*. The exact meaning may vary geographically, because different States and communities have adopted and amended different building codes, or different editions of those codes, and thus have different minimum design and construction requirements.

One of the most important aspects of enhanced code construction for consumers and communities to recognize is that the mere designation or advertising of a building as being enhanced code construction does not necessarily mean the building will survive a hurricane or other severe event without damage. The MAT observed some enhanced code houses in Galveston County, TX, with flaws that led to building damage during Hurricane Ike, sometimes under less than design conditions.

Consumers and communities should also keep in mind that the criteria used to designate enhanced code construction evolve over time, and a house that satisfied enhanced code criteria at one point in time (and was truthfully claimed to be enhanced code construction) may not meet today’s criteria.

7 http://www.blueprintforsafety.org/glossary.php

8 See the Builder’s Guide at http://disastersafety.org/text.asp?id=builder_guide for more details

One important aspect of enhanced code construction in coastal areas is designing and constructing buildings to withstand flood levels above the BFE. Accomplishing this will require the addition of freeboard (see Section 7.1.1), strengthening foundations, and using flood damage-resistant materials above the lowest floor. A Hurricane Ike Recovery Advisory, *Designing for Flood Levels Above the BFE* (see Appendix D), is available to assist communities, design professionals, builders, and consumers.

Chris Jones
Larry Tanner
David Johnston
Dave Low
Mark Matulik
Tom Smith
Wallace Wilson

HURRICANE IKE IN TEXAS & LOUISIANA

3 Performance of Residential Buildings (Flood and Wind), One- to Two-Family and Multi-Family

Assessing the structural and building envelope performance of residential buildings was one of the main goals of the MAT.

3.1 Structural Performance

Assessing the structural and building envelope performance of residential buildings was one of the main goals of the MAT (the other being the assessment of critical facility performance—see Chapter 4). Making these assessments required location-specific information, gathered prior to and during the MAT's field investigations, and knowledge of the flood and wind loads and conditions to which the buildings were exposed during Hurricane Ike. In a few cases, additional data were gathered after field work was completed, but in most cases building performance judgments were based on information available to the MAT while in the field. Although the MAT believes its assessments of buildings described in this chapter are correct, statements made herein are not intended to represent final judgments as to the cause of damage to individual buildings—the MAT recognizes that further investigation by others may refine or alter judgments made by the MAT. Nevertheless, general damage patterns and trends observed by the MAT are valid and can be used as the basis for recommendations to improve residential design and construction.

3.1.1 Foundation Performance

Foundations in coastal areas must be able to perform several functions:

- Elevate the building above the surge and wave crest level
- Remain intact and functional despite scour and erosion effects
- Provide a continuous load path from the elevated building to the ground, and resist all vertical and lateral loads transferred from the elevated building to the foundation
- Resist flood loads—including storm surge, wave, and floodborne debris impacts—acting on the foundation and on any below-flood level obstructions that do not break away

Failure to perform any of these functions can result in building damage or loss. The MAT observed foundations that performed well (Figure 3-1), and foundations that failed to satisfy one or more of the requirements listed above.

Failures of the most common type of foundation observed by the MAT—the open (e.g., pile or column) foundation—were usually associated with one of two factors: insufficient embedment into the ground, or breakage of the piles or columns.

Embedment Failures. Embedment failures occur where a foundation is not deep enough in the ground to resist wind and flood loads pushing on the structure; a leaning foundation or overturned building results (Figure 3-2). Scour and erosion can exacerbate this mode of failure by reducing embedment.

Pile and Column Breakage. Pile and column breakage occur where the strength of the piles or columns is inadequate to resist the bending moments or shear forces caused by the flood and wind loads acting on the structure (Figures 3-3 and 3-4). Scour and erosion contribute to this mode of failure by increasing the un-braced pile/column length and by increasing the bending moments in the pile/column.

The methods used to secure an elevated building to the top of the foundation can affect the overall foundation strength. Connections at the tops of the piles or columns that do not provide fixity (i.e., resistance to rotation) allow greater stresses to develop in the piles or columns than would develop with connections that rigidly tie the structural elements together.

In most buildings the MAT evaluated, timber construction was used and the tops of the piles or columns were connected to the elevated buildings with bolted connections (Figure 3-5). This type of connection provides limited fixity; weakness in this type of connection can be overcome in some instances through the use of larger piles or columns and other design details that help to stiffen the foundation.

Figure 3-1.
Louisiana house sufficiently elevated on a foundation that withstood Ike flood loads

Figure 3-2.
A house on timber piles was pushed over by wind and flood loads and the load path failed at the connection between the floor beam and the piles. Embedment and elevation were also insufficient at this Bolivar Peninsula, TX, site.

Figure 3-3.
Broken timber piles (Galveston Island, TX)

Figure 3-4.
This concrete column failed due to lateral loads. Note limited overlap of reinforcing steel at the bottom of the column.

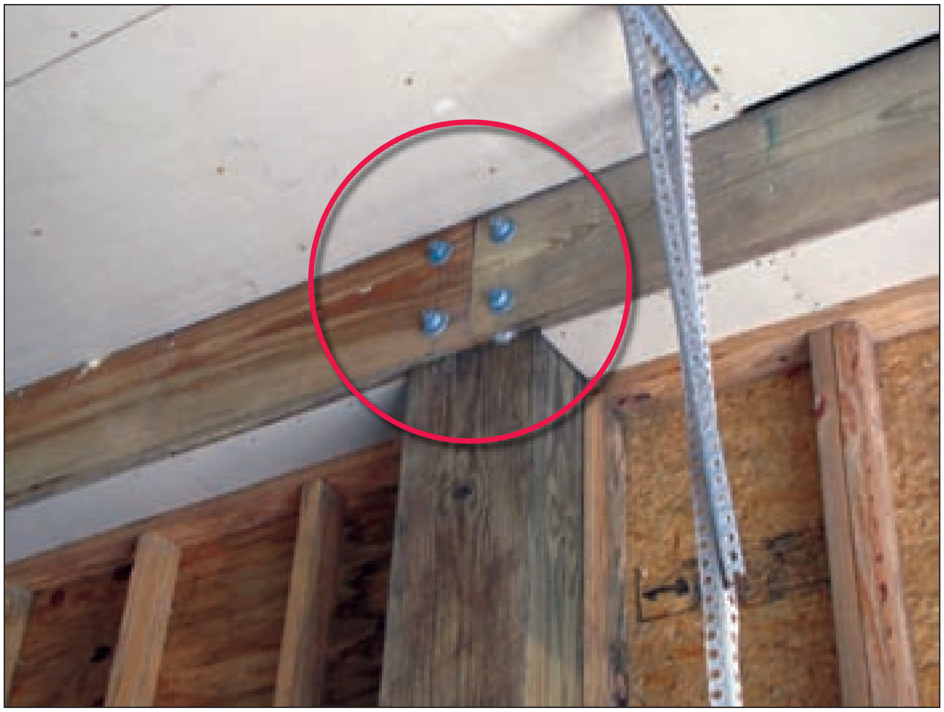


Figure 3-5.
Typical bolted connection between wood columns and wood beams

3.1.1.1 Foundation Function 1: Elevate the Building

Elevation is one of the most important keys to a successful coastal building. The MAT observed many residential buildings along the Gulf shoreline that were elevated above the effects of Ike's storm surge and waves, and sustained no significant damage; on the other hand, nearby buildings that were at lower elevations were heavily damaged or destroyed (Figure 3-6).

Figure 3-6.
Unlike the older and lower house on the right, the Zone V house on the left was elevated approximately 5 feet above the 16-foot National Geodetic Vertical Datum (NGVD) BFE and sustained no structural damage due to flooding (Crystal Beach, TX)

The MAT's observations of wave damage and analysis of building elevation data indicate that the wave crest elevation on much of the Bolivar Peninsula reached approximately 2 to 5 feet above the BFE.

It was difficult to obtain HWMs for flood levels on Bolivar Peninsula due to the magnitude of the destruction there. However, the MAT was able to supplement high water mark data collected by government agencies (see Section 1.2.3) with wave damage data in elevated houses that remained standing after Ike. For instance, houses such as the one shown in Figure 3-6 indicate that the wave crest elevation at that location was below the bottom of the elevated floor system (due to the fact that the floor system was intact). Damage such as that shown in Figure 3-7, where the shore-parallel floor joists were displaced landward, indicates the onset of wave damage to an elevated floor system. By carefully examining several such houses and by acquiring the corresponding lowest floor elevations from NFIP Elevation Certificates, the MAT concludes that the wave crest elevation reached approximately 18 to 20 feet NGVD, an elevation approximately 2 to 4 feet higher than the BFEs at these particular houses. Although it is possible that the wave crest reached higher elevations relative to the BFE, it is unlikely based on the lack of wave damage at some houses that were approximately 5 feet above the BFE (waves apparently passed beneath those elevated houses).

Figure 3-7. The landward displacement of shore-parallel floor joists indicates the onset of wave damage to an elevated floor system (Bolivar Peninsula, TX)

The MAT also observed many bay shoreline and inland examples that demonstrate the importance of elevation. Houses situated at higher elevations, whether because of elevated foundations or because of being sited on high ground, sustained little or no damage, while adjacent houses with lower elevations were damaged or destroyed. In many cases, undamaged bay-front houses were elevated above the surge and wave elevation on pile foundations. Figure 3-8 shows a house elevated above the BFE and Ike wave effects that suffered no significant damage due to flooding. However, the nearby at-grade house shown in the inset was heavily damaged. On some bay-front shorelines (or inland areas) where storm wave heights were smaller and where erosion did not threaten a house, siting on natural high ground or fill provided the required elevation and support for the house (Figure 3-9).

The MAT observed many houses in more inland locations that were not elevated high enough to avoid Ike flooding, and were apparently subject to surge inundation, low-velocity storm surge flow, and, in some cases, minor wave action. These houses sustained varying degrees of flood damage depending on site-specific flood depths, flood loads, and construction details. Some

Figure 3-8.
This elevated house (Zone V, BFE = 15 feet) suffered no significant damage due to flooding. The nearby at-grade house in the background, shown in the inset, was heavily damaged (Baytown, TX).

Figure 3-9.
Adjacent houses south of Baytown, TX. The house on the left (Zone X) was above the surge and wave runup level and sustained no flood damage. The house on the right (Zone A, BFE = 13 feet) was at a lower elevation and was largely destroyed by surge, waves, and floating debris.

were inundated by several feet of flooding, as they had been during Hurricane Rita in 2005. The house shown in Figure 3-10 was not subject to wave action during Ike and suffered no apparent structural damage. However, flood damage to contents and finishings were likely severe. Other houses sustained significant structural damage due to storm surge flow (Figure 3-11). Some floated or were washed off their foundations (Figure 3-12).

Figure 3-10.
The Ike flood level reached approximately 3 feet above the floor slab (1 foot above the 6-foot BFE) of this Zone A house (see inset), which was reported to have been similarly inundated during Hurricane Rita. The MAT was told that the house will be elevated (Lake Charles, LA).

Figure 3-11.
This house sustained significant structural damage due to storm surge and small waves above the 9-foot BFE in Zone A (Bridge City, TX). Note flood debris line on the roof.

Figure 3-12.
This house floated off its foundation due to insufficient elevation and inadequate connections between the foundation and the house (Golden Meadow, LA)

The tallest residential foundations the MAT observed were at *Fortified... for safer living*® houses (see text box and Section 2.4) on Bolivar Peninsula. The houses are elevated with their lowest floor at approximately 27 feet NGVD (21 feet above the ground), 10 feet above the BFE (Figure 3-13). These foundations are reinforced, cast-in-place concrete columns connected to concrete slabs and drilled concrete shafts (extending 10 feet below grade). Ten of the 13 houses survived Ike, and three were destroyed.

WARNING

Elevation alone is not adequate to ensure a building will perform well during a high wind and flood event. A building must be elevated on a well-designed and constructed foundation. Some of the tallest foundations the Ike MAT observed either failed or were in danger of failing.

The houses had substantial timber decks connected to the columns at or just above the BFE, approximately mid-way between the ground and the elevated houses. Although not designed as breakaway decks, the decks broke away during Ike, probably a result of both wave and flood-borne debris effects. The deck failures damaged some of the concrete columns where the decks were connected (Figure 3-14).

The concrete columns left standing between the slabs and the (destroyed) elevated decks were observed to have a series of horizontal cracks in the columns (Figure 3-15). These cracks likely resulted from the columns bending in response to a combination of wind loads on the elevated houses, flood loads (waves, currents, debris) on the columns, and transfer of flood loads from the decks to the columns.

FORTIFIED... FOR SAFER LIVING®

The *Fortified... for safer living*® designation is from the Institute for Business and Home Safety. The "Fortified®" program specifies design and construction guidelines to increase a house's resistance to natural disasters such as hurricanes. For more information: www.disastersafety.org/text.asp?id=fortified.

Figure 3-13.
Looking toward the Gulf, past Zone V houses on tall concrete column foundations (with the lowest floor 10 feet above the 17-foot BFE). Four of the five tall houses shown in this photograph survived Ike (red circle indicates destroyed house). The red arrow points to exposed geotextile tube (under former dune). Note other destroyed houses (not on tall foundations) seaward of the highway (Bolivar Peninsula, TX).

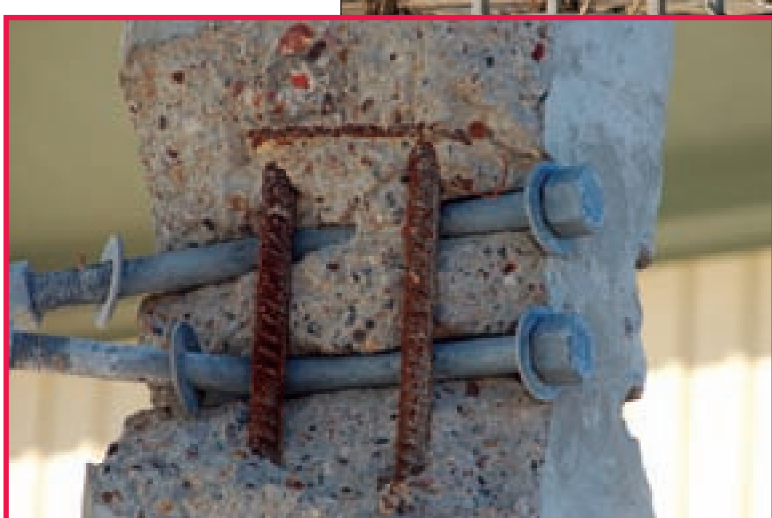


Figure 3-14.
Ground-level view of elevated houses with inset showing typical column damage where the timber deck broke away (Bolivar Peninsula, TX)

Figure 3-15.
Concrete column showing cracking that was likely caused by extreme column bending stresses due to lateral loads on the elevated house and foundation (Bolivar Peninsula, TX)

3.1.1.2 Foundation Function 2: Resist Scour and Erosion

Residential building performance in coastal areas often depends on the capability of the building foundation to accommodate a lowering of the ground elevation and loss of soil support. The lowering of the ground is often accompanied by high winds, storm surge, large waves, and debris propelled by wind or water, which further magnify any adverse effects of soil loss.

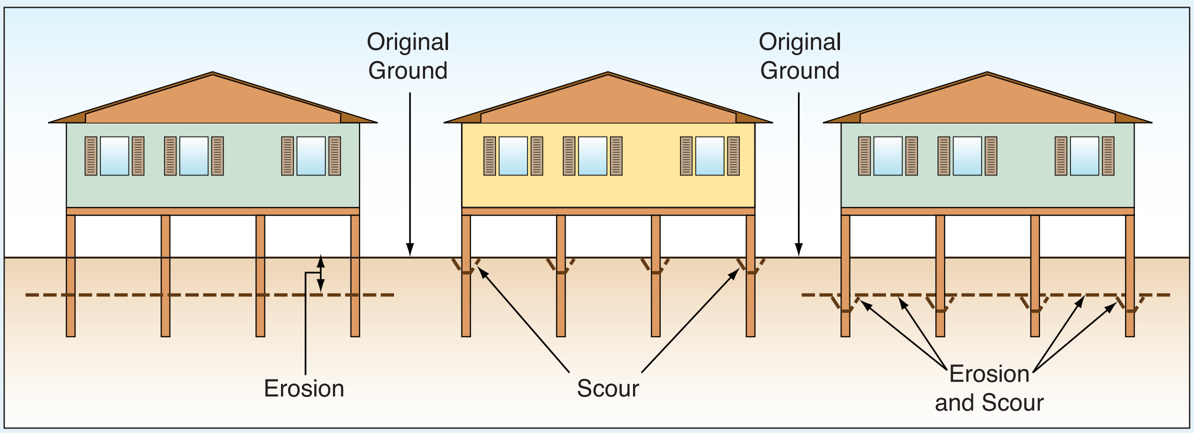
For foundation design purposes, it is important to distinguish the nature and extent of soil loss expected around a building, since these can affect the stillwater flood depth and the magnitude of the flood conditions at the site (see erosion and scour text box on next page).

The MAT observed significant levels of erosion and scour near buildings situated along the Gulf of Mexico. Erosion was widespread along the Gulf of Mexico shoreline of Follets Island, Galveston Island, and Bolivar Peninsula, TX, and portions of southwest Louisiana. Scour was particularly evident around building foundations on Bolivar Peninsula and at Holly Beach (Cameron Parish, LA). The MAT believes that erosion and scour were among the major contributors to structural failure of buildings close to the Gulf shoreline. Significant erosion and scour were not observed by the MAT along the bay shorelines, although there may have been some locations where such erosion and scour occurred.

EROSION AND SCOUR

Erosion is a lowering of the ground surface over a large area, usually brought on by a coastal storm or long-term shoreline recession. Erosion increases the unbraced length of vertical foundation elements and increases the stillwater depth at the building, allowing larger waves to reach the foundation.

Scour is a localized loss of soil immediately around an object or obstruction. Scour also increases the unbraced length of vertical foundation elements, but does not act to increase the stillwater flood depth across which waves propagate (thus, scour can be ignored for wave height calculation purposes). Walls, columns, pilings, pile caps, footings, slabs, and other objects found under a coastal building can contribute to localized scour.



Depending on the building location, soil characteristics, and flood conditions, a building may be subject to either coastal erosion or scour, or both. Refer to Hurricane Ike Recovery Advisory on *Erosion, Scour and Foundation Design* (Appendix D) for additional information.

A preliminary review of pre- and post-Ike aerial photographs suggests that between 100 and 200 feet of dunes and vegetation were lost during Ike along much of the Gulf shoreline (see Figure 3-16).

This loss occurred in areas with natural dunes and in areas where previously eroded dunes had been rebuilt and reinforced with geotextile tubes (see Figures 3-13 and 3-17). As of 2003, approximately 7.6 miles of geotextile tube dune reinforcement had been installed along the Texas shoreline, mostly along the Bolivar Peninsula and western Galveston Island shorelines (Gibeaut et al., 2003). Virtually all of these tubes were uncovered by Ike, and many were destroyed.

Figure 3-16.
Pre- and post-Ike aerial photographs of the east end of Galveston Island, TX, illustrating some of the most significant loss of dunes and vegetation during Ike

SOURCE: USGS, http://coastal.er.usgs.gov/hurricanes/ike/photo-comparisons/galveston.html

The Ike MAT noted that the amount of scour around pile foundations was far greater than that observed during previous post-storm investigations, both in terms of frequency of occurrence and depth of scour. Most of the scour was observed at foundations with concrete slabs at ground level, but this is likely due to the prevalence of this type of construction; significant scour was also observed around some pile foundations before the slabs had been constructed. Significant scour (several feet deep, tens of feet in diameter) was observed after Ike at hundreds of the buildings that were still standing near the Gulf shoreline.

Figure 3-17. Exposed geotextile tubes formerly covered by sand and dune vegetation. Note erosion behind the tubes and under Zone V (BFE = 18 feet) buildings (yellow arrow at left).

Figures 3-18 and 3-19 show buildings at Holly Beach, LA, both of which sustained significant scour around foundations. Of the approximately 20 pile-elevated houses in existence at Holly Beach prior to Hurricane Ike, nearly half experienced significant foundation scour (virtually all of buildings at Holly Beach were destroyed by Hurricane Rita in 2005, and the houses observed by the Ike MAT had been built since 2005).

> The amount of scour around pile foundations observed by the Ike MAT far exceeded what current design guidance predicts.

Figure 3-18. Foundation scour observed at Holly Beach, LA

Figure 3-19.
Foundation scour observed at Holly Beach, LA (Zone V, ABFE = 16 feet)

Figure 3-20 shows a case of extreme foundation scour at a house on Bolivar Peninsula. The scour depression shown was reported by a local contractor to have been as much as 10 feet deep. The house was able to withstand the scour and the wind and flood loads acting on the structure, but lack of soil support allowed the bottoms of some of the piles supporting the deck on the right side of the house to be shifted toward the left.

Figure 3-20.
Foundation scour was reported to be 10 feet deep—note the bottoms of the piles on the right side of building that have been pushed toward the building (Bolivar Peninsula, TX; Zone V)

In some cases, pile foundations subject to erosion and/or scour were not embedded deeply enough to resist the loads and conditions that were present during Ike. Figure 3-21 shows such a case where a pile foundation shifted under an elevated house. Scour and erosion contributed to the failure. The presence of the attached, but broken, concrete slab could also have contributed to the foundation failure by reducing the lateral support formerly provided by the intact slab, and by causing eccentric loading of the piles (see Section 3.3.3).

Figure 3-21.
Failure of a timber pile foundation undermined by scour and erosion. Inset shows close-up of concrete slab failure and rotation of some of the foundation piles (Galveston Island, TX; Zone V).

One other aspect of scour was noted by the MAT—linear scour features that result in the loss of soil around or under buildings when storm surge flow is channeled or directed across a building site. This process usually takes place where storm surge flow is constrained between large buildings or gaps in shore protection, or when storm surge return flow to the sea follows paths of least resistance, such as along canals and roads (Figure 3-22). Some of the many buildings lost during Ike were likely lost as a result of this process.

Figure 3-22.
Linear scour features tend to align with canals and roads as storm surge returns to the Gulf. Houses such as this one were fortunate not to be undermined and lost during Ike, as many homes undoubtedly were (Bolivar Peninsula, TX).

3.1.1.3 Foundation Function 3: Provide a Continuous Load Path to the Ground

Loads acting on a building follow many paths through the building and must eventually be resisted by the ground, or the building will fail. Loads accumulate as they are routed through key connections in a building (connections between members are usually the weak links in a load path). Load paths must be continuous, from the top of the building, through the foundation, and into the ground; failed or missed connections cause the loads to be rerouted through unintended load paths, potentially overloading those paths and resulting in structural failure. A graphic illustrating vertical and horizontal load paths from an elevated building to the foundation and into the ground is shown in Figure 3-23.

Connections between structural members are often the weak point in a load path, and the MAT observed many load path failures at the floor system-pile connection. The MAT also observed instances where this connection was adequate to prevent structural failure during Ike. Figure 3-24 shows an example of a wood-frame house elevated on concrete columns. The house survived with no structural damage even though the owner reported a flood level above the lowest floor. The attachment of the timber floor beams to the concrete columns provided load path continuity and prevented the house from floating or washing off its foundation (Figure 3-25). Although this house survived Hurricane Ike, this type of connection only provides limited resistance to lateral loads and applied moments—had the house experienced a higher surge or stronger winds, it may not have survived. The MAT estimated the 3-second gust wind speed (Exposure C) during Ike was approximately 85 mph at this site, but if wind speeds or lateral flood loads had been higher, this house could have sustained structural damage.

Figure 3-23.
Example load path through a pile foundation (note: some building components are not shown)
SOURCE: FEMA P-762, *LOCAL OFFICIALS GUIDE FOR COASTAL CONSTRUCTION*

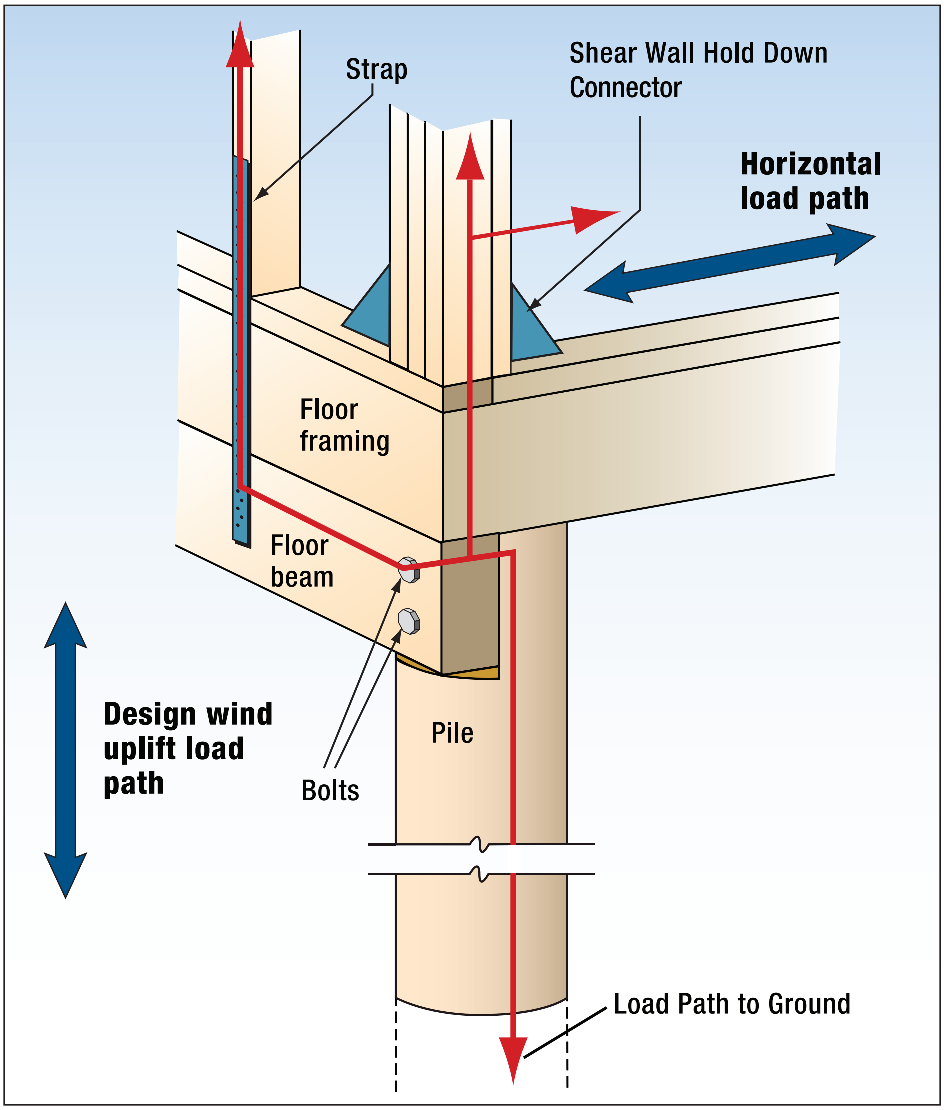


Figure 3-24.
This Bridge City, TX, house sustained no structural damage, despite the fact that the owner reported that Ike flood levels rose above the lowest floor

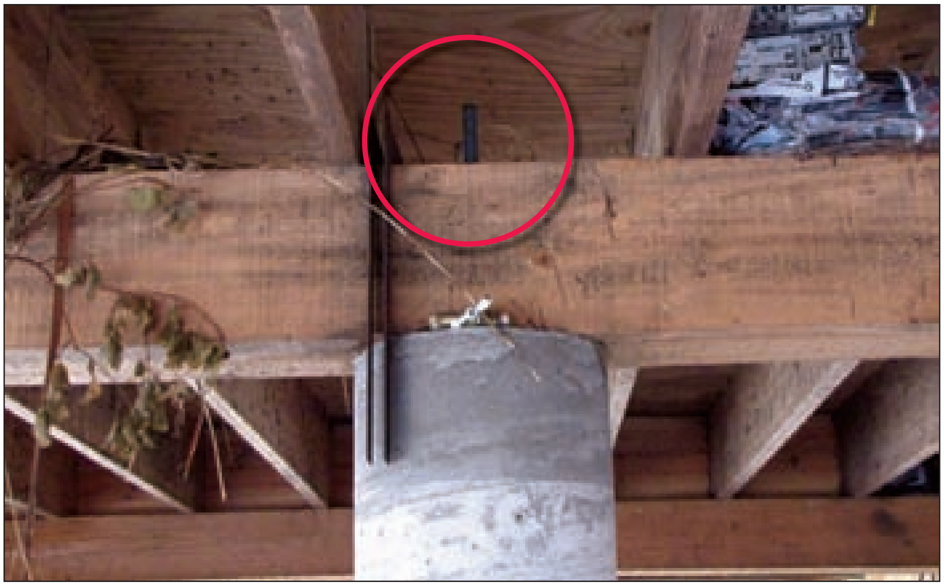


Figure 3-25.
A ⅝-inch diameter galvanized steel anchor bolt in red circle (with washer and nut, not visible in this photograph) provided connections between beam and column for the house shown in Figure 3-24. This does not appear to be an engineered connection.

Some designs rely on connections between columns and beams to provide fixity (resistance to rotation), particularly in commercial or multi-family buildings of concrete construction. Figure 3-26 shows one such example—reinforcing steel that will extend into a concrete beam (under construction) and connect columns and beams. The cast-in-place concrete connection will provide resistance to rotation.

Figure 3-26.
Reinforcing steel extending from the top of a concrete column (building under construction) (Galveston Island, TX)

The MAT noted instances of other types of foundation load path failures, including those at the point where a column attached to a pile cap, slab, or grade beam. Deterioration of timber piles contributed to load path failures in some foundations (Figure 3-27). The deterioration could have been the result of inadequate preservative treatment or poor design/construction practice. In other cases, deterioration was observed that did not result in foundation failure during Ike; however, such a weakened foundation would be more susceptible to failure in the future (Figure 3-28).

Figure 3-27.
Deterioration in the wood piling likely contributed to the foundation failure (Bolivar Peninsula, TX)

Figure 3-28.
Deterioration in wood piling. The foundation did not fail during Ike, but it was weakened and will be more susceptible to failure in the future (Galveston Island, TX).

The MAT also noted cases where houses survived Ike, but must not have been exposed to high winds or large flood loads; otherwise the lack of load path continuity would have resulted in foundation failure. The house shown in Figure 3-29 is resting on top of precast concrete piers, stacked concrete masonry units (CMUs), and shallow footing pads—the necessary structural connections are missing. This design will not provide a continuous load path from the elevated house to the ground, and does not comply with minimum NFIP or building code requirements. This foundation will likely fail if it is subject to high winds and/or waves, velocity flow, or scour. Additional discussion of load paths is provided in Section 3.1.2.3.

Figure 3-29.
House resting (i.e., with no structural connection) on top of precast concrete piers, stacked CMUs, and shallow footing pads (New Iberia, LA)

3.1.1.4 Foundation Function 4: Resist Flood Loads

Flood loads acting on a coastal building can include:

- Hydrostatic loads (pressure from standing or slowly moving water). Vertical hydrostatic forces are known as buoyant forces, and cause objects to float, including houses that are poorly attached to their foundations. Lateral hydrostatic forces will not harm pile or column (open) foundations, but can cause damage to foundation walls and enclosure walls that do not have the flood openings required to allow inside and outside water levels to equalize.
- Hydrodynamic loads (forces caused by fast-moving water, the up-rush of broken waves, etc.). Storm surge flowing past or around a foundation or building will lead to hydrodynamic loads.
- Wave loads (caused by waves breaking on or striking a building foundation). Wave loads are high magnitude, short duration loads that can cause rapid destruction of inadequately elevated or constructed buildings. Hundreds of waves can strike a building during an episode of hurricane flooding.
- Floodborne debris impacts (parts of broken structures striking a building, or becoming lodged in a building foundation and transferring other flood loads to the foundation). Large numbers of buildings destroyed by flood forces contributed to large quantities of floodborne debris, and undoubtedly led to additional building failures during Ike.

Flood damages to residential buildings observed by the MAT were consistent with the nature and magnitudes of the flood loads described above.

- In locations where waves were small and flood velocities were low, there was little damage to houses elevated above the flood level on NFIP-compliant foundations. Houses constructed at grade, or not elevated high enough above the ground to escape the flooding, were inundated and sometimes dislodged from their foundations.
- In locations where waves were larger, flow velocities were greater, and floodborne debris generation was significant. Houses not elevated high enough were severely damaged or destroyed. Houses elevated above the wave crest level were still subject to damage or destruction if their foundations could not withstand the flood loads and failed.

Typical, low-rise residential buildings near the shoreline can be designed and constructed to resist wind loads, but must be elevated high enough on a pile or column (open) foundation to avoid flood loads.

Wind pressures acting on walls of low-rise buildings are almost always less than 100 pounds per square foot (psf), and these loads can be resisted easily by proper design and construction. However, fast-moving storm surge and floodborne debris can exert pressures several times higher than wind pressures against a building wall. Wave pressures against walls can reach several hundred, or in extreme cases, thousands of psf.

Even lateral flood loads acting on pile or column foundations can reach 1,000 pounds or more against each pile or column. These loads can be resisted, but only by properly designed and constructed open foundations.

The typical wave damage patterns described above are illustrated in Figure 3-30. Damage to properly designed and constructed elevated houses is generally minor until the waves reach the elevated floor system, at which point the damage increases dramatically with increasing water level and wave height. The importance of adding freeboard—elevating above the wave crest level—is apparent (see Section 3.1.3 and the Ike Recovery Advisory, *Designing for Flood Levels above the BFE).*

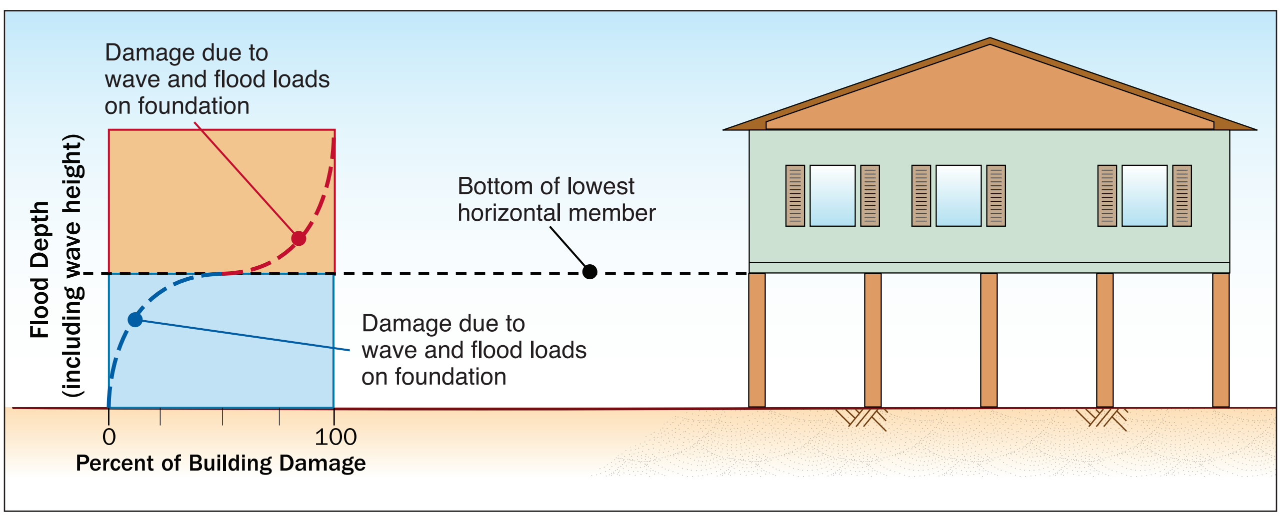


Figure 3-30. Idealized depth-damage relationship for an elevated building subject to waves

Wave effects and floodborne debris impacts were a major cause of building structural failure during Hurricane Ike, both on lands near the Gulf of Mexico and immediately adjacent to many bay-front shorelines. Damage was more severe and widespread along the Gulf shoreline, as would be expected, since the wave heights were larger there. Also, the loss of many buildings along the Gulf shoreline added greatly to the debris stream available to strike and damage other buildings farther inland.

> An estimated 3,600 buildings, (approximately 61 percent of the pre-Ike buildings) on Bolivar Peninsula were destroyed by Hurricane Ike, and approximately 2,200 (37 percent) more were damaged (Halff Associates, 2008). Much of the Peninsula was inundated by an estimated 6 to 10 feet of stillwater, and experienced wave effects above that level—meaning that Ike flood levels exceeded the BFE for virtually all of the Peninsula. This would explain the widespread loss of elevated houses on the Peninsula, and the survival of only those houses elevated the highest, with deep foundations resistant to waves, debris, storm surge, erosion, and scour.

It is not always possible to separate damages caused by waves alone from that caused by floodborne debris, especially since the debris is carried by the surge and waves. However, the direct and indirect effects of waves should be considered one of the two most damaging aspects of coastal flooding for coastal residential buildings (erosion and scour being the other).

Figure 3-31 shows a comparison of pre- and post-Ike photographs for the Crystal Beach area of the Bolivar Peninsula. The Peninsula is the region where Hurricane Ike storm surge levels and wave heights appear to have reached maximums along the Gulf shoreline. Buildings along the Gulf shoreline of the Peninsula were likely subject to the greatest flood forces during Ike, and sustained the worst damage. Damage in this area has been compared to the Mississippi coast following Hurricane Katrina.

Figures 3-32 and 3-33 show examples of houses affected by waves and the inland penetration of large debris fields. The combination of waves and debris led to the destruction of many houses on Bolivar Peninsula.

Figure 3-31.
Pre- and post-Ike aerial photographs of the Crystal Beach area of Bolivar Peninsula, TX
SOURCE: USGS[1]

1 http://coastal.er.usgs.gov/hurricanes/ike/photo-comparisons/bolivar.html

Figure 3-32.
Seaward side of Zone V house struck by waves. The deck, the elevated floor system, and the seaward walls were destroyed or heavily damaged (Bolivar Peninsula, TX).

Figure 3-33.
Roofs, walls, and other parts of destroyed houses washed landward to and inland of this location, approximately ½ mile from the Gulf shoreline of Bolivar Peninsula, TX

Although flood levels and wave conditions were not as severe on Galveston Island as on the Bolivar Peninsula, many houses were also lost there, largely as a result of waves and erosion. Figure 3-34 shows one example, approximately 3 miles west of the seawall, where two Gulf-front houses were lost.

Figure 3-34.
Broken piles beneath destroyed Gulf-front houses, Galveston Island, TX (west of the seawall)

Figures 3-35 and 3-36 show examples of Ike wave damage typical for Galveston Bay, where wave heights were less than those on the Gulf shoreline. These at-grade buildings were gutted or destroyed by storm surge, waves, and floodborne debris. In both cases, nearby buildings elevated on pile foundations survived, with damage only to breakaway walls and access stairs.

Figure 3-35.
Damage to at-grade house in Zone V likely caused by wave and surge along the northern Galveston Bay shoreline in Baytown, TX

Figure 3-36.
Likely wave and debris damage to townhouse building along the western Galveston Bay in Seabrook, TX. The building was supported on shore-parallel masonry walls, and is landward of another building that was destroyed by Ike.

3.1.2 Main Wind Force Resisting System

According to ASCE 7-05, the MWFRS is an assemblage of structural elements that provide support and stability for the overall structure. The MWFRS can be thought of as the portion of a building's structural frame that collects wind loads from the building envelope and transfers those loads to the ground via the building's foundation. Elements of the building envelope that do not qualify as a part of the MWFRS are identified as C&C. While some may consider the foundation to be part of the MWFRS, the following discussion will focus on that portion of the structural system above the foundation.

3.1.2.1 High Winds

High winds can originate from a number of events—tornadoes, hurricanes, extra-tropical cyclones, and other coastal storms. The most current design wind speeds are given by the national load standard, ASCE 7-05. Figure 3-37, taken from ASCE 7-05, shows the geographic distribution of design wind speeds for Gulf of Mexico and Atlantic Ocean portions of the United States.

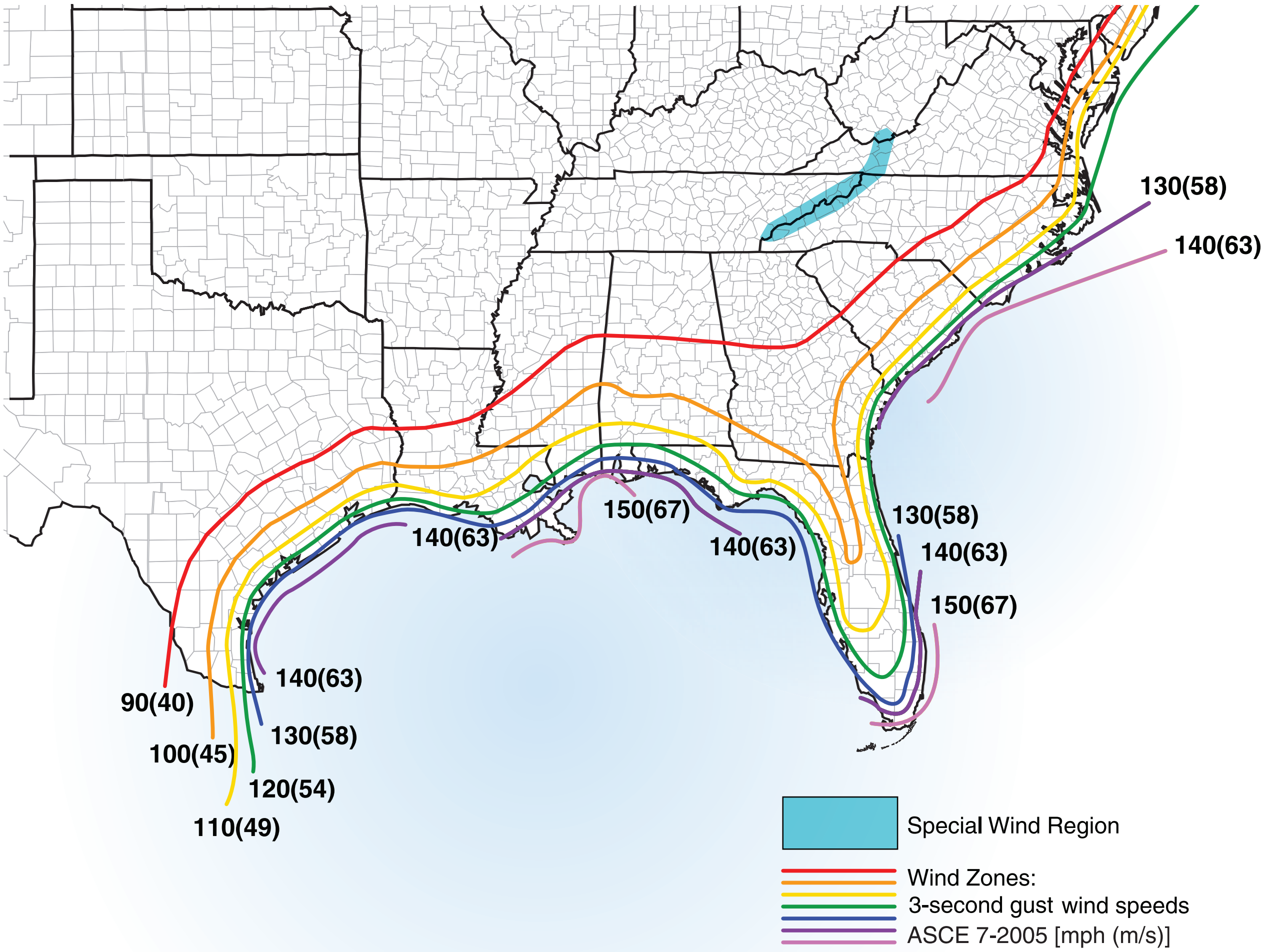


Figure 3-37. ASCE wind speed map (ASCE 7-05)

High winds are capable of imposing large lateral (horizontal) and uplift (vertical) forces on buildings (see Figure 3-38). Residential buildings can suffer extensive wind damage when they are improperly designed and constructed and when wind speeds exceed design levels. The damages shown in Figures 3-39, 3-40, and 3-41 exemplify poor design and construction, since Ike's winds were less than design levels.

The effects of high winds on a building will depend on several factors:

- Maximum wind speeds, gustiness of the winds, wind directions, and duration of high winds
- Height of building above ground
- Exposure or shielding of the building (by topography, vegetation, or other buildings) relative to wind direction
- Topographic effects (hills and escarpments) that create wind speedup
- Strength of the structural frame, connections, and envelope (walls and roof)
- Shape of building and building components

- Number, size, location, and resistance to damage of openings (e.g., windows, doors, and vents)
- Presence and strength of shutters or opening protection
- Type, quantity, and velocity of windborne debris

Proper design and construction of residential structures, particularly those close to open water or near the coast, demand that every factor mentioned above be investigated and addressed carefully. Failure to do so may ultimately result in building damage or destruction by wind. Hurricane Ike winds removed the roof structure on the house shown in Figure 3-41. Hurricane straps could have been added, thereby greatly increasing the resistance to wind. Refer to IBHS 2005 Standards for proper connection of roof structural elements.

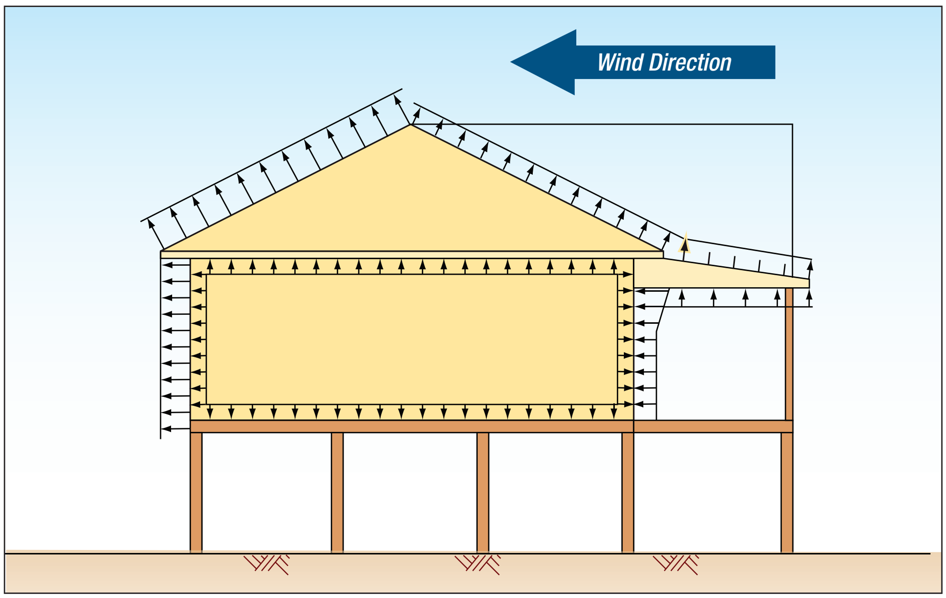


Figure 3-38.
Code-defined MWFRS wind loads on an elevated residential structure
SOURCE: FEMA 55

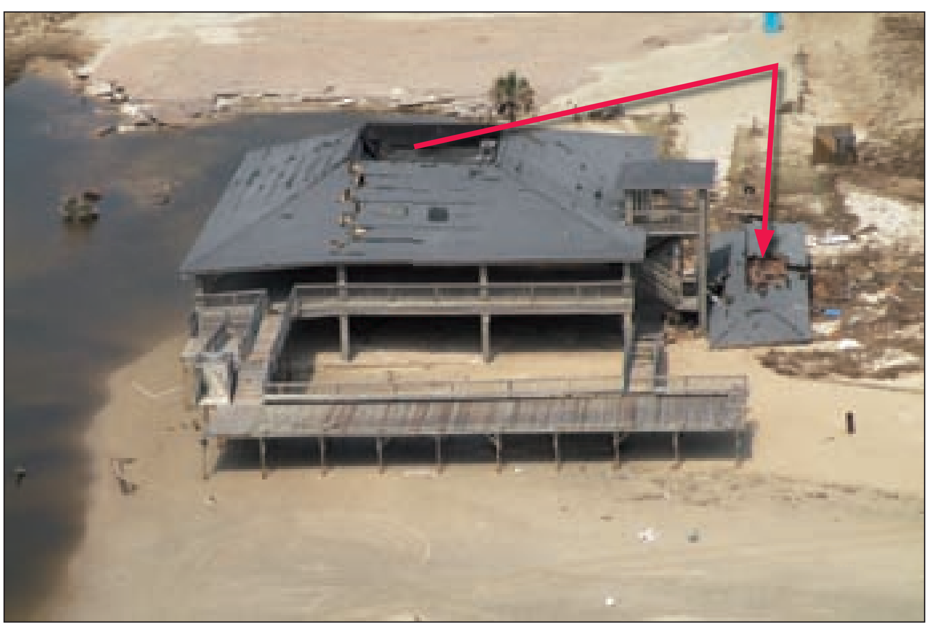


Figure 3-39.
Galveston, TX, West End Beach house with roof structure removed by Hurricane Ike.
The cause of the failure is unknown, but Ike wind speeds in this area were below design speeds (Hurricane Ike estimated wind speed in this area: 93 mph, Exposure C).

Figure 3-40.
This West Bay, Galveston Island, TX, apartment experienced gable-end wind damage as a result of sheathing failure and poor connection of the brick veneer to the stud walls (Hurricane Ike estimated wind speed in this area: 90 mph, Exposure B)

Figure 3-41.
The roof structure was poorly connected to this house in Grand Isle (Jefferson Parish, LA) and was blown off by 50-mph Ike winds (Exposure B)

3.1.2.2 Combination of Loads – MWFRS and C&C

Some elements of low-rise buildings are considered to be part of the C&C or part of the MWFRS, depending upon the wind load being considered. Using the example of the exterior walls of a masonry building, the MWFRS provisions are used to determine the in-plane shear forces in the design of these masonry walls, and the C&C provisions are used to determine the out-of-plane design bending loads.

The pressure (positive/inward or negative/outward suction) exerted by wind flowing over and around a building varies with time and location on the building. The highest pressures occur over small areas for a very short time in the regions of a building where the wind flow separation is quite significant (such as at corners of roofs and walls, ridges, hips, and overhangs). This flow separation can cause small vortices to form that can cause much higher pressures in small localized areas. These flow separation regions generally occur along the edges of the roof and corners of exterior walls (see Figures 3-42 and 3-43). Therefore, the design wind pressures for the design of the C&C element can be nearly three times the pressure used to design the structural framing of the building. Proper assessment of the design wind pressures is critical to developing the design of a building's structural frame and the selection of appropriate exterior cladding.

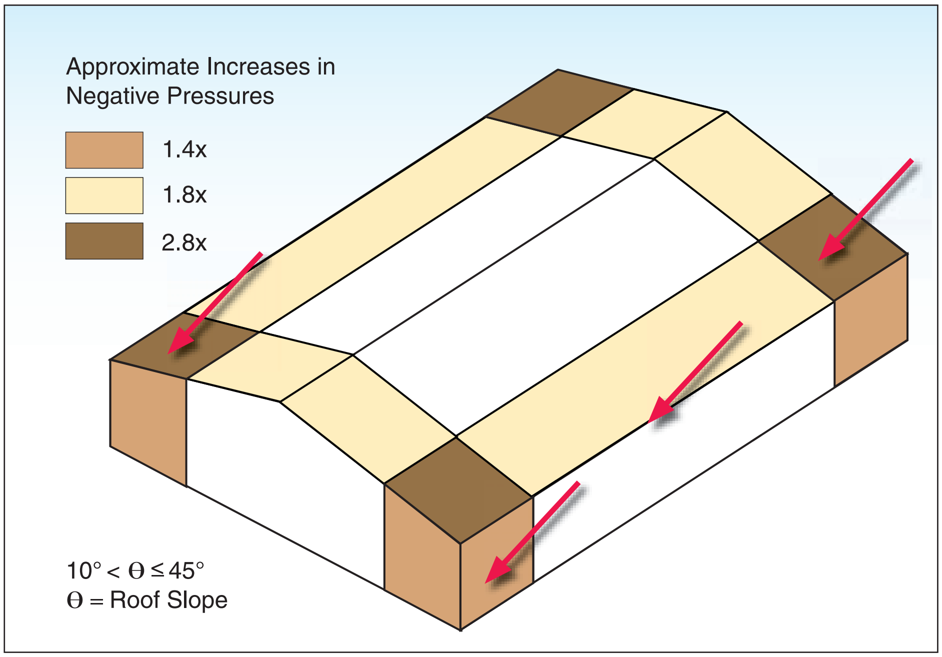


Figure 3-42.
Areas of roof covering loss (red arrows) indicate zones of higher wind pressure on a roof

Figure 3-43.
Galveston, TX, West End Beach house with roof damage in high pressure zones (Hurricane Ike estimated wind speed in this area: 95 mph, Exposure C)

In addition to these external pressures, openings and the natural porosity of the building components contribute to internal pressures. As seen in Figure 3-44, internal pressures introduced by building openings are additive to (or subtractive from) the external pressures. The magnitude of the internal pressures depends on whether the building is "enclosed," "partially enclosed," or "open" as defined by ASCE 7-05. In hurricane-prone regions as defined by ASCE 7-05, in order for a building to be considered "enclosed" for design purposes, glazing must either be impact-resistant or protected with shutters or other devices that are impact-resistant. This requirement also applies to indoor glazing and skylights. Refer to Section 3.2.4 for the discussion on windows and shutters and their performance in Hurricane Ike. As previously stated, Hurricane Ike was not a wind design event and therefore the MAT did not observe any notable examples of building failures resulting from internal pressurization.

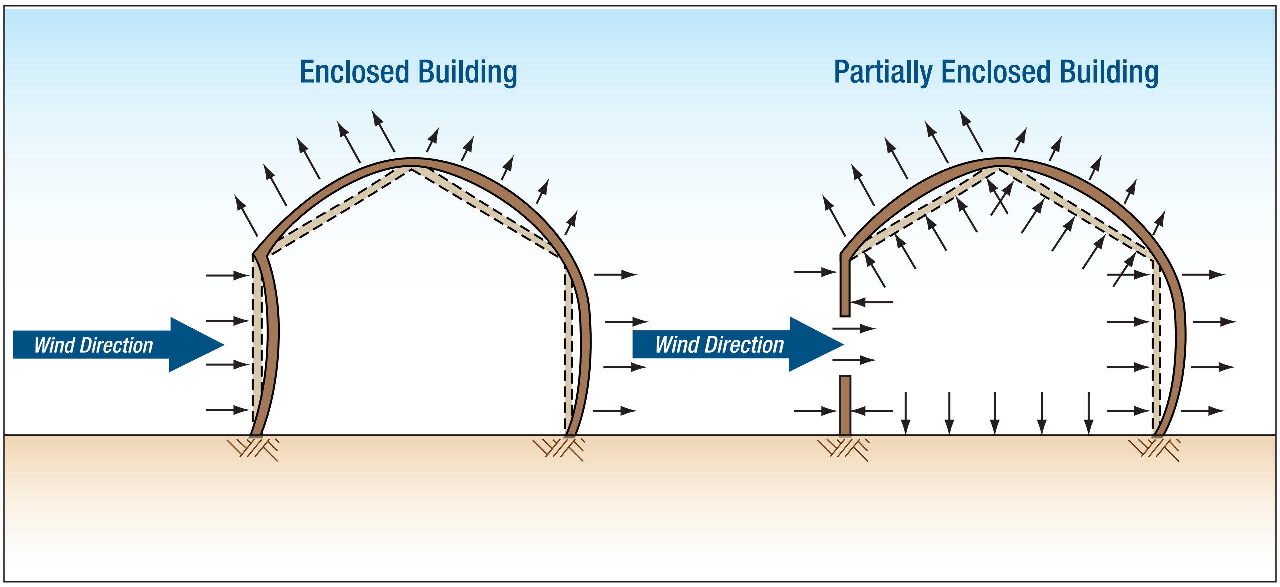


Figure 3-44.
Effect of wind on an enclosed building and a building with a wall opening producing a partially enclosed building by allowing internal pressurization of the structure

3.1.2.3 Load Paths

Figures 3-45 and 3-46 illustrate the load path concept for the elevated portion of a building. Wind loads collected and concentrated as shown in these figures must be passed through the foundation to the ground (see Figure 3-23).

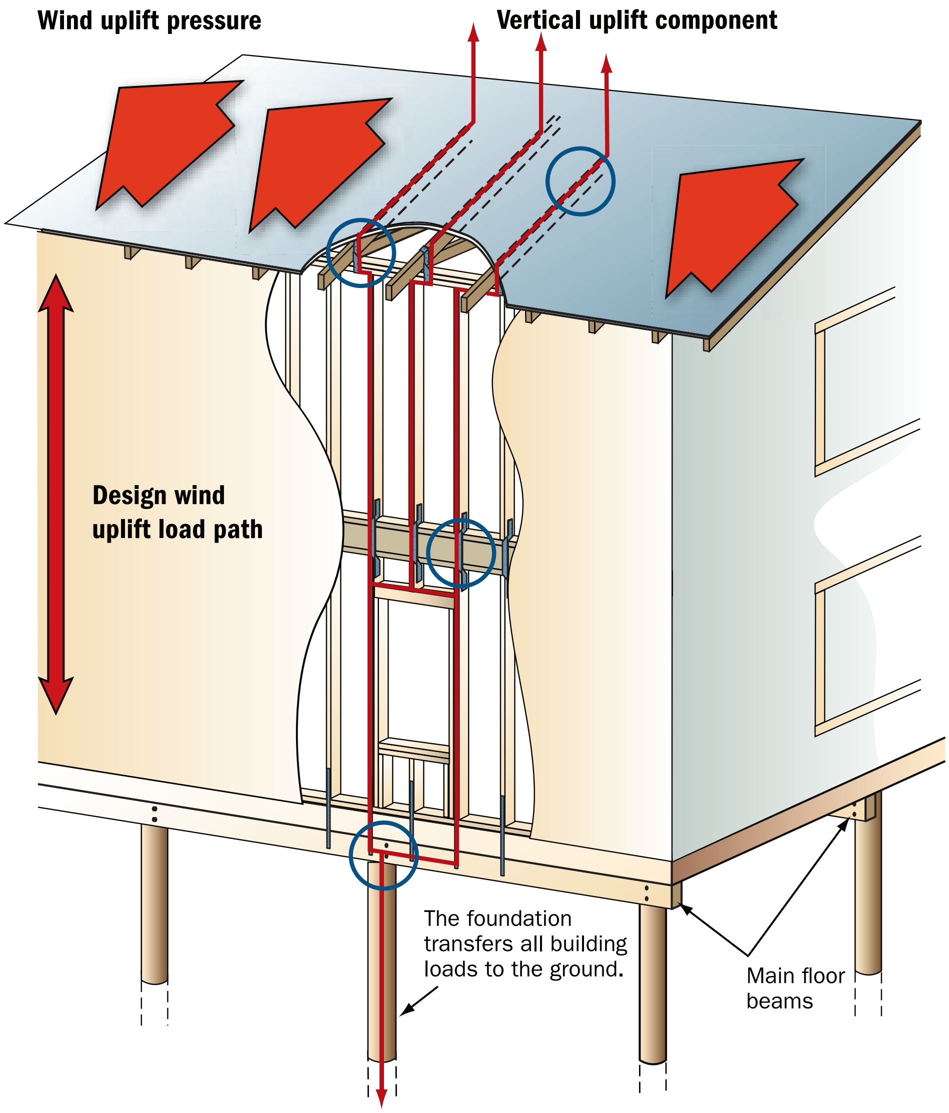


Figure 3-45. Depiction of a building load path

SOURCE: FEMA 489

Figure 3-46.
Load path around openings and connection to foundation pile
SOURCE: FEMA 499

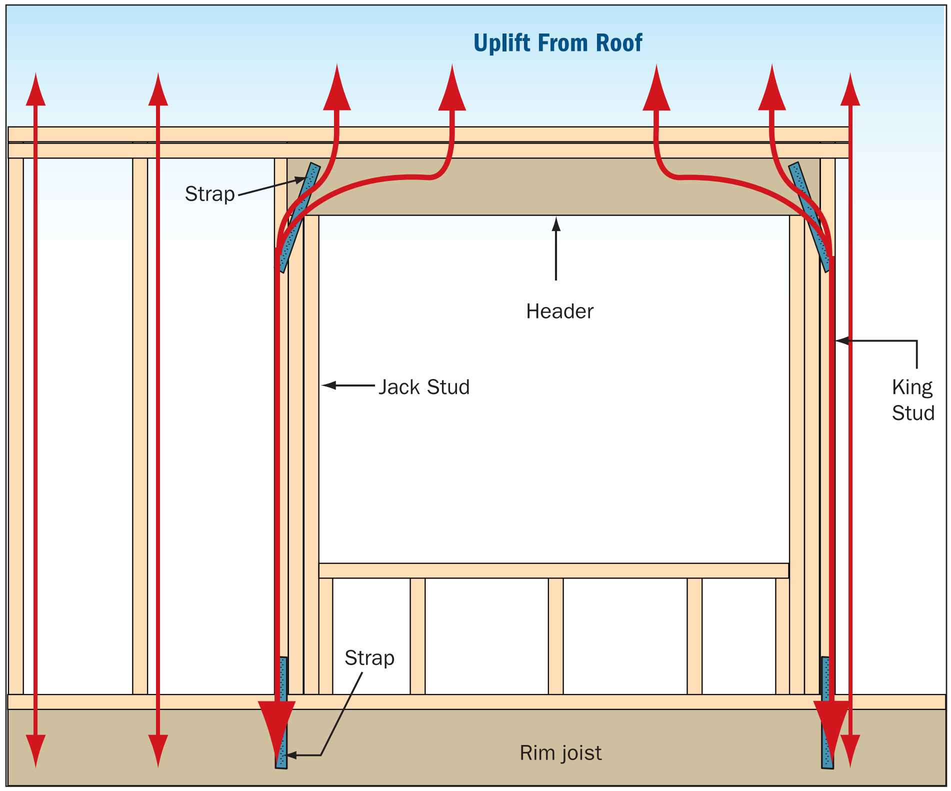


Figure 3-47 shows a house on western Galveston Island that collapsed during Ike. High water levels and waves acted on the foundation while winds (blowing from land toward the Gulf of Mexico) pushed the house seaward. The result was a foundation failure—the foundation could not provide the required load path continuity to the ground without breaking.

Figure 3-47.
Collapse of a West Galveston Island, TX, house due to foundation failure

Figure 3-48 shows a house on Bolivar Peninsula that remained standing although severely damaged by surge, waves, and wind. The house survived because its MWFRS and foundation load paths remained intact.

Figure 3-48.
Though much of the cladding and structural sheathing was destroyed by Ike's surge, the MWFRS of this Bolivar Peninsula, TX, beach house remained intact and connected

Piling connections to floor beams of elevated structures were routinely observed by the MAT. However, unless the building was substantially damaged or under construction, most load path connections of wall and roof structural elements were covered by building finishes and not visible for inspection. Some beam-to-piling connections were found to be strong and robust as seen in Figures 3-49 and 3-50. Many others were weakly connected with nails, too few bolts, or columns weakened by deep mortises (Figures 3-51).

Figure 3-49.
Strong concrete column-to-beam steel saddle connector

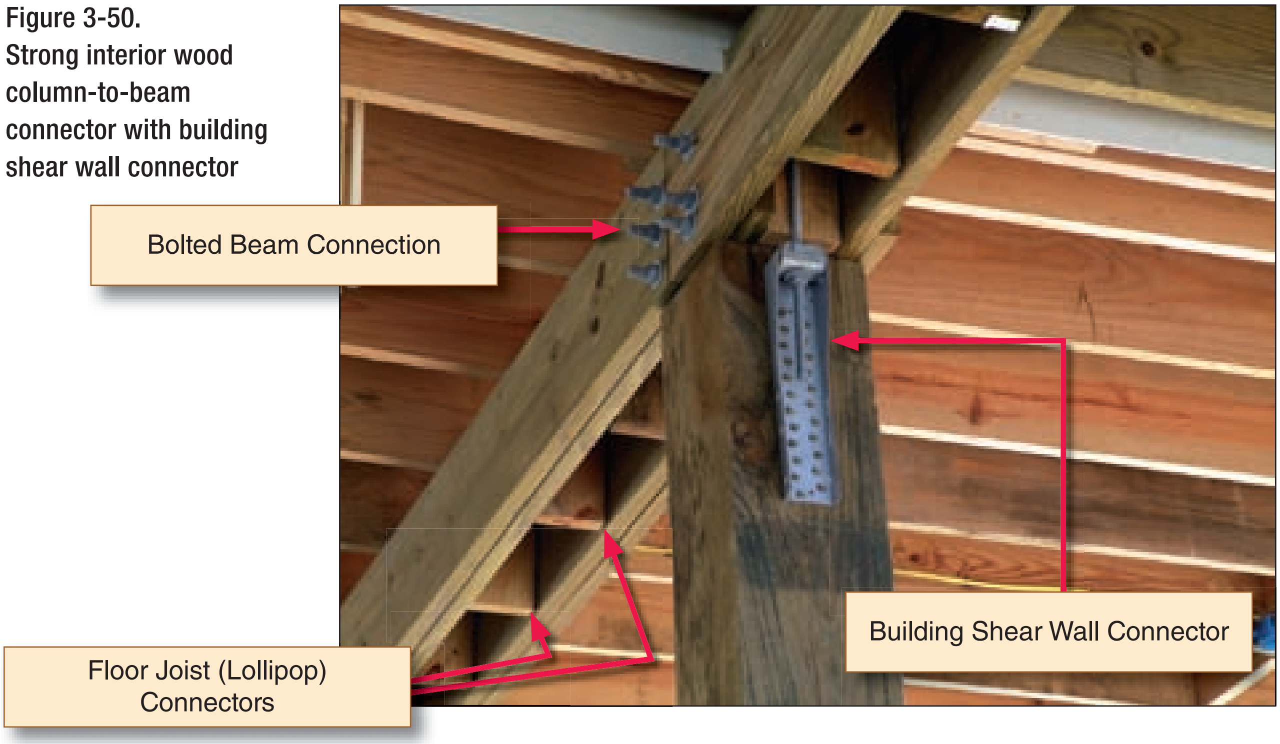


Figure 3-50.
Strong interior wood column-to-beam connector with building shear wall connector

Figure 3-51.
Poor beam connection to corner column

New construction was frequently observed with robust construction such as sill plates bolted to slabs-on-grade, studs clipped to double top plates, and wall-to-roof construction (Figures 3-52, 3-53, and 3-54).

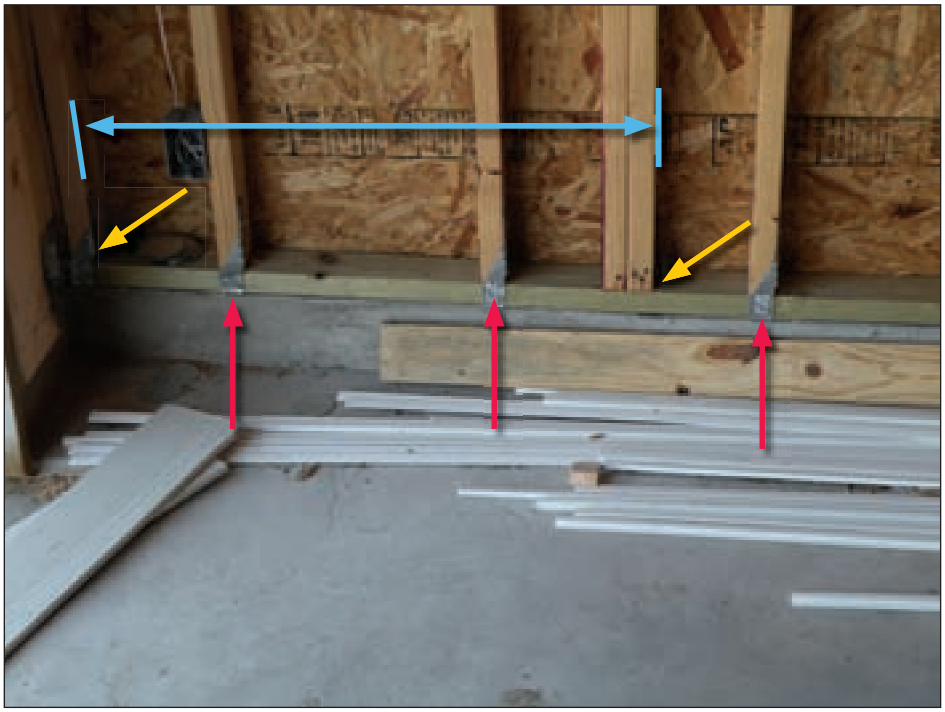


Figure 3-52.
Studs and sill plate connected in new house (sill bolts yellow arrows and clips red arrows). However, sill bolts are spaced too far apart (2 feet is the maximum spacing allowed) and did not have 3-inch by 3-inch by 1/8-inch washers per 2003 IRC and TDI-adopted IBHS guidelines. Blue line shows 3-foot spacing (Webster, TX).

Figure 3-53.
Studs clipped to double top plate; rafter-to-top-plate connector has yet to be installed. Better framing practices could have avoided some of the problems shown in this photo. Ceiling joists are not well nailed to the rafter and may twist in the future. The builder did not take advantage of aligning wall framing and rafter framing to simplify connections for wind loads.

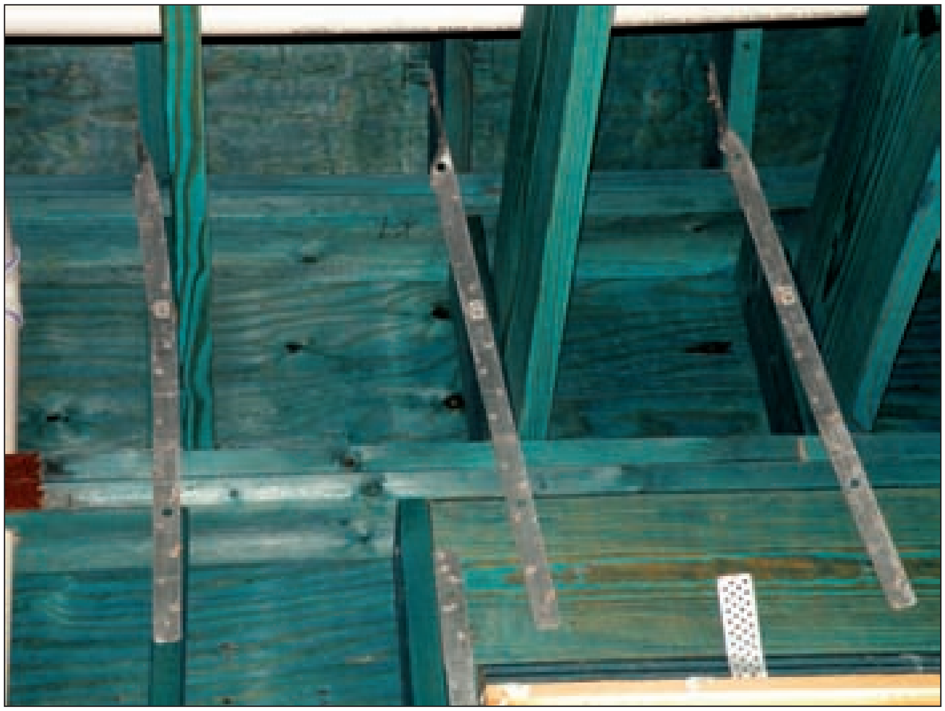


Figure 3-54.
Wall-to-roof strapping. Details for uncommon framing details should be specifically provided by the designer on building plans, including specifying the specific connection and application to ensure a continuous load path.

Numerous new and older houses, however, were observed without proper hurricane connections or improperly installed connections (Figures 3-55 and 3-56).

Figure 3-55.
Toe-nailed connection of floor joists on band beam on house under construction. Floor joist should be installed using either galvanized metal joist hangers or ledger beams (LaPorte, TX).

Figure 3-56.
Existing house shear wall connector incorrectly located (red arrow). Connector should be located on column line or the beam and beam-to-column connection should be designed to resist the uplift load, which is carried by a nailed connection in the absence of bolts (Sunset Crystal Beach, Bolivar Island, TX).

3.1.3 Elevation and Freeboard

The observations of the Ike MAT investigation clearly demonstrate the importance of elevating buildings above the flood level, including any effects of waves and floodborne debris. Elevating only to the BFE does not guarantee a house will remain free of flood damage during a specific hurricane or coastal flood event. As was stated in Section 2.1.1, FISs and FIRMs may not depict the true lateral and vertical extents of actual flooding during the base flood event (100-year flood event) for a variety of reasons. Nor will construction to the 100-year flood event shown on the maps offer protection against floods that exceed the true base flood.

The key to successful coastal buildings is to construct them higher than the BFE by adding freeboard. The desired amount of freeboard will depend on a number of factors, but the age of the FIRM and the nature of the building being constructed are the most important factors. Old FIRMs tend to be less accurate than newer FIRMs in showing the contemporary 1-percent-annual-chance flood level. Critical facilities should be constructed with higher freeboard than typical residential and commercial structures.

The MAT recommends any post-Ike reconstruction and new construction in Ike-flooded areas be carried out with a minimum of 3 feet of freeboard above the BFEs shown on the Effective FIRMs at the time of Ike (refer to Section 3.1.1.1 for additional information). Freeboard is necessary to compensate for out-of-date flood hazard maps and to provide an additional degree of flood protection not afforded by the Effective FIRMs.

3.1.4 Siting Effects on Structural Performance

While many people recognize that how buildings are constructed will affect flood damage to that building (e.g., building floor elevation and foundation design), they may not appreciate the importance of where buildings are constructed in determining flood damage. Post-hurricane inspections typically observe the greatest flood damage, loss of coastal buildings, and loss of roads and infrastructure in the area closest to the shoreline. This was also the case with Hurricane Ike.

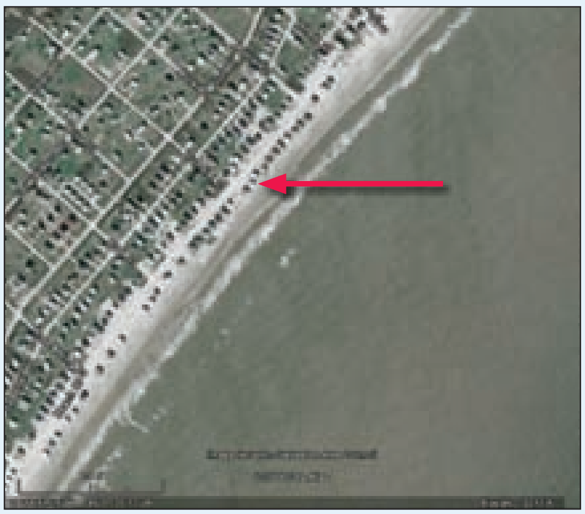
The greatest damage occurs in the area closest to the water since buildings and infrastructure situated there are subject to the most extreme flood forces and conditions during a hurricane, i.e., the highest waves and the greatest erosion (Figures 3-57 and 3-58). Buildings situated closest to the shoreline are also at greatest risk for the effects of long-term erosion, sea level rise, and other long-term changes affecting the shoreline (see Surfside Beach text box).

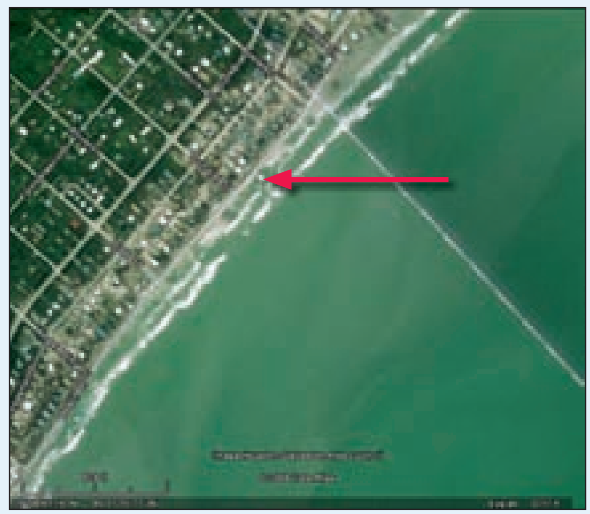
Figure 3-57. Post-Ike photograph of West Galveston Island, TX, illustrating increased severity of flood damage near the shoreline

Figure 3-58. Post-Ike photograph of Bolivar Peninsula, TX, illustrating increased severity of flood damage near the shoreline

SURFSIDE BEACH, TX

The closer a building is located to the shoreline, the more vulnerable it becomes. This is not only due to the increasing flood forces close to the shoreline, but also because a building's foundation designed for a given location and set of conditions (ground elevation, stillwater flood depth, wave height, etc.) will find itself exposed to a different set of conditions (lower ground, higher wave height, etc.) as the shoreline erodes over time, and the building may not be able to withstand those new conditions. A classic case is Surfside Beach, TX, where long-term erosion had resulted in dozens of houses standing on the beach, seaward of the line of vegetation. Many of these houses were ordered removed by the State of Texas; some were removed, but others remained and litigation resulted. Hurricane Ike destroyed most of the houses standing on the beach (see photos below).





The presence of reinforced dunes and revetments and seawalls can reduce damage slightly in areas close to the shoreline when those dunes and erosion control structures remain intact during a storm event. However, when they fail they offer little protection to upland buildings. Of the structures observed by the MAT, only the Galveston Seawall provided significant protection to buildings against wave attack and erosion. The recently completed Surfside Beach revetment appears to have survived Ike with minor damage, and undoubtedly offered some protection to upland buildings, but this revetment was not subject to the extreme forces that the Galveston seawall and shorelines farther east were.

Although wave and erosion effects in the bays were not as severe as on the Gulf coast, buildings sited close to the bay shoreline were at increased risk to flood damage, relative to buildings farther from the bay shoreline.

3.2 Envelope Damage

The MAT observed building envelope damage as far west as the west end of Galveston Island, TX, and as far east as Terrebonne Parish, LA, a distance of approximately 150 miles. The MAT also observed building envelope damage as far inland as the north side of the City of Houston, approximately 45 miles from the coast (see Figure 1-16). Sections 3.2.1 through 3.2.6 describe building envelope performance, including roof systems, non-load-bearing walls and wall coverings, doors, windows and shutters, soffits and roof ventilation, and exterior-mounted equipment.

Blow-off of building envelope components frequently results in damage to adjacent buildings and vehicles, as well as the building itself. The most notable building envelope issues during Hurricane Ike, and the most common windborne building envelope debris, were roof coverings and vinyl siding. Figure 3-59 illustrates the magnitude of building envelope debris that occurred in some areas.

As expected, the building envelope on older houses did not perform as well as on new houses. Specifically, houses constructed prior to 1985 in Texas and prior to the adoption of the IRC in 2005 in Louisiana exhibited the poorest envelope performance. Post-1985 Texas home construction in the counties affected by Hurricane Ike were governed by the Texas Windstorm Program (refer to Section 2.3), and all post-2005 houses in Louisiana were governed by the newly adopted IRC.

The extent and magnitude of envelope damage observed by the MAT was greater than would be anticipated given that the estimated actual wind speeds of Hurricane Ike were less than the design speeds given by ASCE 7-05 and IRC 2006. The poor performance of the newer houses is therefore related to the lack of contractor knowledge of proper hurricane construction, material installations not conforming to manufacturer's requirements for hurricane zones, and poor code enforcement.

Figure 3-59. A substantial amount of siding (the white lines scattered around the ground), along with roofing materials, blew off these West Galveston, TX, houses (Hurricane Ike estimated wind speed in this area: 90 mph)

3.2.1 Roof Systems

Historically, damage to roof coverings 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 interior finishes and contents. 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 Ike by the lack of electrical power to run fans and dehumidifiers.

LIQUID-APPLIED ROOF COVERING

The MAT observed one residence that had a liquid-applied roof covering over a concrete deck. FEMA investigations after Hurricane Marilyn (1995) in the U.S. Virgin Islands found that this type of roof covering has excellent wind performance.

The MAT observed a variety of roof coverings, including asphalt shingles, metal panels, metal tiles, and tile. In the areas observed by the MAT, roof covering damage was common, and quite variable as shown in Figure 3-60. This type of variability is consistent with what was observed by the Hurricane Charley, Ivan, and Katrina MATs (see FEMA 488, *Hurricane Charley in Florida: Observations, Recommendations, and Technical Guidance* [April 2005a]; FEMA 489, *Hurricane Ivan in Alabama and Florida: Observations, Recommendations, and Technical Guidance* [August 2005e]; and FEMA 549, *Hurricane Katrina in the Gulf Coast: Building Performance Observations, Recommendations, and Technical Guidance* [July 2006b]).

Figure 3-60.
Some of the roofs on these Jamaica Beach, TX, houses had no roof covering damage, while one had moderate damage (blue arrow) and one had extensive damage, including loss of underlayment (red arrow) (Hurricane Ike estimated wind speed in this area: 90 mph)

At several residences, a large amount of roof covering was blown away, as shown in Figures 3-60, 3-66, 3-67, and 3-69. However, more commonly, roof covering damage was limited to a small area such as at corners, eaves, rakes, or ridges. In the case of asphalt shingled roofs, sometimes a few shingles in the field of the roof were blown away. Had Hurricane Ike's winds been closer to current design wind speeds, the roof covering damage would likely have been greater. The following subsections present asphalt shingle, metal panel, and tile roof observations.

3.2.1.1 Asphalt Shingles

Most of the residences observed by the MAT had asphalt shingle roof coverings. There were two notable observations, as discussed below: 1) use of shingles that had been tested and labeled in accordance with relatively new criteria, and 2) the use of roof tape at deck sheathing joints.

New Shingle Labels. Asphalt shingles are now available with Class D, G, or H labels (see text box). At the time of Hurricane Katrina (2005), only a limited number of shingles were available with the new ratings. However, several products are now available with the new classifications.[2]

Figure 3-61 shows a shingle bundle wrapper at a house under construction at the inset in Figure 3-61. The shingle bundle wrappers indicate the shingles meet Class H (i.e., suitable for up to 150 mph). The IRC/ASCE 7 design wind speed for this locaton is 120 mph, hence use of a Class G shingle would have been sufficient. This is the first and only house observed by a MAT wherein it was known that shingles meeting one of the new Class ratings was installed. There was no apparent wind damage to this house.

> **ASPHALT SHINGLE CLASS RATINGS**
>
> Testing and labeling is prescribed in ASTM D 7158.* The following classes of shingles are specified in this standard:
>
> **Class D:** Suitable for use up to 90 mph
>
> **Class G:** Suitable for use up to 120 mph
>
> **Class H:** Suitable up to 150 mph
>
> **Class F:** Shingles with this classification are tested in accordance with the old test method prescribed in ASTM D 3161, a test method widely recognized as antiquated for evaluating the wind resistance of self-sealing shingles
>
> * Wind speeds cited are design wind speeds in IBC/IRC/ASCE 7 (based on Exposure C, and a maximum mean roof height of 60 feet).

The MAT observed several other newly installed roofs, but was unable to determine if the shingles met any of the new classifications. Even if the shingles did meet Class G or H, failure could have initiated along the rake, eave, or hip/ridge unless there was special securement (such as that shown in Technical Fact Sheet 20, *Asphalt Shingle Roofing for High-Wind Regions*, in FEMA 499), as described below.

The newly constructed house shown in Figure 3-62 is on the same block as the one shown in Figure 3-61. Bleeder strips were installed along the rake; however, as discussed in Section 5.4.1.3 of the Katrina MAT report (FEMA 549), unless the shingles are hand-tabbed as described in Technical Fact Sheet 20, bleeders do not provide reliable securement.

2 See the following TDI Web site for product listings: http://www.tdi.state.tx.us/wind/documents/ashglcnf08ibcircrev031009b.pdf

Figure 3-61.
View of a shingle bundle wrapper at the Webster, TX, house shown in the inset. This shingle has a Class H rating (red arrow) (Hurricane Ike estimated wind speed in this area: 104 mph).

Figure 3-62.
Shingle damage at a house near the one shown in Figure 3-61 (Webster, TX)

Figure 3-63 shows a house under construction on Bolivar Peninsula that lost shingles along the eave (it is also shown on the front cover of this report). Failure along eaves commonly occurs because of incorrect application of the starter course and lack of hand-tabbing (as recommended in Technical Fact Sheet 20). For further discussion of eave issues, see Section 5.4.1.2 in FEMA 549.

Figure 3-63.
Loss of shingles along the eave in Bolivar Peninsula, TX (Hurricane Ike estimated wind speed in this area: 110 mph)

Figure 3-64 shows a house that was reportedly constructed in 2005 on Bolivar Peninsula. It lost shingles and underlayment at a corner area (red circle at the inset) and shingles in the field of the roof near the exhaust fan (blue arrow). Loss of shingles was likely due to lack of hand-tabbing. These shingles reportedly met Class F.

Figure 3-64.
Loss of shingles and underlayment in a corner area, and loss of shingles from the field of this roof in Bolivar Peninsula, TX (Hurricane Ike estimated wind speed in this area: 110 mph)

Figure 3-65 shows a house under construction on Bolivar Peninsula. It lost shingles along the hip. Also, at areas along the exposed hip, either the underlayment did not completely lap over the hip line, or if it did, portions of the underlayment blew away. Water could leak into the building in the vicinity of the two red arrows. Unless hip and ridge shingles are hand-tabbed, as recommended in Technical Fact Sheet 20, they are very susceptible to blow-off (for further discussion, see Section 5.4.1.1 in FEMA 549).

Taping of Sheathing Joints. Figure 3-66 shows some relatively new *Fortified…for safer living*® houses in the Audubon Village area of Bolivar Peninsula (refer to Section 3.1.1.1 text box for more information on *Fortified…for safer living*® homes).

As shown in Figure 3-66, some of the roof coverings had no apparent damage, but the shingles and underlayment were blown off of one roof (red arrow). Also, a portion of the roof overhang blew off of one of the houses (blue arrow). When the MAT observed blow-off of roof framing and/or sheathing, it typically occurred on older buildings, rather than new construction.

Figure 3-65.
Loss of hip shingles and portions of the underlayment in Bolivar Peninsula, TX (Hurricane Ike estimated wind speed in this area: 110 mph)

Figure 3-66. Roof covering and roof structure damage at *Fortified...for safer living®* houses in the Audubon Village area on Bolivar Peninsula, TX (Hurricane Ike estimated wind speed in this area: 110 mph)

The *Fortified…for safer living®* requirements include special provisions pertaining to attachment of roof underlayment in order to make them more wind-resistant in the event the shingles are blown off. The MAT was unable to determine whether or not the failed underlayments complied with the *Fortified…for safer living®* requirements. However, according to IBHS investigators deployed after Hurricane Ike, two layers of #15 felt were installed. (Use of two layers of #15 is one of the underlayment options in the current *Fortified…for safer living®*.) The underlayment was attached with plastic capped-head nails, spaced at 6 inches on center along the laps and 12 inches on center in the field (this spacing is consistent with the original *Fortified…for safer living®* spacing guidance). This underlayment and attachment spacing is consistent with underlayment Option 2 in Technical Fact Sheet 19, *Roof Underlayment for Asphalt Shingle Roofs*, in FEMA 499.

The IBHS is preparing a report on Audubon Village. This report is expected to be available on the IBHS Web site by the end of 2009. Refer to: www.ibhs.org

The *Fortified…for safer living®* requirements also include a requirement to tape the sheathing joints with a minimum 4-inch-wide modified bitumen roof tape. The tape is intended to provide an additional line of defense against water infiltration in the event the shingles and underlayment blow off. The use of roof tape was recommended in the 2000 edition of FEMA 55 and it is recommended in Technical Fact Sheet 19 in FEMA 499.

Several of the *Fortified…for safer living®* houses that lost underlayment had taped joints, including the one shown in Figure 3-67. However, as shown in Figure 3-68, the taping was not effective. Observations by IBHS investigators revealed application problems with the tape. Staples were used to attach the tape because bonding problems were experienced during application. Apparently the applicator did not realize the tape was intended to prevent water from leaking through the sheathing joints. With the tape in an un-bonded and wrinkled condition, it was incapable of fulfilling its intended purpose. Self-adhering modified bitumen roof tape normally bonds quite well to sheathing. Bonding problems are commonly attributed to dust on the sheathing, wet sheathing, a surfacing on the sheathing that interfered with the bonding, or using inappropriate tape. According to IBHS, problems with bonding self-adhering modified bitumen to oriented strand board (OSB) had been previously experienced at a demonstration project. In evaluating that demonstration project, IBHS discovered that although the OSB manufacturer had recommended application of a primer before installation of the self-adhering modified bitumen because of the presence of a wax on the OSB, a primer had not been installed.

According to IBHS, the shingles at the *Fortified…for safer living®* houses at Audubon Village met Class H (i.e., suitable for use up to 150 mph).

Figure 3-67.
This *Fortified...for safer living®* house had taped sheathing joints (red arrow)

Figure 3-68.
This tape did not provide a watertight seal. Note the wrinkles (which allow water migration) and the staples (blue arrow) that were used to attach the tape (Audubon Village, TX).
CREDIT: IBHS

3.2.1.2 Metal Panels

Several metal panel roofs performed exceptionally well during Hurricane Charley (2004), even though they were exposed to very high winds. For further discussion, see FEMA 488.

For guidance on metal roofs, see Hurricane Ike Recovery Advisory, *Metal Roof Systems in High-Wind Regions* (Appendix D).

Metal panels were the second most common type of residential roof covering observed by the MAT. However, there were substantially fewer metal roofs than asphalt shingle roofs. Their performance was quite varied, as illustrated by a new housing area near the west end of the Galveston seawall. All of the houses in that area (around a dozen) had metal panel roofs. Three of the houses experienced panel blow off. Two of these failures are shown in Figures 3-69 and 3-70. Fortunately, as shown in the figures, the underlayment did not blow away, so it provided leakage protection. The panels shown in Figure 3-69 have snap-lock seams. One side of the seam was attached with concealed fasteners. The seam unlatched, but lack of roof access prevented MAT investigation of the cause of the unlatching.

Figure 3-69. These snap-lock seam panels were attached with fasteners through one side of the seam (Galveston Island, TX; Hurricane Ike estimated wind speed in this area: 110 mph)

The panels shown in Figure 3-70 were attached with concealed clips, which unlatched from the panels. The first row of clips (just above the red line) was several inches from the end of panels; this first row should have been within a few inches from the eave.

Figure 3-70.
These architectural metal panels unlatched from the concealed clips. The red line shows location of the first row of clips (Galveston Island, TX; Hurricane Ike estimated wind speed in this area: 110 mph).

3.2.1.3 Tile

The MAT observed very few tile roofs. As with asphalt shingles and metal panels, the performance was quite varied. Figures 3-71 and 3-72 show two houses along the coast of Galveston Island. The roof shown in Figure 3-71 was observed from the air and ground. No tile damage (including hips) was observed. Figure 3-72 shows damage at hips, the eave, and the field (which was likely caused by windblown eave and/or hip tiles.

For further information on tile roof performance, see the MAT reports for Hurricane Charley and Hurricane Ivan (FEMA 488 and 489, respectively), wherein a large number of tile roofs were observed. For guidance on design and installation of tile, see Technical Fact Sheet 21, *Tile Roofing for High-Wind Areas,* in FEMA 499.

Figure 3-71.
This tile roof on Galveston Island, TX, did not experience any wind damage (Hurricane Ike estimated wind speed in this area: 106 mph)

Figure 3-72.
This tile roof on Galveston Island, TX, experienced hip, eave, and field damage (Hurricane Ike estimated wind speed in this area: 106 mph)

3.2.2 Non-Load-Bearing Walls and Wall Coverings

This section covers exterior wall coverings (also known as cladding or siding) including brick veneer (Section 3.2.2.1), vinyl siding (Section 3.2.2.2), fiber-cement siding (Section 3.2.2.3), and wood and hardboard siding (Section 3.2.2.4). In the area visited by the MAT, the most common exterior wall coverings were fiber-cement lap siding; vinyl siding; and panels of wood, hardboard, or fiber cement. Although not a prevalent residential cladding, Exterior Insulation Finish System (EIFS) was observed in a few locations. Because most of the houses surveyed were elevated, brick was predominantly observed on a few commercial or institutional buildings, and on one multi-family residential complex.

In Louisiana, the MAT observed a variety of siding and cladding failures, despite the fact that wind speeds were less than current code-specified values. The damage observed was mostly, but not always, on older buildings, which (presumably) had been designed and constructed without full consideration of wind resistance (Figures 3-73 and 3-74).

Figure 3-73.
Loss of siding due to winds, Chauvin, LA (Terrebonne Parish; Hurricane Ike estimated wind speed in this area: 50 to 60 mph, Exposure B)

Figure 3-74.
Loss of siding at Holly Beach, LA, home (Cameron Parish; Hurricane Ike estimated wind speed in this area 80 mph, Exposure C)

Gable end walls are frequently covered with a non-structural sheathing, such as foam plastic or thin fiberboard and gypsum sheets. Because there is no interior wall covering, the sheathing and cladding assembly is exposed to the full force of the wind pressure differential between the attic and outside. Where this pressure is negative (that is, the side of the house is downwind or parallel to the wind direction), substantial suction pressure is exerted against the sheathing, which can transfer the load to the cladding and thereby produce cladding failure. The MAT observed several cases where both sheathing and cladding over the gable end were blown out (Figures 3-75 and 3-76).

Figure 3-75. Complete loss of thin gypsum sheathing and brick veneer from gable end (West Bay, Galveston Island, TX; Hurricane Ike estimated wind speed in this area: 90 mph, Exposure B)

Figure 3-76. Loss of fiberboard sheathing and fiber cement siding from gable end wall of an apartment complex (West Bay, Galveston Island, TX; Hurricane Ike estimated wind speed in this area: 90 mph, Exposure B)

3.2.2.1 Brick Veneer

Numerous brick veneer failures were observed at one Galveston apartment complex. Figure 3-77 shows failed brick veneer at one complex. The brick ties were randomly spaced with the horizontal spacing ranging from 32 inches to 16 inches on-center and the vertical spacing ranging from 48 inches to 24 inches on-center. Many of the corrugated ties were rusted and broken, were not embedded in the masonry, or had minimal embedment. Figure 3-78 illustrates common problems with brick veneer installations and Figure 3-79 illustrates proper methods of installation.

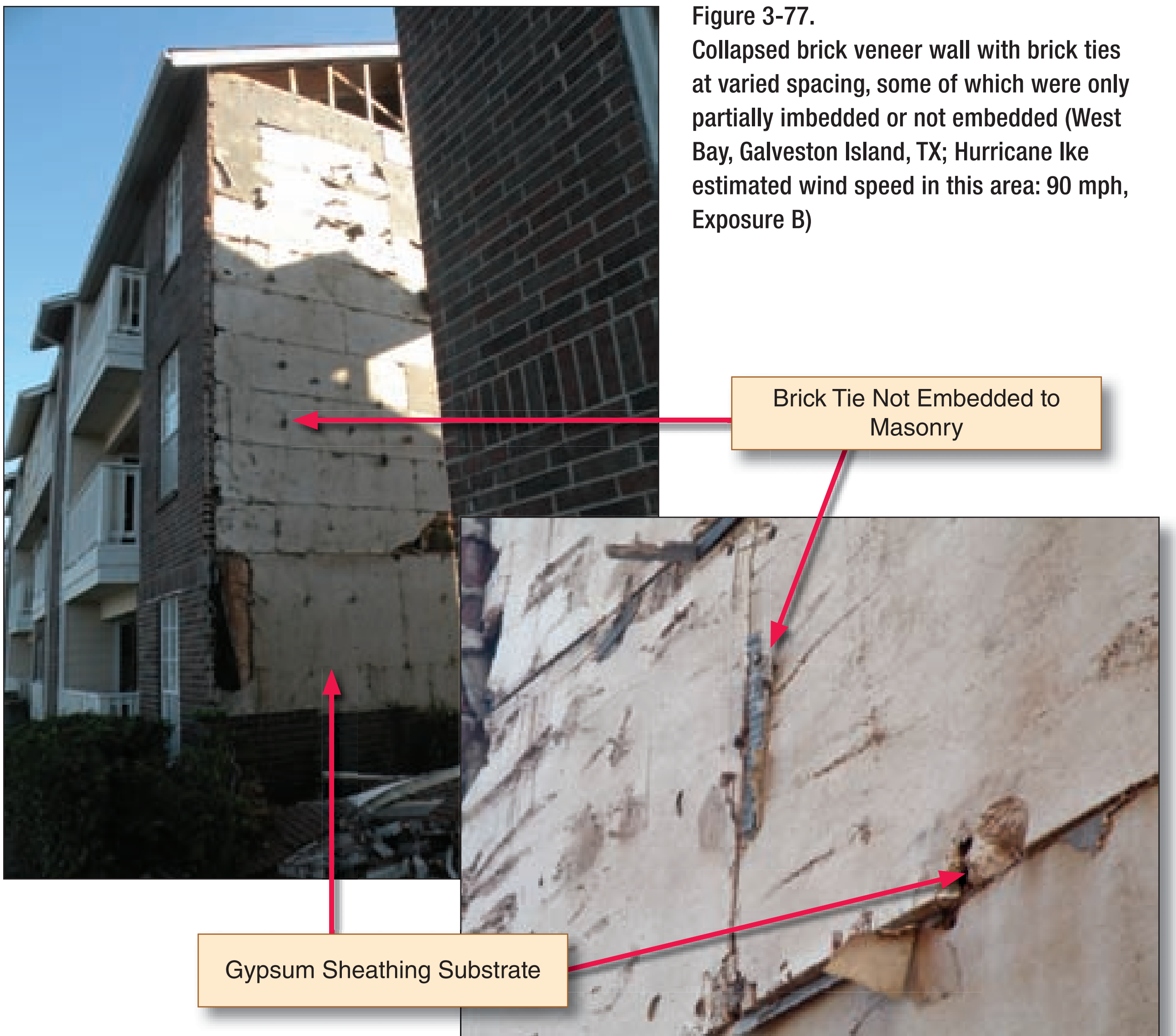


Figure 3-77.
Collapsed brick veneer wall with brick ties at varied spacing, some of which were only partially imbedded or not embedded (West Bay, Galveston Island, TX; Hurricane Ike estimated wind speed in this area: 90 mph, Exposure B)

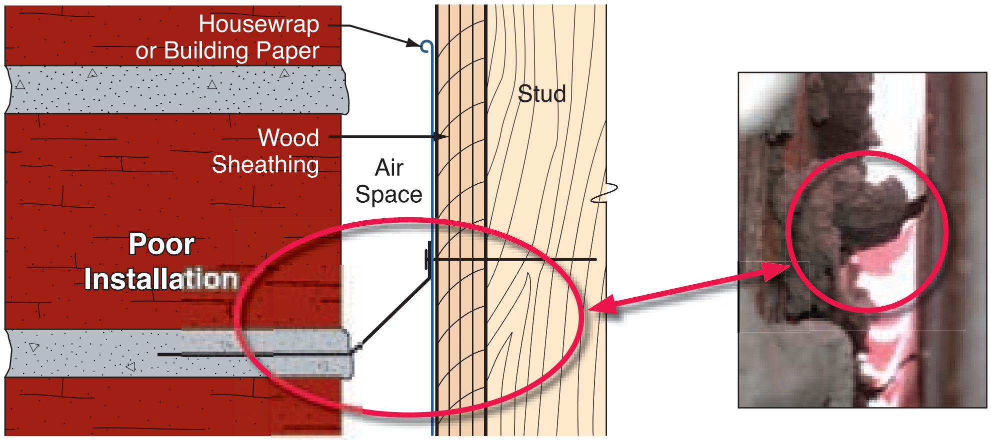


Figure 3-78. Misalignment of the tie reduces the embedment and promotes veneer failure

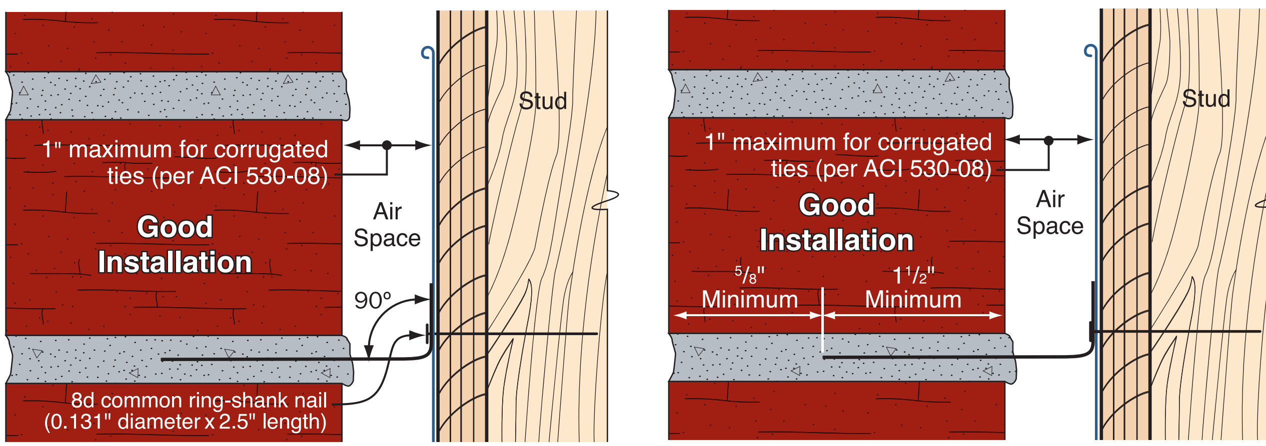


Figure 3-79. Proper installation and embedment of corrugated brick ties

The Brick Industry Association's (BIA's) Technical Notes 28 *Anchored Brick Veneer, Wood Frame Construction* (2002) specifies a maximum tie spacing of 24 inches in each direction for 16-inch stud spacing for buildings in standard 90-mph wind zones. Table 3-1 indicates the required tie spacing for high wind zones. Though Galveston experienced less than design wind speeds, the proximity of the adjacent complex shown in Figure 3-77 may have produced increased wind pressures, thereby producing the catastrophic failure of the poorly anchored brick veneer. However, the installed tie spacing was not suitable for this back bay Galveston location with a design wind speed of 120 mph.

FEMA Hurricane Ike Recovery Advisory, *Attachment of Brick Veneer in High-Wind Regions* (Appendix D), provides recommended practices for brick veneer attachment. The advisory is based on observations from Hurricanes Ivan, Katrina, and Ike.

Table 3-1. Brick Veneer Tie Spacing

Wind Speed (mph) (3-Second Peak Gust)	Wind Pressure (psf)	Maximum Vertical Spacing for Ties (inches)	
		16-inch stud spacing	24-inch stud spacing
90	-19.5	24[a,b]	16[a]
100	-24.1	24[a,b]	16[a]
110	-29.1	20½ [b]	13½
120	-34.7	17	NA[c]
130	-40.7	15	NA[c]
140	-47.2	13	NA[c]
150	-54.2	11	NA[c]

Notes:

1. The tie spacing is based on wind loads derived from Method 1 of ASCE 7-05, for the corner area of buildings up to 30 feet high, located in Exposure B with an importance factor (I) of 1.0 and no topographic influence. For other heights, exposures, or importance factors, engineered designs are recommended.
2. Spacing is for 2 ½-inch long 8d common (0.131-inch diameter) ring-shank fasteners embedded 2 inches into framing. Fastener strength is for wall framing with a Specific Gravity G=0.55 with moisture contents less than 19 percent and the following adjustment factors, C_t=0.8; and C_D, C_M, C_{eg}, and C_{tn}=1.0. Factored withdrawal strength W'=65.6#.
3. The brick veneer tie spacing table is based on fastener loads only and does not take into account the adequacy of wall framing, sheathing, and other building elements to resist wind pressures and control deflections from a high-wind event. Prior to repairing damaged brick veneer, the adequacy of wall framing, wall sheathing, and connections should be verified by an engineer.

a Maximum spacing allowed by the American Concrete Institute (ACI) 530-08.

b In locales that have adopted the 2006 IBC/IRC, the maximum vertical spacing allowed by ACI 530-05 is 18 inches.

c 24-inch stud spacing exceeds the maximum horizontal tie spacing of ACI 530-08 prescribed for wind speeds over 110 mph.

3.2.2.2 Vinyl Siding

Vinyl siding was the most frequently used exterior cladding and was found in all the areas observed by the MAT, on both newer and older buildings. Vinyl siding was observed to be commonly used to re-cover older wood cladding (Figure 3-80). Panel widths observed were typically between 8 and 12 inches, with double-four (two 4-inch) faces, double-five, and triple 3 ½-inch profiles being the most common. Siding was most commonly installed over plywood or OSB sheathing, and usually, with a water-resistant barrier (house wrap) over the sheathing. Where the siding was covering older wood plank or panel siding, a layer of foam sheathing was frequently applied. The foam sheathing, typically ½-inch to 1-inch extruded polystyrene sheets, served as both additional thermal insulation and flat substrate against which to place the siding.

Figure 3-80.
Typical vinyl siding failure. Vinyl was installed over older wood cladding (red arrows) (Sea Isle, TX; Hurricane Ike estimated wind speed in this area: 95+ mph, Exposure C).

Vinyl siding failure was frequently initiated at the building corners and along the bottom edges of elevated houses. The higher wind corner pressures produced unlatching along the bottom strip that resulted in the unzipping of the entire wall (Figure 3-81). When vinyl siding was blown off, the water-resistant barrier (either asphalt-saturated felt or housewrap) was often blown away. Though not witnessed by the MAT, this loss of the siding and underlayment could have allowed wind-driven rainwater to enter the wall cavity and the house, thereby causing water damage to interior finishes and contents. Vinyl siding and soffits that become windborne debris can potentially break unprotected glazing.

The most important factors influencing whether vinyl siding will remain on the wall during a high wind event are: (1) selection of siding appropriate for the basic wind speed at the location, and (2) the use of proper application techniques and installation details. The latter category includes use of proper accessories such as starter strips, receivers and utility trim; nail selection and placement; and locking of successive panel courses to each other.

Detachment of vinyl siding attributed to application deficiencies is frequently seen after high wind events (e.g., excessive spacing between fasteners and improper nail head size of the fasteners). In other cases, while proper fastening may have been used, the type of vinyl siding used may not have been appropriate for use in high wind locations.

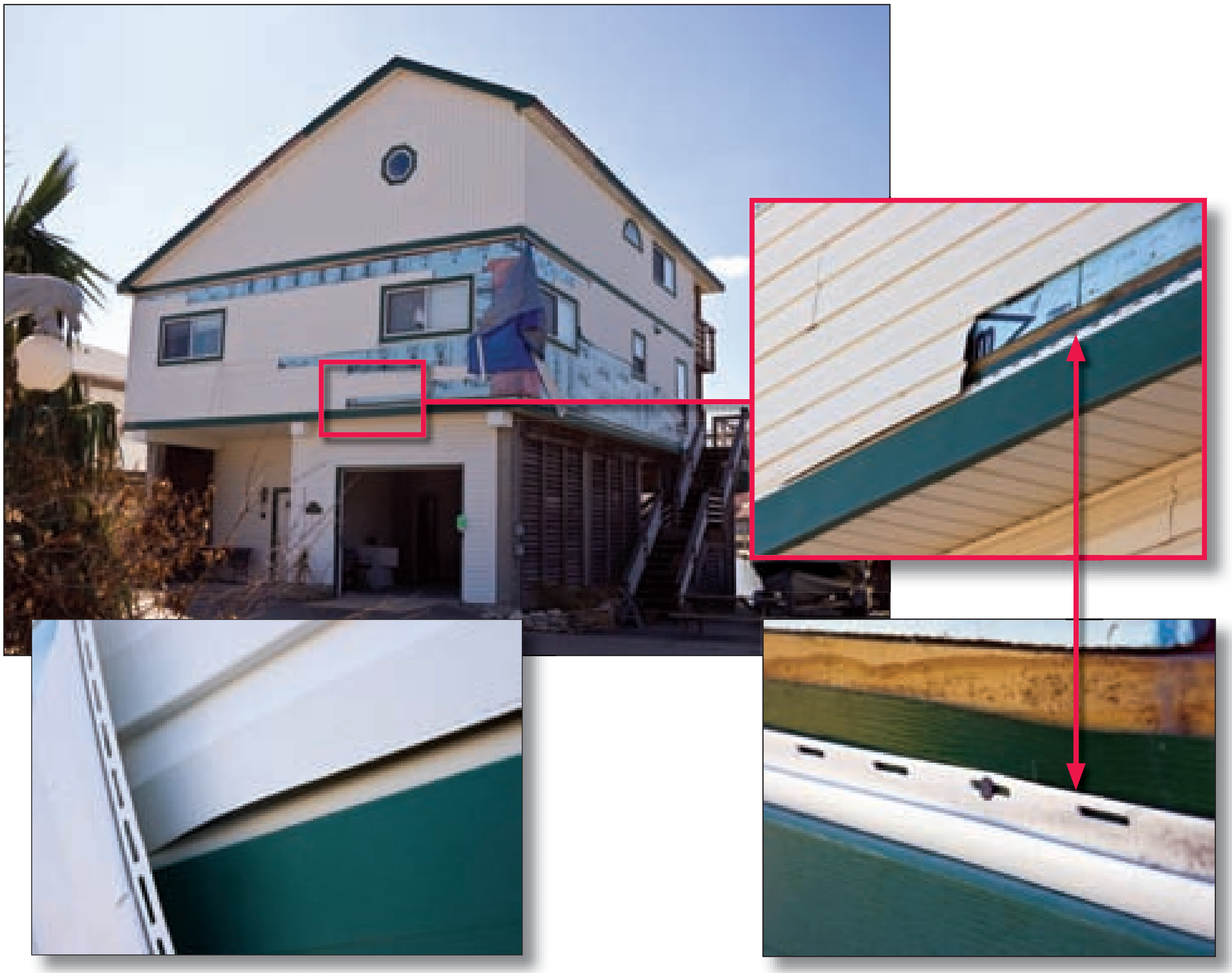


Figure 3-81. Improper installation led to extensive loss of siding up the house wall. The bottom lock of the lowest course of siding was cut off, and utility trim substituted for the correct starter strip. The poorly retained bottom edge pulled out under wind pressure, leading to extensive loss of siding up the house wall (Tiki Island, TX; Hurricane Ike estimated wind speed in this area: 88 mph, Exposure B).

Siding that is intended for locations with a basic wind speed greater the 110 mph usually has a double-layer nail hem (Figure 3-82). This double layer strengthens the vinyl at the point where the nail attaches so the siding better resists tearing or pull-through of the nail head. Conventional vinyl siding has a single-layer nail hem. Most of the siding that was removed from the wall (and therefore exposed for inspection by the MAT) had a single nail hem and was thus not likely to have been rated for high wind locations. Although it is possible that the siding that stayed on the wall (and therefore wasn't inspected) was predominantly high-wind rated, it seems likely that a significant percentage of the siding installed in the high wind zones of this area of the Texas coast is not intended for that application. This conclusion would appear reasonable, since winds produced by Ike varied from maximum 3-second gusts of 90 mph on the west end of Galveston to 110 mph on the east end of Bolivar Peninsula, and the ASCE 7-05 assigned wind speeds for these locations is 130 mph.

Figure 3-82.
Vinyl siding rated for high wind has a double-layer nail hem

As with any building system, even high-wind rated siding needs to be properly installed in order to function as designed. The MAT observed several common installation methods that tended to allow siding to be blown from the building by Hurricane Ike, including:

1. Starter strip attachment along the first (lowest) course of siding

Starter strips consist of a nail hem and locking profile that matches the shape of the lock on the lower edge of the siding panel (called the buttlock). The starter strip is fastened to the lowest part of the wall and the first course of siding is locked into it. If this lock is not strong, wind can get under the first course and detach it from the starter strip. The loose piece of siding will place stress on the lock of the course above, as well as its own nail hem, leading to successive loss of courses up the wall. In order to protect against this, the starter strip should be designed for use with the particular profile (shape) of siding being used, and the siding should be firmly locked into the starter strip.

Proper use of the starter strip is particularly important with elevated structures, where the wind passes at high velocity underneath the structure as well as against the walls. On Galveston Island, Bolivar Peninsula, and Tiki Island, where elevated houses were predominant, a large percentage of siding loss originated at the lowest course and led to loss of the courses above. The MAT saw numerous instances where a “generic” starter strip (having just a bulge, rather than a lock shaped to match the siding) was used. In other cases, J-channels, which do not lock into the panel at all, or field-fabricated substitutes for starter strips were used. Elevated structures with poorly implemented starter strips were most vulnerable to siding loss starting at the lowest edge of the elevated wall (Figure 3-83).

Vinyl siding installers should be advised to use starter strips that are specifically designed for the brand and model or profile of the siding that will be used and generic starter strips should be avoided. Installers should consult the manufacturer’s instructions to identify the starter strip to be used. Installers should also test the fit of the starter strip to the siding to make sure it locks securely before installing. On elevated structures, the starter strip should not extend below the lowest edge of the vertical wall or the exposed edge may catch the wind blowing under the house.

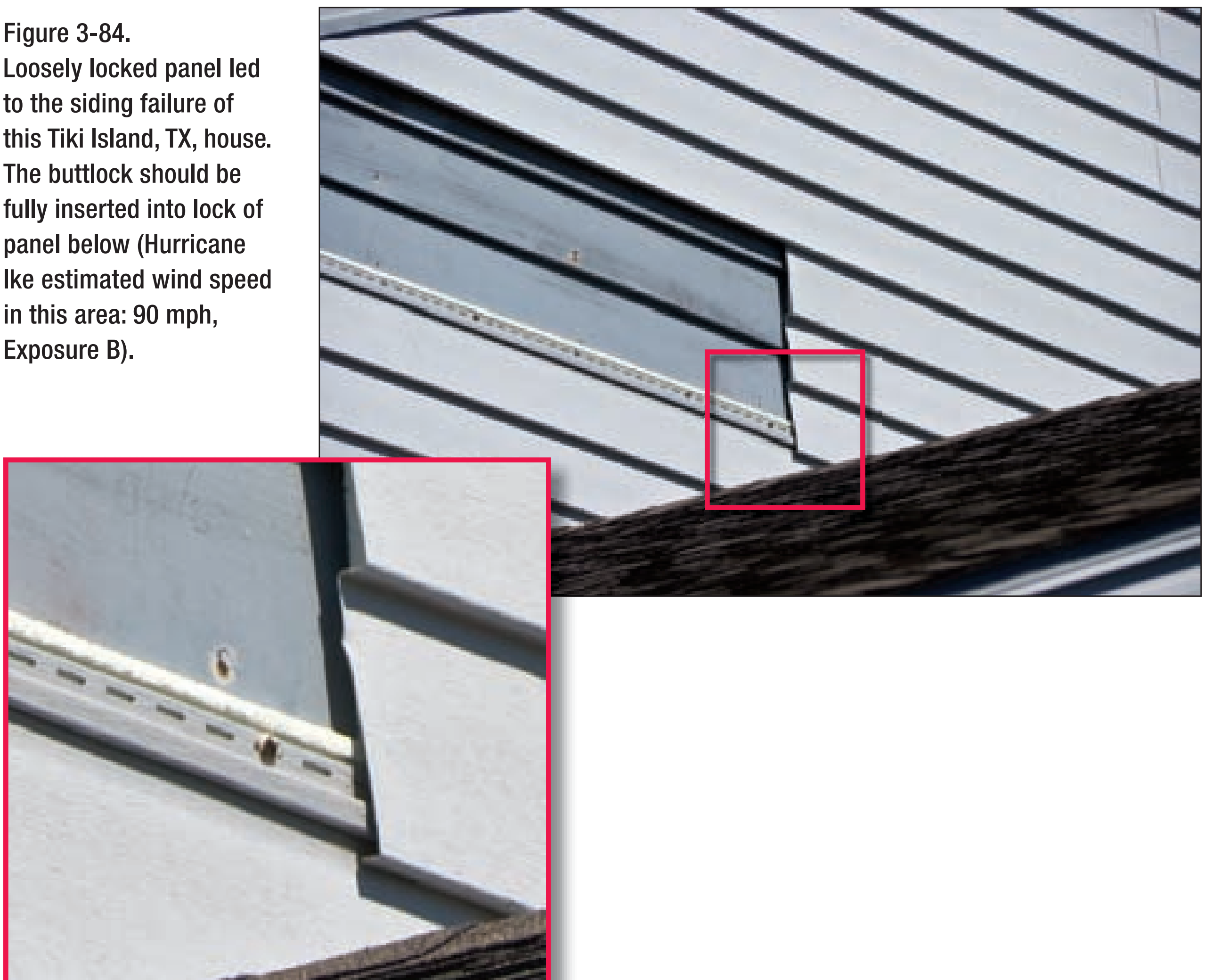
Figure 3-83.
Use of a generic starter strip contributed to loss of siding on this house. The shape of the starter strip did not properly match the shape of the siding, and the relatively weak strip bent up at the end and released the siding lock (blue inset). The edge of the starter strip also extended slightly below the edge of the building, which further contributed to the failure (red inset) (Tiki Island, TX; Hurricane Ike estimated wind speed in this area: 88 mph, Exposure B).

2. Locking of mid-wall siding courses

Siding loss frequently begins midway up the wall rather than at the bottom course. Many of these instances are the result of failure to fully and securely lock the buttlock of the siding into the locking shape of the siding course below. This can happen when the siding is pulled up too tightly before being nailed, thereby placing it under tension when the siding is not fully pushed into the lock (Figure 3-84), or when the siding is allowed to sag before nailing. These modes of failures frequently occur when installers try to align the horizontal course lines on one wall with those of an adjacent wall by installing several courses loosely.

Each course of siding should be installed by pushing the buttlock firmly upward into the lock of the course below until it snaps into place and goes no further. The siding should be held in the lock by pushing up from the bottom while the first several fasteners are placed to hold it in position. Siding should never be pulled up from the nail hem. When properly installed, siding should be able to slide back and forth without undue force; neither tight fasteners at the nail hem nor friction in the buttlock should prevent the siding from sliding. Installers should properly locate the starting points for siding on adjacent walls and check alignment of horizontal lines every course or two to avoid needing to make adjustments further up the wall.

Figure 3-84.
Loosely locked panel led to the siding failure of this Tiki Island, TX, house. The buttlock should be fully inserted into lock of panel below (Hurricane Ike estimated wind speed in this area: 90 mph, Exposure B).



3. Using utility trim at windows and other locations where the top edge of siding must be removed

When a course of siding intersects the bottom of a window or other large opening, a section of the top portion of the panel must be removed to fit around the window. With the nail hem removed, special techniques must be used to stabilize and secure the cut edge of siding. An accessory called utility trim must be installed beneath the window. The cut edge of the siding panel is notched with a snap lock punch. The edge of the siding is inserted into the utility trim, which grabs and holds the punched notches (Figure 3-85). A furring strip may need to be used underneath the utility trim to place it at the right level to match the angle of the siding. An overlap between adjacent siding panels should never be located directly beneath a window or similar opening (Figure 3-86). The same technique must be used to finish the top course of siding where the nail hem is cut off to match the location of the eave line.

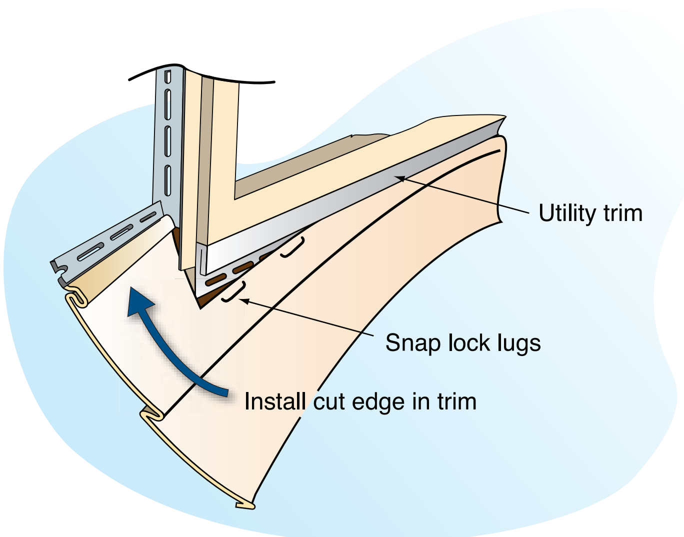


Figure 3-85.
Use of utility trim under window to securely attach cut and notched siding section
SOURCE: VSI INSTALLATION MANUAL

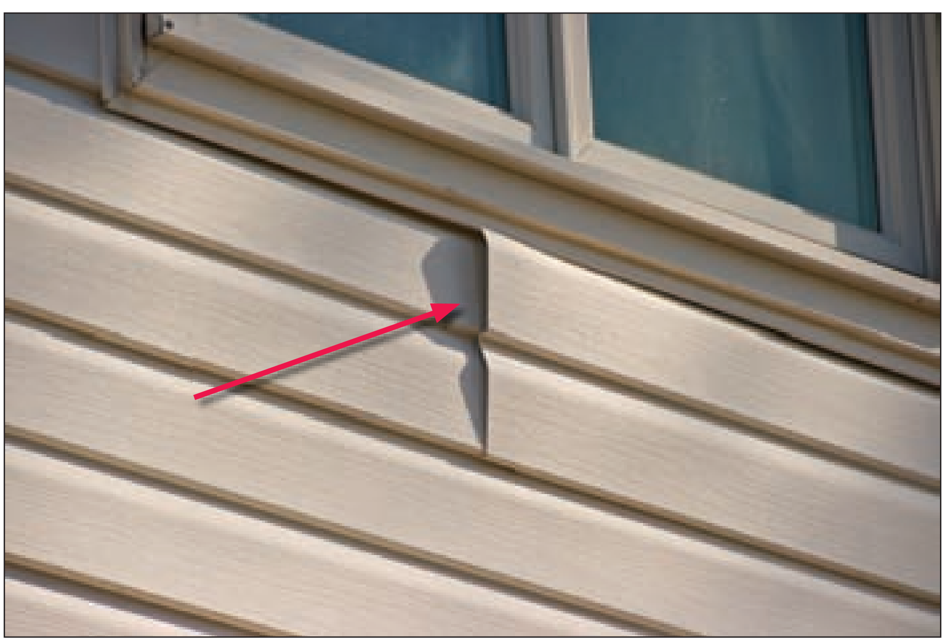


Figure 3-86.
Siding partially detached by wind as a result of improper placement of joint directly under window. Factory-notched end is not held by utility trim (Tiki Island, TX; Hurricane Ike estimated wind speed in this area: 88 mph).

Although most cases of vinyl siding loss can be traced to improper installation techniques or use of incorrect products and accessories, there is room for improvement in product testing and documentation. It is recommended that the vinyl siding industry reevaluate the test standards used for validating the strength of the siding material and its installation. ASTM D 3679, *Standard Specification for Rigid Poly (Vinyl Chloride) (PVC) Siding*, specifies a 1.5 product safety factor. Given the MAT observations, this safety factor appears to be too low. ASTM D 5206, *Standard Test Method for Windload Resistance of Rigid Poly (Vinyl Chloride) (PVC) Siding*, tests the product installations using a static load. Considering the flexible nature of vinyl siding and the dynamic nature of wind loading, a dynamic test appears to be prudent for vinyl siding. Manufacturers should provide clearer and more explicit information in the product literature (including Web sites) and installation instructions on high-wind applications, including explicit information on:

- Windload ratings for specific products and profiles, and any limitations or conditions needed to achieve the rated performance
- Specific accessories (e.g., starter strips, trim pieces) needed to provide the rated performance
- Any applicable fastener specifications, spacing frequency, and installation details needed for high-wind applications

3.2.2.3 Fiber Cement Siding

The MAT observed fiber cement siding on many residential structures, primarily as a reside cladding (Figure 3-87).[3] The observations included lap (plank) siding of varying exposures, perforated soffit material, and siding panels and sheathing material below elevated structures.

Figure 3-87. Fiber cement plank siding, installed as a reside over the original plywood siding, was torn from this West Bay, Galveston Island, TX, house (Hurricane Ike estimated wind speed in this area: 100 mph, Exposure C)

3 Reside cladding relates to the installation of a cladding material over an original cladding, usually sandwiched between foam board insulation and house wrap.

Lap siding damage varied from the loss of a few planks to entire walls (Figure 3-88). In most cases, the siding had been blind nailed at each stud (Figure 3-89), which is standard for non-high wind zones. Published ratings and ICC Evaluation Reports for the application of fiber cement lap siding in high wind zones require that the siding be face nailed through both layers of siding at the lap joint, shown in Figure 3-90. The spacing of the nails (16-inch or 24-inch) and permitted material exposure is dependent upon the thickness and width of the siding boards and wind zone.

Figure 3-88.
Fiber cement lap siding was blown off this West Bay, Galveston Island, TX, house (Hurricane Ike estimated wind speed in this area: 100 mph, Exposure B)

Figure 3-89.
Damaged fiber cement plank siding. Note that blind nailing alone (red arrows) is recommended only for 90-mph or less installation. Higher wind zone installations should include both blind and face nailing (Hurricane Ike estimated wind speed in this area: 93 mph, Exposure B).

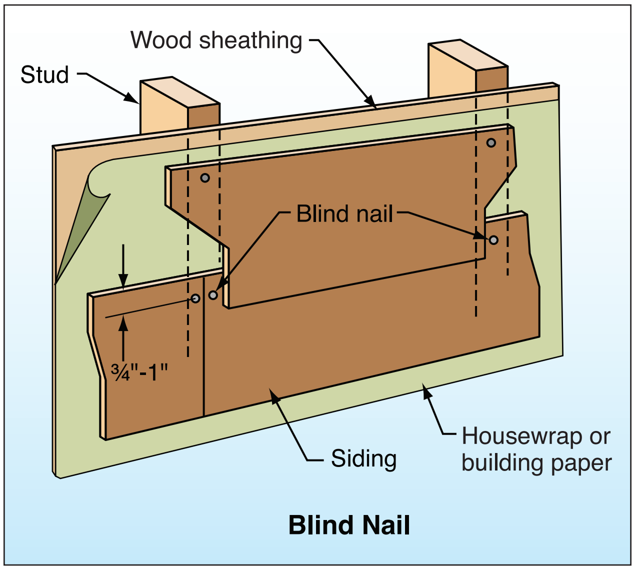
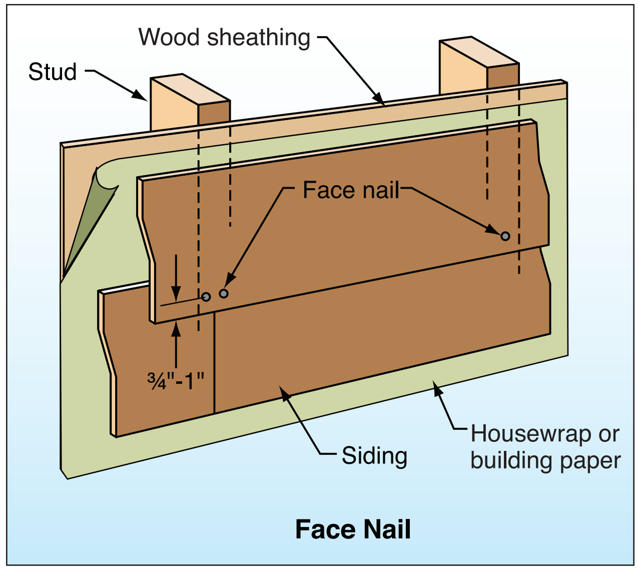


Figure 3-90. Standard wind zone installation



High wind zone installation

Another area of vulnerability for fiber cement siding is the exposure of the underside of the first course of lap siding, or the bottom edge of panel siding. In setting the first (lowest) course of lap siding, a shim is used to place the board at the proper angle. If the shim is not flush with the bottom of the board, a lip is formed that can catch wind pressure, and force this board up. The first board acts as a lever under the second, and loss of siding progresses up the wall. This is a particular issue with elevated structures, where the wind accelerates under the building. The MAT observed numerous cases where a projecting lip of the first course on an elevated structure led to significant loss of siding (Figure 3-91). If the bottom edge of the panel extends below the lowest edge of the elevated structure, or there is a gap between the panel and the lowest structural member, wind pressure can catch the edge and pry the panel off.

Shims under lap siding should be placed flush with the bottom of the first course, and panel siding should be fastened tightly to the substrate so that no gap is created at the lowest edge. Consideration should be given to placing a trim piece below the lower edge of the siding to fully close off the edge. Neither lap siding nor panel siding should extend below the lowest structural member of an elevated building, where it would be exposed to the full force of the wind (Figure 3-92).

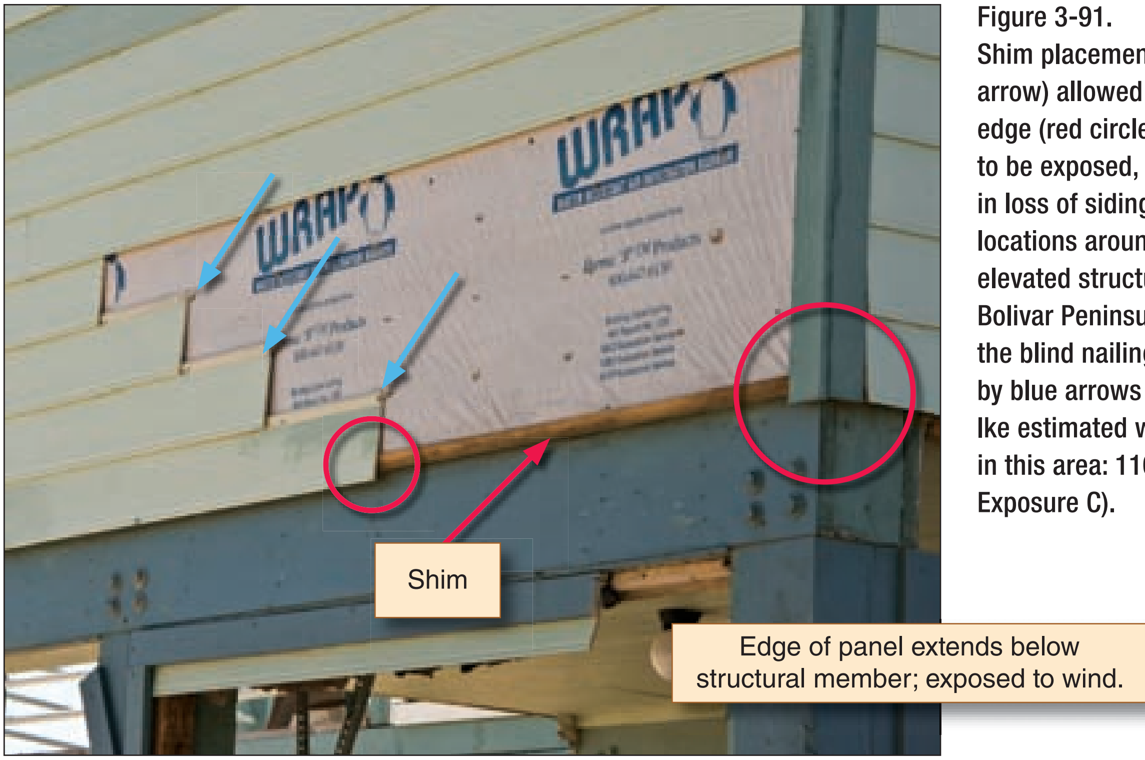


Figure 3-91.
Shim placement (red arrow) allowed the lower edge (red circles) of siding to be exposed, resulting in loss of siding at several locations around this elevated structure on Bolivar Peninsula, TX. Note the blind nailing shown by blue arrows (Hurricane Ike estimated wind speed in this area: 110 mph, Exposure C).

Figure 3-92.
Loss of fiber cement panels due to lower edge exposure. Inset shows lower edge exposed to wind (Bolivar Peninsula, TX; Hurricane Ike estimated wind speed in this area: 110 mph, Exposure C).

3.2.2.4 Wood and Hardboard Siding

Most of the older houses on Galveston Island, Tiki Island, and Bolivar Peninsula that were originally constructed with plywood or hardboard siding had been re-sided with either vinyl or fiber cement siding. The performance of the remaining plywood and hardboard siding was basically a function of maintenance. The clapboard-sided house shown in Figure 3-93 was well maintained and performed well, though the second floor failure was produced when a non-breakaway wall was destroyed by surge. Failure of the plywood siding shown in Figure 3-94 appeared to be the result of decayed plywood removed by the wind pressures.

Figure 3-93. Clapboard-sided house with siding that performed well; damage resulted from failure of a non-breakaway wall (Tiki Island, TX; Hurricane Ike estimated wind speed in this area: 103 mph, Exposure C)

Figure 3-94. Decayed plywood siding removed by wind pressures (Tiki Island, TX; Hurricane Ike estimated wind speed in this area: 103 mph, Exposure C)

3.2.3 Doors

Failure of an exterior door has two important consequences. First, the 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 leading 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 3.2.4.

Many door failures observed by the MAT were the result of flood loads, which doors are not designed for. Personnel door failures in slab-on-grade houses and houses elevated below the BFE were commonly seen, along with catastrophic failure of the entire house. Garages with garage doors are frequently installed below elevated homes, and are designed to fail due to flood loads in conjunction with breakaway walls.

3.2.4 Windows and Shutters

Most building codes incorporate the wind provisions from ASCE 7-05 and require that buildings within the most hazardous portion of the hurricane-prone region, called the windborne debris region, be equipped with shutters or impact-resistant glazing and designed as enclosed structures. The 2003 IRC allows a residence without either protection to be designed as a partially enclosed structure (as if the windows and doors are broken out). Designing a partially enclosed structure typically requires upgrading structural components and connections. In Texas, the TDI requires opening protection for both Seaward and Inland I zones (refer to Figure 3-69 for wind zone locations). Few impact-resistant glazed window units were observed by the MAT, with homeowners and builders generally opting to use shutters to provide debris impact protection. However, the MAT observed four new houses being constructed on the east beach of Galveston Island that were installing impact-resistant glazing (Figure 3-95).

Figure 3-95.
Impact-resistant door and window glazing in new East Galveston, TX, house. Inset shows manufacturer's label indicating glazing is impact resistant.

The MAT observed that glazing at most houses was protected by some form of shutter. The shutter types varied from simple plywood to roll-down shutters. Figures 3-96 to 3-101 show a variety of shutters seen by the MAT.

Figure 3-96.
Clear Lake, TX, house with plywood shutters installed on the accessible first floor and roll-down shutters installed on the less accessible second floor (Hurricane Ike estimated wind speed in this area: 90 mph, Exposure B)

Figure 3-97.
Tiki Island, TX, house with adjustable shutters (Hurricane Ike estimated wind speed in this area: 103 mph, Exposure C)

Figure 3-98.
Texas City, TX, house with corrugated clear plastic shutters (Hurricane Ike estimated wind speed in this area: 88 mph, Exposure B)

Figure 3-99. Traditional wood swinging shutters on Tiki Island, TX (Hurricane Ike estimated wind speed in this area: 103 mph, Exposure B)

Figure 3-100. Corrugated metal shutters on house in West Galveston, TX (Hurricane Ike estimated wind speed in this area: 95 mph, Exposure C)

Figure 3-101. Snapped-on vinyl canvas window covers (red arrows) in West Bay, Galveston Island, TX (Hurricane Ike estimated wind speed in this area: 90 mph, Exposure B)

Since Ike's winds were below design wind speeds in both Texas and Louisiana, no failures or debris impacts were observed. The 2006 IRC/IBC and TDI require that all shutters be attached to the building structure and not to the window frame, siding, or veneer (Figure 3-102); they require that all shutters be tested to ASTM Standards E 1886 and E 1996. The MAT observed plywood shutters mounted directly to the wall cladding or window frame as seen in Figure 3-103. Further information regarding shutters can be obtained from Technical Fact Sheet 26, *Shutter Alternatives*, in FEMA 499.

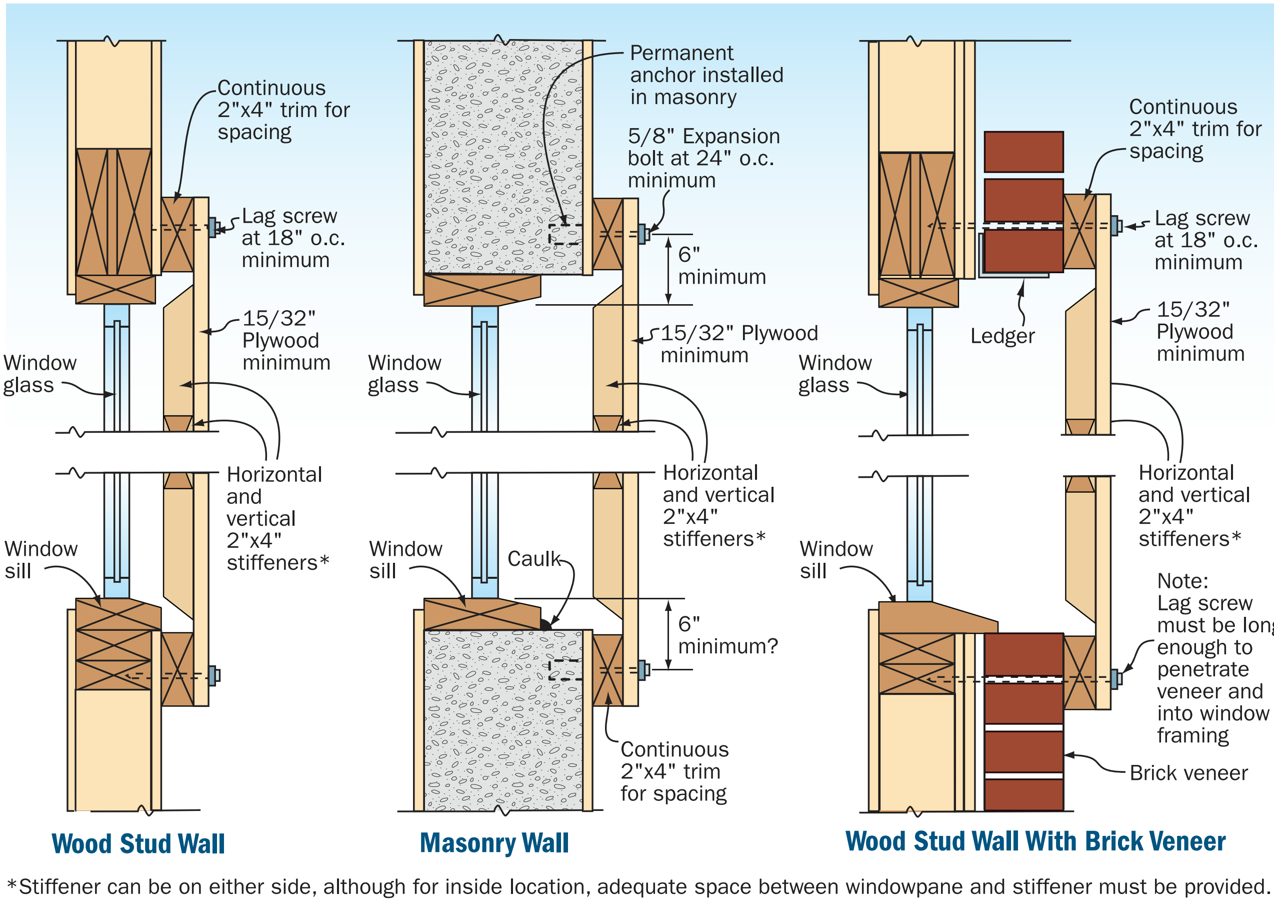


Figure 3-102. Common methods for plywood shutter attachment to wood-frame and masonry walls
SOURCE: FEMA 499 TECHNICAL FACT SHEET 26

Figure 3-103. Plywood shutters installed into the wall cladding (red circles) in Clear Lake, TX (Hurricane Ike estimated wind speed in this area: 90 mph, Exposure B)

3.2.5 Soffit and Roof Ventilation

Hurricane winds can drive large amounts of water through attic ventilation openings. The accumulating water soaks insulation, which can lead to mold growth and, in some cases, to the collapse of ceilings. Attic ventilation can be provided by a number of devices, most of which have been observed to allow water intrusion under certain conditions and some of which have been observed to blow away. These devices include:

- Soffit vents
- Ridge vents
- Gable end vents
- Off-ridge vents (not observed by Ike MAT)
- Gable rake vents (not observed by Ike MAT)
- Mechanical vents – wind-powered turbines or electric-powered fans (not observed by Ike MAT)

3.2.5.1 Soffits

The opening created where a roof extends beyond the plane of the wall below (called eaves on the downslope side of a roof and a rake for the end of a gable roof) is normally closed off with a soffit. Soffits typically have small openings, slots, or perforations to provide ventilation to the attic, this ventilation is particularly important in the hot, humid climate of coastal Texas and Louisiana. Soffit venting allows air to enter the attic space, circulate through the attic, and be exhausted through passive vents (ridge vents, gable-end vents) or mechanical vents (either wind-powered turbines or electric-powered fans). The soffits along the roof eave and rake are the primary line of defense against entry of wind-driven rain into attics. Rain driven into attics can cause significant damage as water soaks through ceiling materials and into the interior of the building.

In non-high wind regions, a soffit is typically attached with fasteners to the roof structure only on one side—on the house side or to the underside of the fascia—if at all. In such installations, the channel formed by a bend in the fascia cover receives and supports the end of the soffit. In high-wind zones, most soffit manufacturers indicate the soffit should be attached at both ends and at intermediate points so that there is no span greater than 12 inches.

The primary materials observed for roof soffits in the surveyed area were vinyl, aluminum, fiber cement, and plywood. In general, fiber cement and plywood soffits remained connected to the house (Figure 3-104), while vinyl and aluminum soffits were more likely to have blown off.

By far the most frequently observed form of failure was loss of the aluminum fascia cover from the fascia board (the vertical board used to close off the end of eave spaces or form the outer edge of the rake), as shown in Figures 3-105 and 3-106. The fascia cover normally covers the ends of vinyl and aluminum soffits. Aluminum fascia covers are typically nailed every few feet along the length with color matched trim nails. The IRC currently has no guidelines for the installation of fascia covers. Vinyl fascia covers are also available. They are typically installed using utility trim along the upper side of the fascia board. The continuous nature of the attachment may provide better wind resistance than the aluminum covers. The MAT did not observe any vinyl fascia covers.

Figure 3-104.
Fiber cement soffit remained connected; soffit vent slots shown with red arrows. Fiber cement plank siding was damaged (Tiki Island, TX; Hurricane Ike estimated wind speed in this area: 88 mph, Exposure B).

The frequent loss of fascia covers is a significant concern. In most instances where the fascia cover was observed by the MAT to be fully or partially removed, the soffit itself remained in place or lost only a few sections, as further shown in Figures 3-105 and 3-106. The loss of the fascia cover can increase the risk of loss of the soffit. Even where the soffit remains, rain can be driven directly past the exposed soffit ends. The MAT did not have access to the interior of houses to determine whether interior moisture damage was a frequent result of fascia cover loss, but such damage would be expected.

The frequency of fascia cover failure suggests that design and installation of this component needs to be better addressed in construction standards for buildings in high wind locations. The fact that most soffits stayed in place despite loss of the fascia cover suggests that most soffit installations were performed properly or the design was sufficiently robust to resist winds that occurred during Ike. However, loss of soffits exposed by fascia cover removal would likely have been much greater had winds approached design speeds.

Figure 3-105.
Loss of aluminum fascia cover (red arrows) exposed ends of vinyl soffit (blue arrows) to direct entry of wind-driven rain (Tiki Island, TX; Hurricane Ike estimated wind speed in this area: 88 mph)

Figure 3-106.
Loss of fascia cover (red arrow) led to loss of soffit (blue arrow), exposing the attic to wind-driven rain (San Luis, TX; Hurricane Ike estimated wind speed in this area: 93 mph, Exposure C)

3.2.5.2 Ridge Vents

The exhaust portion of the attic ventilation system includes ridge vents, gable end vents, off ridge vents, and mechanical vents. The MAT only observed damage produced by ridge vents and gable end vents. To accommodate the ridge venting system, roof decking is cut or left short of the gable ridge beam. Buildings can be retrofitted for ridge vents by cutting the gable slot in the existing deck. The ridge vent is normally the last part of the roof cover to be installed. The ridge vent should be a tested assembly with a baffle in front of the vent tube that provides passageway for hot attic gases to escape. The baffle is intended to trip any flow of wind and water blowing up the surface of the roof and deflect it over the top of the roof ridge. The ridge vent should be installed with stainless steel screws, not roofing nails, into the roof structure. The MAT team was unable to climb onto residential roofs, but it was reported by the homeowner that the damage to a second floor ceiling shown in inset of Figure 3-107 was the result of a leaking ridge vent.

Figure 3-107.
The roof ridge vent (red arrows) on this Bolivar Peninsula, TX, home leaked, and it is presumed that the water was shed down the underside of the roof decking and/or structure, thereby producing ceiling damage along the wall of this second story room (Hurricane Ike estimated wind speed in this area: 110 mph, Exposure C)

3.2.5.3 Gable End Vents

Virtually all gable end vents (Figure 3-108) will leak when the wall they are mounted on faces into the wind-driven rain. The pressure developed between the outside surface of the wall and the inside of the attic are sufficient to drive water uphill for a number of inches and, if there is much wind flow through the vent, water carried by the wind will be blown considerable distances into the attic. Remedial measures include installing shutters, preferably on the outside of the house (Figure 3-109). The gable end vent shown in Figure 3-110 was not attached to the building structure and was blown off the apartment building.

Refer to FEMA Hurricane Ike Recovery Advisory, *Minimizing Water Intrusion Through Roof Vents in High-Wind Regions* (Appendix D), for further discussion of off-ridge vents, gable-end rake vents, and mechanical vents.

Figure 3-108. Gable end vent (red arrow)

Figure 3-109. Shuttered gable end vent (red arrow)

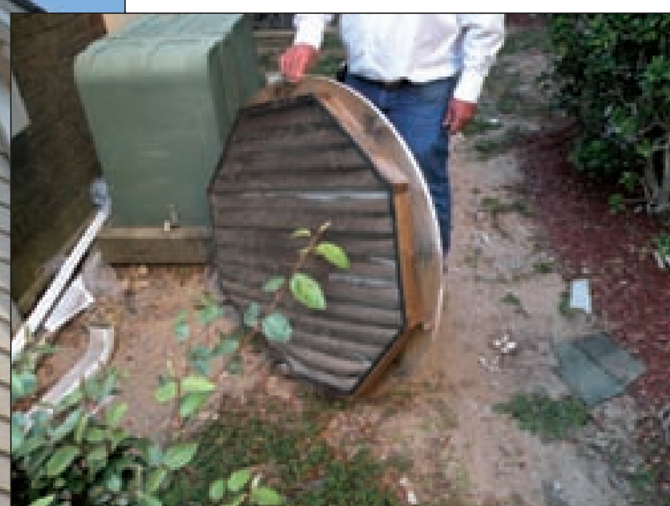


Figure 3-110.
Gable end vent blew off this Galveston, TX, Back Bay apartment building (Hurricane Ike estimated wind speed in this area: 90 mph, Exposure B)

3.2.6 Exterior-Mounted Equipment

Residential condensing units should be elevated in floodprone areas. Condensers at many residences observed by the MAT were supported on cantilevered platforms as shown in Figure 3-111. Cantilevered platforms are preferred because they are less susceptible to damage from floodborne debris impacts than are pile or knee-brace supported platforms. Outside floodprone areas, condensers are normally mounted at grade or on rooftops. In all cases, the units should be permanently anchored to prevent them from being moved (Figure 3-112).

Figure 3-111. Typical cantilevered condenser (Jamaica Beach, TX; Hurricane Ike estimated wind speed in this area: 80 mph, Exposure B)

Figure 3-112. Improperly secured condensing unit was knocked from its platform (Kahala Beach, TX; Hurricane Ike estimated wind speed in this area: 80 mph, Exposure B)

Maintenance should be considered in the design and installation of elevated supports. Figure 3-113 shows a unit that is closely caged, making maintenance difficult. If units are caged, the railings should either be removable or the platform made sufficiently large to allow service to the unit. Further information regarding equipment protection can be obtained from Technical Fact Sheet 29, *Protecting Utilities*, in FEMA 499.

Figure 3-113.
Elevated condenser is tightly enclosed, making service access difficult (Bermuda Beach, TX; Hurricane Ike estimated wind speed in this area: 95 mph, Exposure C)

3.3 Other Damage

3.3.1 Breakaway Walls

The Ike MAT found that solid breakaway walls performed as expected in the vast majority of cases. The walls broke free without causing significant or structural damage to elevated buildings. In some cases, failure of the breakaway walls led to propagation of damage to the building exterior above the lowest floor (Figure 3-114). In other cases, attachment of utilities to breakaway walls either prevented their successful breakaway, or contributed to utility damage (Figure 3-115).

Figure 3-114.
Propagation of damage above lowest floor when breakaway walls broke free (Seabrook, TX)

Figure 3-115. Attachment of utilities to breakaway wall may have prevented the wall from breaking away, thereby resulting in additional damage to the structure (Galveston Island, TX)

The MAT did not document specific cases where breakaway wall panels from one building led to identifiable damage to adjacent buildings. However, the ubiquitous presence of breakaway walls beneath elevated buildings would undoubtedly increase the quantity of floodborne debris during a severe flood event, and could potentially contribute to damage at adjacent structures.

The MAT observed some breakaway walls in excess of 11 feet high (Figure 3-116). While FEMA promotes elevating houses above the BFE (i.e., adding freeboard), one of the unintended consequences appears to be an increased size of floodborne debris elements due to the presence of these taller breakaway walls.

The MAT observed that louvered panels remained intact longer than solid breakaway walls under the same flood conditions. As a result, houses with louvered panels had less flood-related damage (and repair cost) and contributed less floodborne debris. Figure 3-117 shows louvered panels that allowed Ike floodwaters to pass into and out of the below-BFE enclosure without damage to the louvered panels. These louvers were installed on the same building shown in Figure 3-116, where the solid breakaway wall panel was displaced by floodwaters trapped inside the enclosure.

Figure 3-116.
This 11-foot high breakaway wall panel was pushed out by floodwaters trapped inside the enclosure (Galveston Island, TX)

Figure 3-117.
Louvered panels allowed Ike floodwaters to pass into and out of the below-BFE enclosure without damage to the panels. The building shown here is the same as in Figure 3-116, where a solid breakaway wall panel broke away.

Based on these observations, the Ike MAT recommends the use of louvered panels rather than solid breakaway walls below the BFE. See the Hurricane Ike Recovery Advisory, *Enclosures and Breakaway Walls*, in Appendix D for more details on this topic.

Numerous building owners in one community (Tiki Island, TX) were observed to be replacing solid breakaway walls lost during Ike with louvered panels (Figure 3-118). This action will reduce future flood damages and can result in lower flood insurance premiums. Zone V flood insurance premiums are much less for a building with a below-BFE enclosure formed by louvers than for a building with an enclosure formed by breakaway walls. A building with an enclosure formed by louvers is classified the same as if it had insect screening or open lattice, i.e., as "free of obstructions," while a solid breakaway wall enclosure results in a "with obstruction" rating for the building.

Figure 3-118. Solid breakaway walls lost during Ike are being replaced with louvered panels (Tiki Island, TX)

3.3.2 Sheathing on the Underside of Elevated Buildings

Sheathing is typically installed on the underside of the lowest-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 are used, most often sheets of plywood, hardboard, or fiber cement panels. The sheathing is sometimes covered with vinyl soffit material, or left uncovered and painted.

In locations where the water level or waves reached the elevation of the building, sheathing and any covering was frequently found to be partially or completely removed (Figures 3-119 and 3-120). This was particularly true of the thinner panel types, such as ⅛-inch fiberboard. Other forms of damage, such as gouges from floodborne debris, were observed on the underside of panels.

Figure 3-119. Plywood sheathing removed by storm surge (Jamaica Beach, TX, house on West Bay)

Figure 3-120. Fiber cement board sheathing (red arrow) was removed from the underside of this house, which was elevated approximately 12 feet above ground level (Bolivar Peninsula, TX)

Several examples of vinyl soffit attached directly to floor joists, without sheathing, were observed by the MAT (Figure 3-121).

Where floodwaters did not reach the underside of the building, damage due to wind accelerating underneath the building was often observed. In these cases, vinyl soffit was often blown off. In some cases, but not all, the sheathing above the soffit was also removed. The vinyl soffit covering on the Tiki Island house shown in Figure 3-122 was probably blown off by wind action rather than storm surge.

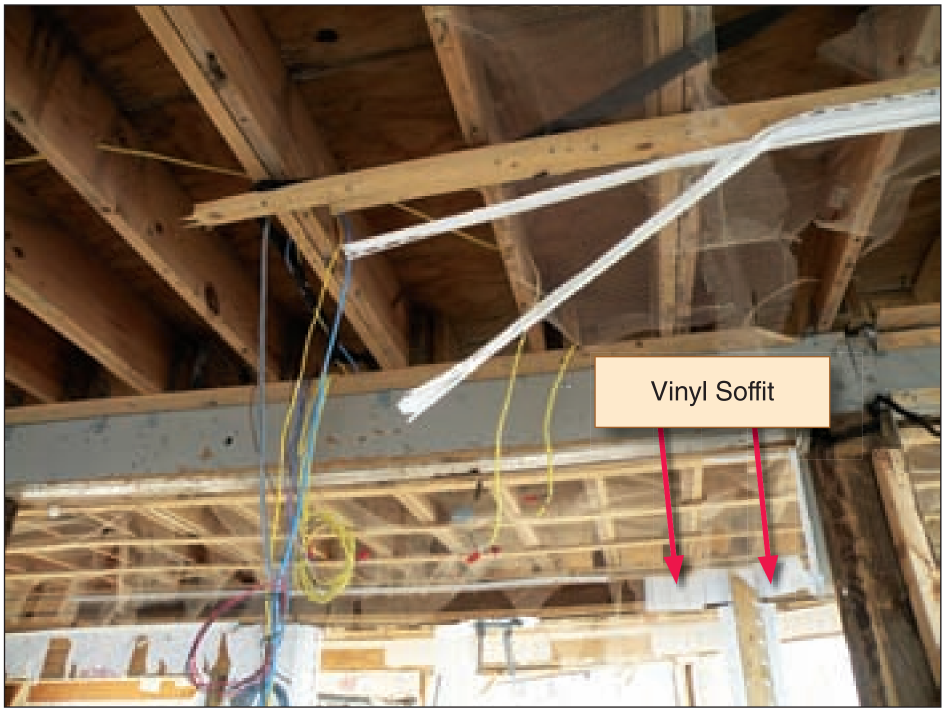


Figure 3-121.
Tiki Island house with vinyl soffit applied without sheathing removed by storm surge (netting was used to contain insulation in joist space)

Figure 3-122.
Vinyl soffit covering over plywood sheathing partially removed (Tiki Island, West Galveston Bay; Estimated Hurricane Ike wind speed: 103 mph, Exposure C)

For further information on the performance of sheathing on the underside of elevated buildings, see FEMA 489.

3.3.3 Parking Slabs and Grade Beams

Many of the houses supported on pile foundations that the MAT visited had concrete slabs constructed at grade. These slabs were typically used as parking slabs beneath the elevated houses (Figure 3-123). Some of the slabs were thin (less than 4 inches thick); others were much thicker. Some had thickened edges and interior sections that acted as grade beams, presumably to stiffen the foundation. Virtually all slabs were reinforced with welded wire mesh and/or steel reinforcing bars.

Figure 3-123. Typical concrete parking slab beneath a pile-supported house (Bolivar Peninsula, TX)

Many of the slabs failed once they were undermined. Where the piles were embedded deep into the ground, the slab was either undermined (and sometimes settled) as shown in Figure 3-124, or the slab collapsed without visible damage to the foundation (Figure 3-125).

Figure 3-124. Undermining of concrete slab that settled but remained intact (Galveston Island, TX)

Figure 3-125. Pile-founded house with a slab thickened to create grade beams. The unthickened portion of the slab collapsed when undermined (Galveston Island, TX).

Where the piles were thought to be less well embedded, failure of the slab could have caused the pile foundation to rotate or rack (Figure 3-126). The MAT believes this was more common with older houses, and was likely a result of portions of the slab causing eccentric loads on the piles and the transfer of flood forces from the slab to the foundation.

The MAT observed instances where the weight of the slab likely contributed to foundation failure and building settlement, illustrated in Figures 3-127 and 3-128. Figure 3-127 shows a Holly Beach, LA, house under construction at the time of Ike. The piles and elevated floor beams had been placed, and a thick slab had been cast; when Ike undermined part of the slab, it cracked and settled, pulling some of the piles and beams downward. Figure 3-128 shows a house at Surfside Beach, TX, that was subject to considerable scour and erosion—when the slab settled and collapsed, it could have pulled part of the house lower as it went. Pile embedment appears to have been the larger issue at the houses shown in Figures 3-127 and 3-128, and insufficient embedment likely allowed the slabs to induce or worsen building settlement.

Figure 3-126.
Slab failure probably contributed to foundation damage (West Galveston Island, TX)
PHOTO COURTESY OF STUART ADAMS, LSU HURRICANE CENTER

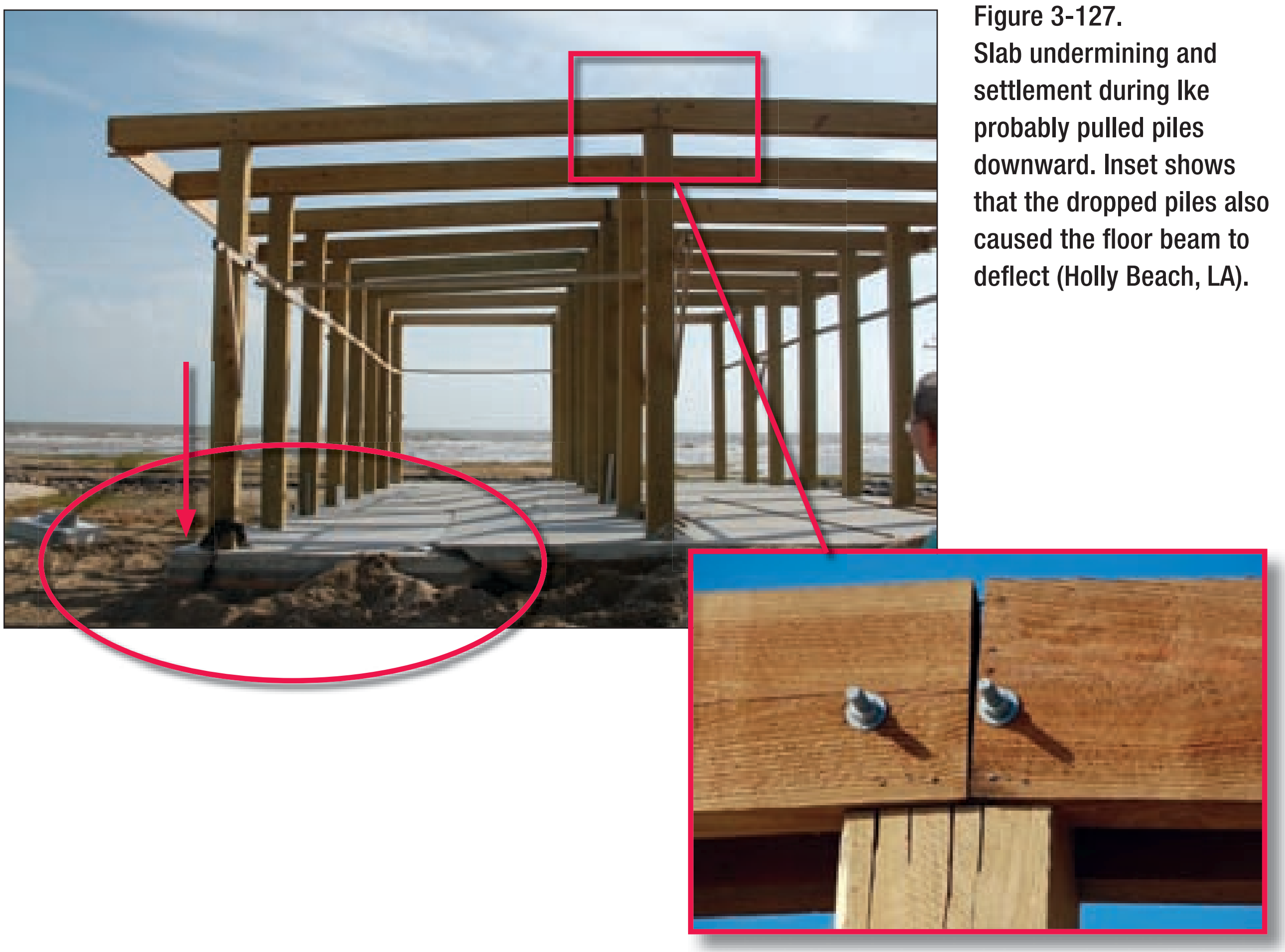


Figure 3-127.
Slab undermining and settlement during Ike probably pulled piles downward. Inset shows that the dropped piles also caused the floor beam to deflect (Holly Beach, LA).

Figure 3-128.
The weight of this slab, undermined due to scour and erosion, could have contributed to settlement and racking of this elevated house (Surfside Beach, TX)

The MAT observed several houses on Galveston Island where parking slabs were constructed in 4-foot square sections and unreinforced. This method of construction is consistent with that recommended in FEMA 55, Third Edition. Where these slabs were observed, their failure did not appear to adversely affect foundations or elevated buildings (Figure 3-129). Section III of the *Galveston County Dune Protection and Beach Access Plan* (2006) requires use of unreinforced fibercrete or concrete slab sections (maximum 4-inch thickness) within 200 feet of the vegetation line in eroding areas.

Figure 3-129.
Thin, unreinforced parking slab sections separated when undermined and collapsed in place, with no apparent adverse impact to the foundation (Galveston Island, TX)

3.3.4 Mold and Contamination

Hurricanes introduce various forms of contaminants and pollution into floodwaters and flooded buildings. Hurricanes also lead to the post-event growth of mold in wind- and flood-damaged buildings. Figure 3-130 illustrates one of many examples of mold and mildew growth observed by the Ike MAT. Guidance on cleanup and restoration of flooded buildings can be found in the Hurricane Katrina Recovery Advisory 2, *Initial Restoration for Flooded Buildings* (July 2006d), and Katrina Recovery Advisory 4, *The ABCs of Returning to Flooded Buildings* (July 2006e).

Figure 3-130. Mildew and mold forming on wall sheathing following flooding (Golden Meadow, LA)

3.3.5 Other Issues and Problems

The MAT observed other construction deficiencies and community enforcement problems. While the details of these particular deficiencies are not known, their existence indicates potential compliance issues that should be monitored and addressed in communities visited by the MAT. Figure 3-131 shows a case where floor beams and joists were improperly notched to allow for plumbing installation. This practice can weaken structural members and should only be done at the direction of a structural engineer. Figure 3-132 shows a case where flood vents did not penetrate through the entire enclosure wall—if this installation was complete when observed by the MAT, this practice is a clear violation of NFIP flood opening requirements.

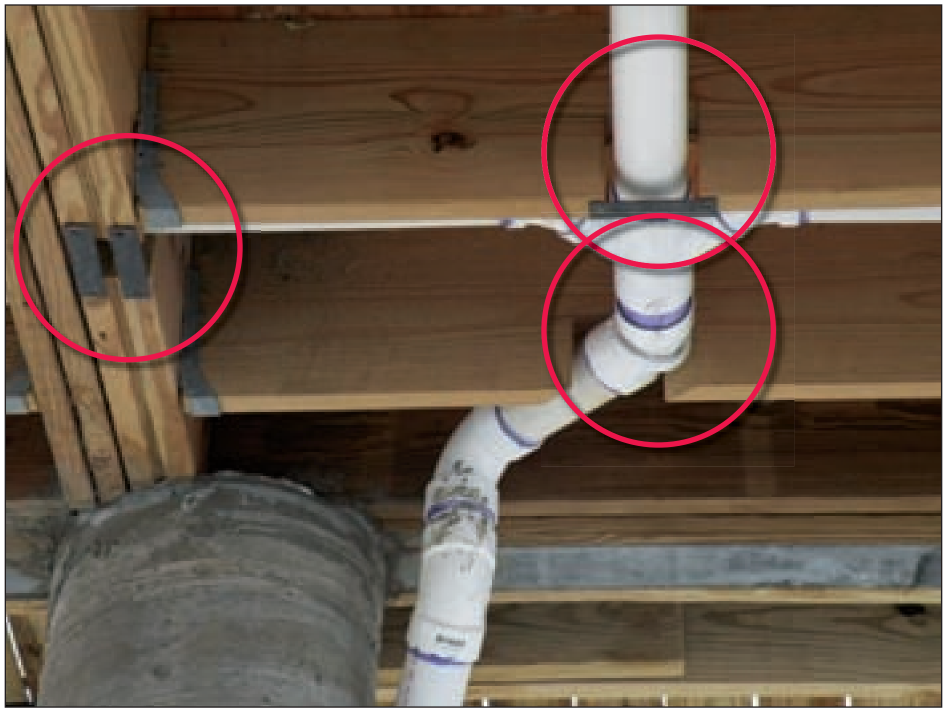


Figure 3-131. Floor joists and beams were notched to allow for plumbing (Sulphur, Calcasieu Parish, LA)

Figure 3-132. Flood vent openings (red circles) that do not extend through the walls (Hackberry, Cameron Parish, LA)

3.4 Manufactured Housing

The MAT visited several communities in south Louisiana and east Texas where large numbers of manufactured homes were damaged by some combination of storm surge, waves, floodborne debris, and wind. In some locations in southwest Louisiana, manufactured housing installed after Hurricane Rita was not elevated to or above the BFE. This may have occurred in existing manufactured housing parks where an NFIP exception allows some homes to be elevated 3 feet above grade, even where this is lower than the BFE, or it may have occurred through incorrect application of the 3-foot exception. Whether this practice was allowed by the NFIP exception or not, the result was the same—large numbers of manufactured homes installed below the BFE after Hurricane Rita were heavily damaged or destroyed by Hurricane Ike.

3.4.1 Texas

In San Leon, TX, the MAT observed a manufactured home that was knocked off its foundation and destroyed. The home was located in a Zone AE (BFE = 11 feet) approximately 150 feet landward of a rip-rapped shoreline. High water marks in the area indicated water levels were over 12 feet NGVD, and 5 feet or more above grade. Coastal A Zone conditions (wave heights between 1½ and 3 feet) likely existed there during Ike.

The home, shown in Figure 3-133, was placed on short, unreinforced and un-mortared "dry stack" masonry piers placed on pre-cast concrete pads (at 8-foot centers [+/-]), and was secured with ground anchors spaced at 4-foot centers (+/-) with metal stabilizer plates.

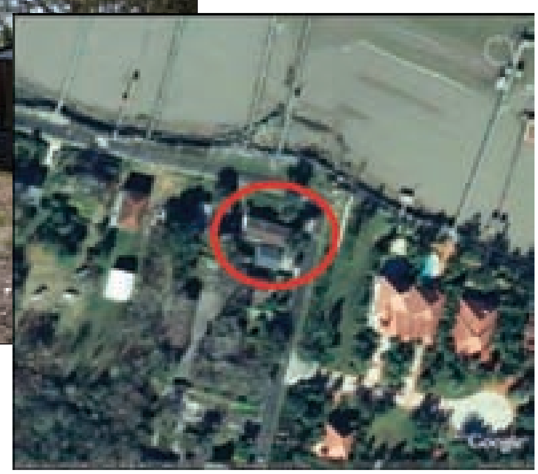


Figure 3-133. Destroyed manufactured home (San Leon, TX)
SOURCE: GOOGLE MAPS FOR INSET SHOWING LOCATION

Evidence suggests that the home was displaced from its piers by moving floodwaters or waves. Scour, undermining the concrete pads beneath the piers, may have contributed. Ground anchor failures were not noted, but the straps connecting the home to the anchors had torn away from the house's anchorage points (Figure 3-134). HUD's 2007 *Manufactured Home Construction and Safety Standard* (MHCSS), 24 CFR Parts 3280 and 3285, place this site in a Wind Zone II. The MHCSS requires Wind Zone II homes to be secured and anchored to their steel frames and to wall ties. No wall ties were observed. This suggests that the home was either non-compliant or was installed before the HUD standards went into effect.

Figure 3-134.
Scour depressions existed around the masonry piers, pads, and ground anchor stabilizer plates (San Leon, TX)

In Oak Island, TX, some manufactured homes were elevated on timber piles. The elevation prevented foundation failure, but some of the homes were still damaged by inundation (Figure 3-135).

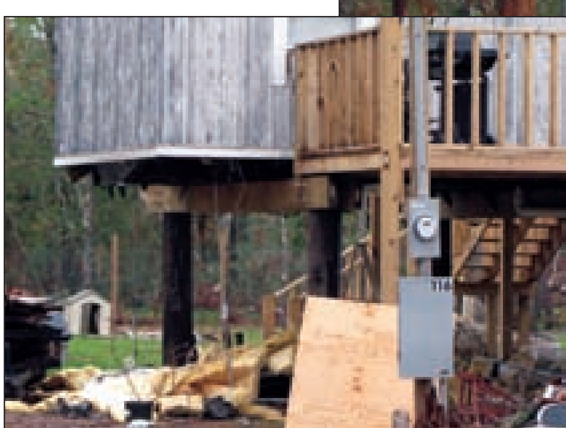


Figure 3-135.
Manufactured home in Oak Island, TX. The house foundation did not fail, but the elevation was insufficient to prevent damage from inundation.

3.4.2 Louisiana

The MAT observed that Zone A manufactured homes elevated at or above the BFE/ABFE on reinforced concrete or reinforced masonry piers with proper anchoring performed well. The best performance of foundations in Zone V was found to be timber piles embedded sufficiently to withstand erosion and scour effects. Zone V homes on piers resting on concrete pads often failed due to flood and erosion/scour effects.

3.4.2.1 Cameron and Vermilion Parishes

Many of the manufactured homes that were present in Cameron and Vermilion Parishes in 2005 are no longer in place. Those structures were destroyed by Hurricane Rita and in many instances, had not been replaced. Many of those that had been replaced after Rita and not elevated to or above the BFE/ABFE were damaged by Ike.

The manufactured homes shown in Figure 3-136 are located immediately east of the Cameron Parish offices along LA Hwy 82 in South Cameron. They are currently located within Zone A, but will be classified as Zone V when the pending new flood maps are adopted. The homes were not properly anchored and were forced off their foundation piers by the storm surge.

Figure 3-136.
Two manufactured homes in Cameron, LA. Homes were displaced off foundations and siding peeled due to inundation and storm surge of approximately 4 feet above ground.

3.4.2.2 Jefferson Parish

The manufactured home shown in Figures 3-137 and 3-138 is located in Zone A (BFE = 10 feet, ABFE = 12 feet) on Grand Isle, Jefferson Parish. Ike floodwaters were approximately 6 feet deep and did not reach the home, which was elevated in compliance with NFIP requirements. Support framing was in place, and strapping secured the walls and the steel chassis frame to the foundation. While effective during Ike, the strapping was installed using non-conventional methods. Its ability to resist a design wind event could not be determined.

The home experienced some wind damage (vinyl siding and portions of the roof covering were dislodged) despite the fact that the Ike wind speeds and wind pressures were far below the HUD and ASCE 7-05 design wind speeds and pressures. Section 305 of the MHCSS, 24 CFR Part 3280, requires that siding be designed to resist wind loads for Exposure C specified in ANSI/ASCE 7-88, or wind pressures specified the HUD Standard table titled Table of Design Wind Pressures. The MHCSS places Jefferson Parish in HUD Wind Zone III, and the Table of Design Wind Pressures requires exterior coverings within 3 feet of corners to resist +/- 58 psf, and exterior coverings in other areas to resist +/- 46 psf. The ASCE 7-05 wind pressures (for a 150 mph basic wind speed) are +49/-65.7 psf at the corners of a building and +49/-53.1 psf in other areas.

Figure 3-137. This elevated manufactured home in Grand Isle of Jefferson Parish, LA, had siding and roof damage, but did not move from its foundation

Figure 3-138. The framing and anchoring system of the house shown in Figure 3-137. Strapping secured the home's walls and frames to its foundation. While the strapping held the home to its foundation during Ike, it could not be determined if the strapping would resist a design wind event (Estimated wind speed during Ike: less than 60 mph, 3-second gust).

3.4.2.3 Lafourche Parish

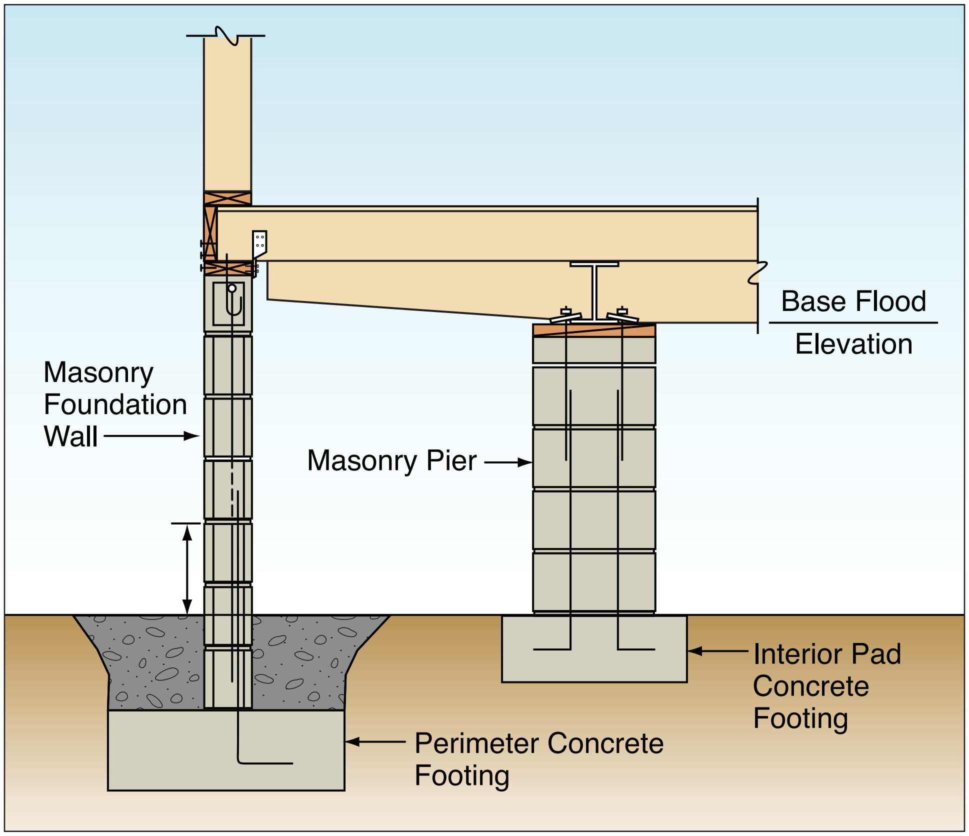
The Zone A home shown in Figure 3-139 in Lafourche Parish was elevated, but not above the BFE. It suffered flood damage from about 3 to 4 feet of water above the floor. Interviews with nearby residents indicated the floodwaters reached the eaves on the house with the green roof to the right. Flood velocities were not sufficient to shift the manufactured home off of its foundation and the floodwaters rose slowly enough to allow leakage into the home, thereby preventing the home from becoming buoyant and floating off its foundation.

Figure 3-139.
Zone A manufactured home in the Golden Meadows section of Lafourche Parish, LA, sustained 3 to 4 feet of flooding above the floor, but did not shift or float off of its foundation. The red arrow indicates the flood level reported by neighbors.

3.4.2.4 Manufactured Home Anchoring and Support Systems

Manufactured homes in SFHAs must be placed on foundation systems that will resist flotation, collapse, and lateral movement (Figure 3-140). The 2005 edition of the NFPA 225, *Model Manufactured Home Installation Standard,* contains performance requirements for flood-resistant manufactured home installations. The 2008 edition, issued in January 2009, also contains prescriptive flood-resistant installations. Other flood-resistant foundation solutions will be contained in the revised FEMA 85, scheduled to be completed in 2009.

Figure 3-140. Prescriptive Flood-Resistant Foundation Design



3.5 Mitigation Projects

The MAT typically looks at funded mitigation projects to determine if the projects were successful. The MAT visited 27 residential mitigation projects in Louisiana and 10 in Texas. Thirty-four of the projects visited were elevation projects, and three were acquisition projects. All of the projects received funds through the Hazard Mitigation Grant Program (HMGP) or through Increased Cost of Compliance payments via NFIP flood insurance policies. There were no structures visible at the three acquisition project sites, and the land had been cleared and restored.

Three of the 34 elevation projects had not been undertaken at the time of the MAT visit. The remaining 31 elevation projects had been completed and were successful as far as preventing Ike flood damage—none of the elevated buildings appeared to have been flooded during Ike, even though many of the building sites were inundated. Most of the buildings had been elevated on masonry piers, tall masonry columns, or timber piles.

While most of the elevation projects appeared to have been constructed in accordance with applicable codes and standards, some load path deficiencies (Figure 3-141) were noted that indicate possible project design and/or compliance problems that should be investigated. Some of the elevated buildings sustained wind damage to the building envelope during Ike (Figure 3-142); this is likely a result of older homes being elevated, as opposed to a problem with the elevation project itself.

Figure 3-141.
Zone A house elevated with Increased Cost of Compliance funds on masonry piers (Iberia Parish, LA). There was no evidence of pier reinforcement, mortar between masonry blocks, or ties between the piers and the elevated home.

Figure 3-142.
House elevated with Increased Cost of Compliance funds (Kemah, TX). Inset shows evidence of wind damage to roof (Hurricane Ike estimated wind speed in this area: 90 mph, Exposure B).

Tom Smith
David Conrad
Dave Low
Mark Matulik
Wallace Wilson

HURRICANE IKE IN TEXAS & LOUISIANA

4 Performance of Critical Facilities

Critical facilities are important before, during, and after natural hazard events. They are needed to prepare for an event, house emergency workers during an event, and manage response and recovery operations after an event. Hurricane Ike had a significant impact on many of these facilities, totally destroying some of them and severely interrupting the operations of several others.

Several of the observed facilities were damaged by flooding, and many experienced wind damage, even though they were subjected to winds that were below current design wind speeds. Most critical facilities did not perform any better than commercial buildings. The poor building performance placed additional burdens on response and recovery personnel as they endeavored to provide assistance to their communities after the event.

Critical facilities are Category III and IV buildings as defined in ASCE 7-05 and the 2006 IBC (Section 1604, General Design Requirements, Table 1604.5). Category III and IV buildings include, but are not limited to, hospitals and other medical facilities, fire and police stations, primary communications facilities, EOCs, schools, shelters, and power stations and other facilities required in an emergency. In addition to the buildings listed in Categories III and IV, other buildings can play vital roles in recovery after an event, such as buildings used to provide housing for emergency workers.

Buildings that sustained damage from flooding may not have been elevated enough to reduce damage from the flood levels experienced. Most of the wind damage was to envelope systems and rooftop equipment. Except for occasional shuttering of glazed openings, most of the investigated buildings did not appear to have been designed and constructed with wind-resistant enhancements to the building envelope and rooftop equipment.

Table 4-1 lists the type and total number of critical facilities that were observed by the MAT. Sections 4.1 through 4.4 describe the performance of some of these critical facilities.

Table 4-1. Critical Facilities Observed by the MAT

Facility Type	Louisiana	Texas		Total Number of Facilities Observed by MAT
	Exposed to flood and wind*	Exposed to wind only**	Exposed to flood and wind	
Schools/shelters (Section 4.1)	2	3	4	9
Hospitals/healthcare (Section 4.2)	2	4	1	7
Police, Fire, EOC (Section 4.3)	5	7	6	18
Government Buildings (Section 4.4)	2	6	6	14

* In portions of Louisiana, critical facilities experienced relatively low wind speeds (e.g., 50 mph or less).

** Critical facilities observed in Texas experienced wind speeds of 90 mph or greater (peak gust, Exposure C, 33 feet above grade).

Special Flood-Related Provisions for Critical Facilities

The 2006 edition of the IBC requires Category III and IV buildings to be designed and constructed in accordance with ASCE 24-05, which calls for these buildings to be elevated above the NFIP minimum elevation requirement. ASCE 24-05 elevation provisions are summarized in Table 4-2 (refer also to Section 2.2).

States and communities often impose their own freeboard requirements on critical facility construction in flood hazard areas. For example, Pennsylvania requires special permits and requires at least 1.5 feet of freeboard (Commonwealth of Pennsylvania, 2001). Louisiana encourages the addition of 1 foot of freeboard for projects receiving State funds.

Under Executive Order 11988,[1] Floodplain Management, Federal agencies undertaking actions (funding, permitting, constructing, etc.) affecting critical facilities are to avoid the 0.2-percent-annual-chance (500 year) floodplain. If that is not possible, Federal agencies are to protect (elevation or floodproofing) critical facilities to the 0.2-percent-annual-chance (500-year) flood level.

Table 4-2. ASCE 24-05 Elevation Requirements for Critical Facilities

Building Component	Category III		Category IV	
	Zone A	Zone V and Coastal A Zone*	Zone A	Zone V and Coastal A Zone*
Lowest Floor Elevation**	BFE + 1 foot, or DFE, whichever is higher	BFE + 1 or 2 feet**, or DFE, whichever is higher	BFE + 2 feet, or DFE, whichever is higher	BFE + 1 or 2 feet**, or DFE, whichever is higher
Dry-Floodproofing	BFE + 1 foot, or DFE, whichever is higher	Not allowed	BFE + 2 feet, or DFE, whichever is higher	Not allowed
Flood-Damage Resistant Materials	BFE + 1 foot, or DFE, whichever is higher	BFE + 2 or 3 feet**, or DFE, whichever is higher	BFE + 2 feet, or DFE, whichever is higher	BFE + 2 or 3 feet**, or DFE, whichever is higher
Utilities and Equipment Elevation	BFE + 1 foot, or DFE, whichever is higher	BFE + 2 or 3 feet**, or DFE, whichever is higher	BFE + 2 feet, or DFE, whichever is higher	BFE + 2 or 3 feet**, or DFE, whichever is higher

BFE = base flood elevations; DFE = design flood elevation

* Coastal A Zone is the area subject to wave heights of 1.5 to 2.9 feet during the base flood; on newer FIRMs it will be the area between the LiMWA (limit of moderate wave action) and Zone V.

** Lowest floor elevation = top of lowest floor (walking surface) in Zone A, and bottom of lowest horizontal structural member supporting the lowest floor in Zone V and Coastal A Zone.

Special Wind-Related Provisions for Critical Facilities

The 2006 edition of the IBC has only two special wind-related provisions pertaining to Category III and IV buildings:

- **Importance factor:** The importance factor for these buildings is 1.15, rather than the 1.0 factor that is used for most other types of buildings. Using the 1.15 importance factor effectively increases the design loads for the MWFRS and C&C by 15 percent.
- **Windborne debris loads:** For buildings located within windborne debris regions (as defined in ASCE 7-05) of hurricane-prone regions, exterior glazing is required to be impact-resistant. For Category III and IV buildings located where the basic wind speed is 130 mph or greater, the glazing is required to resist a larger momentum missile load than the glazing on other types of buildings.

1 http://www.fema.gov/plan/ehp/ehplaws/eo11988.shtm

4.1 Schools/Shelters

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 affect a community's ability to rapidly respond to the needs of disaster victims.

4.1.1 Crenshaw Elementary and Middle School (Port Bolivar, TX)

The Crenshaw Elementary and Middle School in Port Bolivar, TX, opened in 2005 (Figures 4-1 and 4-2). The school is located approximately 2,400 feet inland of the Gulf shoreline. It is elevated on concrete columns, with the bottom of the first floor beams approximately 10 feet above grade.

The facility did not suffer flood damage because of its elevated construction, but considerable floodborne debris washed underneath the school (Figure 4-3). A debris line on a fence under the school indicated the flood depth was approximately 5.5 feet above grade; a debris line on a fence adjacent to the school was surveyed and found to be at elevation 14.8 feet NAVD (URS, 2008).

The school received some wind damage to its roof and rooftop equipment. The gym roof deck is cementitious woodfiber. Other roof deck areas are steel. According to ASCE 7-05, the basic (design) wind speed for this location is approximately 130 mph. The estimated maximum wind speed during Hurricane Ike was approximately 110 mph.[2]

General Wind Damage. The building suffered some wind damage to its roof, as a result of the gutter blowing off the roof and damage to rooftop equipment, described below.

Figure 4-1. September 19, 2008, aerial view of Crenshaw Elementary and Middle School

2 All estimated speeds in this Chapter are peak gust, Exposure C, at 33 feet taken from *Estimates of Maximum Wind Speed Produced by Hurricane Ike in Texas and Louisiana* (ARA, 2008).

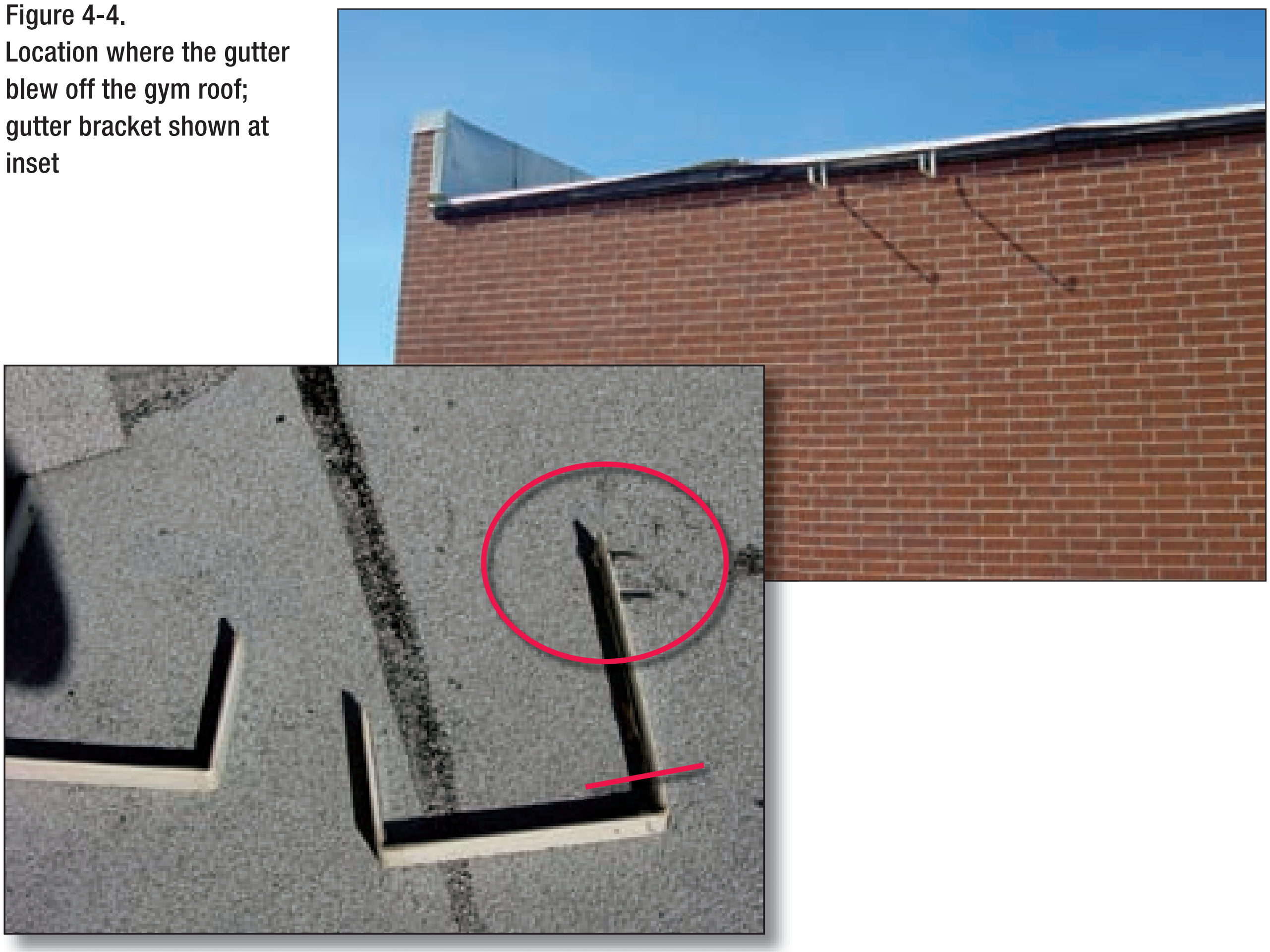
Figure 4-2.
General view of Crenshaw Elementary and Middle School

Figure 4-3.
Wall of house washed underneath Crenshaw School during Ike (note shutters still attached to wall)

The gutter and most of its brackets blew off the gym roof (Figure 4-4), but the roof membrane did not progressively peel as is typically the case when a gutter is blown away. The brackets were attached with two ring-shank nails, both of which were located near the top of the bracket, as shown in the inset in Figure 4-4. Since both fasteners were near the top of the bracket, they provided little resistance to outward rotation (moment) as the wind pulled and lifted the gutter away from the building. Significant permanent outward deformation was observed at gutters at other roof areas of the building (similar to the condition shown by the inset at Figure 4-41). To resist the moment force, a screw should have been placed near the lower edge of the bracket, as shown by the red line in the inset at Figure 4-4. Screws should be used to attach brackets because they are more resistant than nails to dynamically induced pull-out forces. The gutter brackets were not attached to the gutter (see discussion in Section 4.3.2).

The MAT observed the rooftop equipment on the facility. The rooftop exhaust fans had too few fasteners, although none of the fans blew away during this storm. The exhaust fans were attached with two screws per side; for this location, FEMA 543, *Design Guide for Improving Critical Facility Safety from Flooding and High Winds: Providing Protection to People and Buildings* (2007), recommends six screws per side. The hood blew off two units, which allowed rain to enter the building (Figure 4-5).

Figure 4-4.
Location where the gutter blew off the gym roof; gutter bracket shown at inset



Access panels blew off a few pieces of rooftop equipment. As shown in Figure 4-6, rain was able to directly enter the building during the storm and was still able to at the time of the MAT visit. The ductwork shown in Figure 4-6 was easy to shake back and forth by hand (illustrated by the double-headed red arrow). Had the winds been near design conditions, the ductwork may have blown away.

Functional Loss. The school was closed after Ike but served as a location for emergency operations and many community meetings during the post-Ike response and recovery period. At the time of the MAT investigation, the building was being used to house fire department personnel from other areas in Texas. These personnel provided emergency services for those involved in recovery efforts.

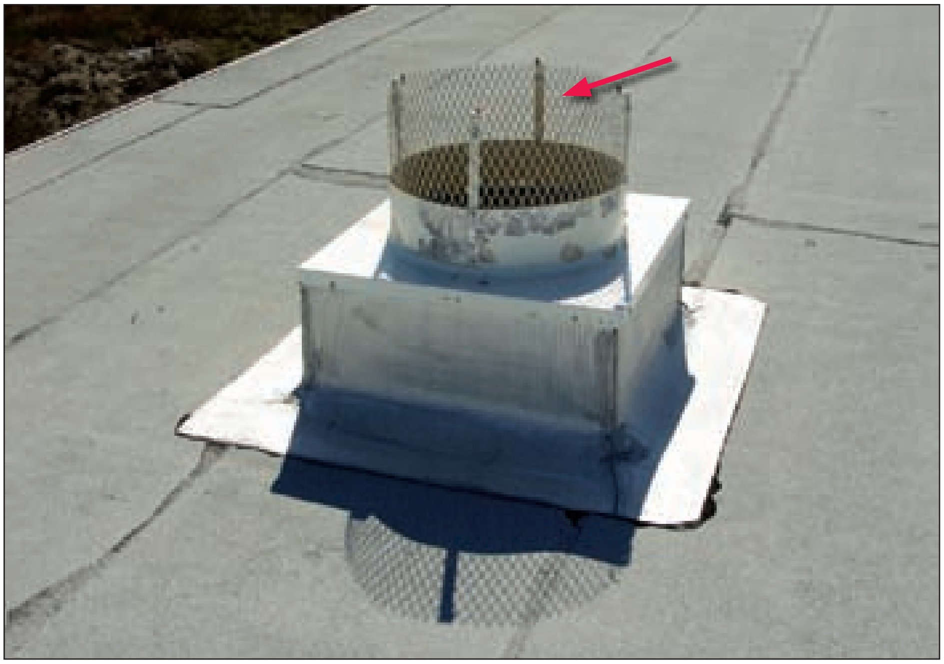


Figure 4-5.
Wind blew off the hood, allowing rain to directly enter the building

Figure 4-6.
Missing access panel allowed rain intrusion; ductwork could be easily flexed

Although some water infiltrated damaged rooftop equipment, the storm's impact on this facility's functioning as a critical facility was minimal. The school reopened in February 2009 when some students were able to return to the school.

Vulnerabilities and Other Observations. Had the winds been stronger, significant water infiltration would have been likely due to roof membrane blow-off associated with gutter failure.

4.1.2 South Cameron Parish High School (Grand Chenier, LA)

The South Cameron Parish High School located in Grand Chenier, LA, received significant damage from flooding during Hurricane Ike. The school is located on Grand Chenier Highway and is approximately 2.1 miles from the Gulf of Mexico shoreline. The facility had been previously damaged by flooding during Hurricane Rita, including extensive damage to the school and gymnasium. Although repairs and reconstruction were still in progress when Ike hit, facility personnel stated that the damages observed by the MAT were caused by Ike. However, no mitigation for flooding had been performed and the facility was not elevated.

The school complex is comprised of two flood zones. The southern portion is located in flood hazard Zone AE (BFE = 12 feet NGVD); the northern portion is located in Zone VE (BFE = 12 feet NVGD). In March 2006, FEMA published ABFE Maps showing the southern portion as Zone AE (ABFE = 13 feet NGVD) and the northern portion as Zone VE (ABFE = 13 feet NGVD). The March 2008 Preliminary DFIRM, released by FEMA after completion of the post-Katrina and Rita flood hazard studies, shows the entire site will be remapped as Zone VE (Coastal High Hazard Areas) with a BFE of 15 feet. The gymnasium and track and the modular units are all in the northern portion.

General Flood Damage. The interiors of all the buildings were flooded. A debris line on the fence at the front of the school indicated flood depths reached approximately 5 feet above grade. The wooden gymnasium floor was damaged, and metal walls seaward of the gymnasium were breached by flooding. Approximately 15 modular classrooms were inundated by storm surge floodwaters (Figures 4-7 and 4-8). At the time the MAT inspected the school, students had been relocated to other schools in the Parish.

General Wind Damage. The MAT did not access the roof at this facility, so a determination of wind damage could not be made.

Figure 4-7.
Damage to South Cameron Parish School modular units

Figure 4-8. High school gymnasium at South Cameron Parish School

Functional Loss. The South Cameron Parish School suffered a complete loss of function. The school experienced storm surge inundation. The school was not operational at the time of the MAT's visit.

4.1.3 Johnson's Bayou School (Cameron, LA)

The Johnson's Bayou School, grades K–12, suffered significant flood damage during Hurricane Ike. Like South Cameron High School, this critical facility is located on Gulf Beach Highway and is approximately 1.3 miles from the Gulf of Mexico shoreline.

General Flood Damage. The facility was flooded by storm surge with depths reaching 5 to 6 feet. Some masonry walls were flood damaged, as were interior walls, furnishings, and electrical systems (Figures 4-9 through 4-12).

Figure 4-9. Johnson's Bayou School interior building damage

Figure 4-10.
Johnson's Bayou School – damage to wall on front side of facility (soffit of driveway canopy was also damaged)

Figure 4-11.
Johnson's Bayou School gymnasium interior damage

Figure 4-12.
Johnson's Bayou School CMU wall collapse. (Note: HVAC units that had previously been damaged were relocated to an elevated platform under the FEMA Public Assistance Program.)

General Wind Damage. Significant wind damage occurred to the roof system for the school gymnasium (Figure 4-13). Figure 4-13 also shows the significant damage to the walkway canopy. The Johnson's Bayou School experienced damage to roof coverings and rooftop equipment. The breached building envelopes allowed widespread rainwater damage and storm surge floodwater intrusion to the interior.

Functional Loss. The combination of storm surge flooding to depths reaching 5 to 6 feet with widespread rainwater damage from the breached building envelope resulted in the loss of school operations. At the time of the MAT inspection, the school was not operational.

Figure 4-13. Johnson's Bayou School gymnasium. The red ovals indicate damage to canopy and roof.

4.2 Hospitals/Health Centers

When a hurricane strikes, hospitals and health centers, EOCs, and shelters are the most important buildings in a community. In addition to providing continuity of care for patients in hospitals before a storm, hospitals also receive large numbers of people seeking medical treatment after strong hurricanes. Blunt-force trauma injuries caused by windborne debris, falling trees, collapsed ceilings, partial building collapse, and flood-related injuries occur during hurricanes; however, most hurricane-related injuries typically occur in the days afterward. These injuries are typically due to chainsaw accidents, stepping on nails, lacerations incurred while removing debris, vehicle accidents at intersections that no longer have functional traffic lights, people falling off roofs as they attempt to make emergency repairs, and carbon monoxide poisoning or electrical shock from improper use of emergency generators. Therefore, at a time when many hospitals in an area may be functionally impaired or no longer capable of providing service due to building damage, hospital staffs are faced with a higher than normal number of people seeking treatment. Before arrival of a hurricane, hospitals also often admit an influx of women in their third trimester of pregnancy who wish to be at the hospital in case they go into labor during the storm or shortly thereafter, when getting to the hospital could be hazardous or impossible.

4.2.1 San Jacinto Methodist Hospital (Baytown, TX)

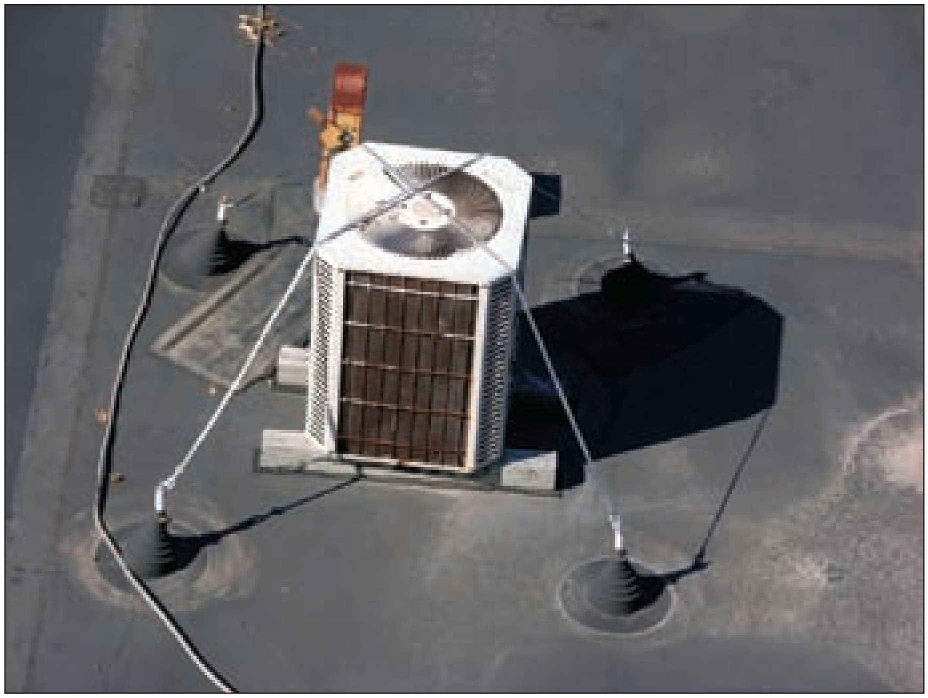
The San Jacinto Methodist Hospital in Baytown, TX, was constructed around 1974, and a medical office building was added in 1995. The hospital sustained some wind and water leakage damage during Hurricane Ike. According to ASCE 7-05, the basic wind speed for this location is approximately 113 mph. The estimated maximum wind speed during Hurricane Ike was approximately 105 mph. Figure 4-14 is a general view of the building. The facility was evacuated on September 11, 2008, because of a mandatory evacuation order. The facility was reoccupied on September 18, 2008.

In the aftermath of Tropical Storm Allison (2001), mitigation work was performed on the facility in 2003–2004 using HMGP grant funds. The work included reroofing the medical office building and a portion of the hospital. The roof that was replaced at the office building was a modified bitumen membrane. The roof that was replaced at the hospital was an aggregate-ballasted, single-ply membrane. Mineral surface modified bitumen membranes over rigid insulation were used for the mitigation work. Both of these roof areas have steel roof decks. According to project records, the new roofs had a Factory Mutual Global 1-90 rating (i.e., the roof system was sufficient for field of roof design pressures up to 45 psf). (Note: The field design uplift load is approximately 30 psf, hence the specified system had sufficient uplift resistance to meet the ASCE 7-02 load.)

General Wind Damage. The facility experienced some water leakage at the three-story wing shown in Figure 4-14. Some of this leakage was likely due to damaged rooftop equipment. The MAT observation of the roof on this portion of the facility indicated that at least one fan cowling was blown away. No special attachment was provided for the fan cowlings (such as that shown in FEMA 577, *Design Guide for Improving Hospital Safety in Earthquakes, Floods, and High Winds: Providing Protection to People and Buildings* [2007]). However, special attachment was provided for the condenser shown in Figure 4-15. Strapping condensers is a practice that is recommended in FEMA 543 and 577. Unless strapped, condensers frequently topple over.

Figure 4-14.
General view of San Jacinto Methodist Hospital

Figure 4-15.
Condenser with tie-down cables



In a few areas, the lightning protection system (LPS) conductors became detached from the roof membrane (Figure 4-16). Loose conductors can puncture and tear roof membranes, and they no longer provide the intended protection. FEMA 543 and 577 provide guidance for attachment of LPSs to resist wind.

Figure 4-16.
Detached LPS conductor

The satellite dish shown in Figure 4-17 was held down only with CMU. This attachment technique was adequate for the winds experienced at this site, but dishes attached by this method have failed in other hurricanes, as shown in the inset at Figure 4-17. The dish shown in the inset was blown completely off the roof; only the CMU remained (FEMA 488).

Figure 4-17.
This satellite dish was held down with CMU only; inset shows all that remains from a similarly mounted dish after a strong hurricane

Functional Loss. Water infiltration resulted in some damage to interior finishes, and the leakage disrupted use of some rooms. However, the disruption did not adversely affect delivery of services. It cost approximately $60,000 to repair the damages. For approximately 3 weeks after the facility was reoccupied, the facility's emergency generator provided power during intermittent municipal power outages. There was no interruption of water or sewer service.

Vulnerabilities and Other Observations. At the two mitigated roofs and the other non-mitigated roofs, had the winds been stronger, extensive damage to rooftop equipment and significant water infiltration would have been likely due to equipment blow-off and roof membrane punctures associated with rooftop equipment failures and detached lightning protection equipment. Also, had the winds been stronger, depending upon wind direction, glazing damage would have been likely from windborne debris comprised of tree branches near the facility and/or aggregate from a built-up roof (BUR) on a building near the hospital campus.

Glazing protection: Since this building is not in a windborne debris region, glazing protection is not required. However, debris-induced glazing damage has been documented to have occurred during wind speeds slightly in excess of 100 mph (peak gust at 33 feet, Exposure C). Accordingly, in hurricane-prone regions, FEMA 543 and 577 recommend glazing protection when the basic wind speed is 100 mph or greater. Providing glazing protection at this facility as part of the mitigation work would have been prudent.

Additionally, had the winds been stronger, portions of the exterior insulation finish system (EIFS) wall covering may have blown away or been penetrated by windborne debris. EIFS wall covering failures are commonplace during hurricanes. This wall covering system can offer good high-wind performance, but great attention to design and application is needed to do so. FEMA 577 does not recommend this type of wall covering on hospitals in hurricane-prone regions.

The MAT also observed a lack of adequate pre-storm preparations. As part of the pre-storm preparations, hospital roof areas should be checked. As part of this check, roof drains, scuppers, and gutters should be cleaned of debris so that they are capable of draining the roof during the hurricane (some of which produce a tremendous quantity of rain). Figure 4-18 is a view of one of the mitigated roofs. Clearly this roof drain area had not been cleared of debris for quite some time.

Performance of HMGP Mitigation Work. When the facility undertook mitigation work, conducting a comprehensive vulnerability assessment and then mitigating the significant vulnerabilities, or alternatively, recognizing the residual risk that remains, would have been prudent (see FEMA 577).

Replacing the aggregate-surfaced roof was appropriate, because aggregate can be blown off and damage glazing or injure people that come to the hospital during a hurricane. However, the mitigation work was not as robust as it should have been. Although the roof membrane choice was appropriate (and one that is recommended in FEMA 577) and had adequate uplift resistance, the new roofs did not incorporate secondary membranes to avoid water leakage in the event the membranes were punctured by windborne debris. In addition, as previously described, much of the rooftop equipment was not adequately anchored, including fan cowlings, fans, some heating, ventillation, and air-conditioning (HVAC) units, condensate drain lines, and the LPS.

Inadequate fan anchorage: One of the 2-foot by 2-foot exhaust fans was attached with two screws per side, but for this location, FEMA 577 recommends four screws per side. One of the 3-foot by 3-foot fans had three screws per side, but for this size of fan, FEMA 577 recommends five screws per side.

In addition to the inadequacies of the mitigation work that was performed, the mitigation work only addressed a portion of the hospital. Other roofs and rooftop equipment had (and still have) significant wind vulnerabilities. Before implementing a mitigation project, a comprehensive vulnerability assessment should be conducted to identify significant vulnerabilities. If funds are not available to correct all identified deficiencies, the work should be systematically prioritized so that the items of greatest need are corrected first. Following this process also allows the building owner to be aware of residual risks that remain when mitigation projects don't address all significant vulnerabilities at a facility. For further information about mitigating existing facilities, see FEMA 577, Section 4.4.

Figure 4-18.
View of one of the mitigated roofs. Note the vegetation growth in the vicinity of the roof drain, indicating a lack of maintenance.

4.2.2 Winnie Community Hospital (Winnie, TX)

The Winnie Community Hospital, constructed in the late 1960s, received wind damage during Hurricane Ike. According to ASCE 7-05, the basic wind speed for this location is approximately 119 mph. The estimated maximum wind speed during Hurricane Ike was approximately 108 mph. Figure 4-19 shows a general view of the building. Because of flooding concerns, Chambers County issued a mandatory evacuation order for this hospital and other healthcare facilities around noon on September 11 (approximately 1 ½ days before Hurricane Ike made landfall). The evacuation was accomplished within 2 hours, but was hampered by a lack of ambulances, which were also needed to evacuate hospitals in Beaumont and Galveston. The hospital reopened to offer limited urgent care 3 days after Ike's landfall.

General Wind Damage. An entry canopy blew away (Figure 4-19). A few windows were broken (likely by windborne debris) and wind-driven water entered at several of the windows. At one area, a portion of the edge flashing deformed outward and the nailer lifted, which caused a few of the bricks at the top course to fall. Had the winds been somewhat stronger, the edge flashing would likely have lifted and caused a portion of the roof membrane to blow away.

Figure 4-19.
A Winnie Community Hospital entry canopy (red oval) blew away

Numerous pieces of HVAC equipment were on the roof. Many condensers toppled, but apparently none punctured the single-ply roof membrane. However, water entered the building where some rooftop ductwork blew away (Figure 4-20). Access panels were blown away at a piece of equipment and the communications tower collapsed (both shown in Figure 4-21).

Figure 4-20.
Water entered the building where ductwork blew away

Figure 4-21.
Collapsed communications tower and blown-away access panels (red circle)

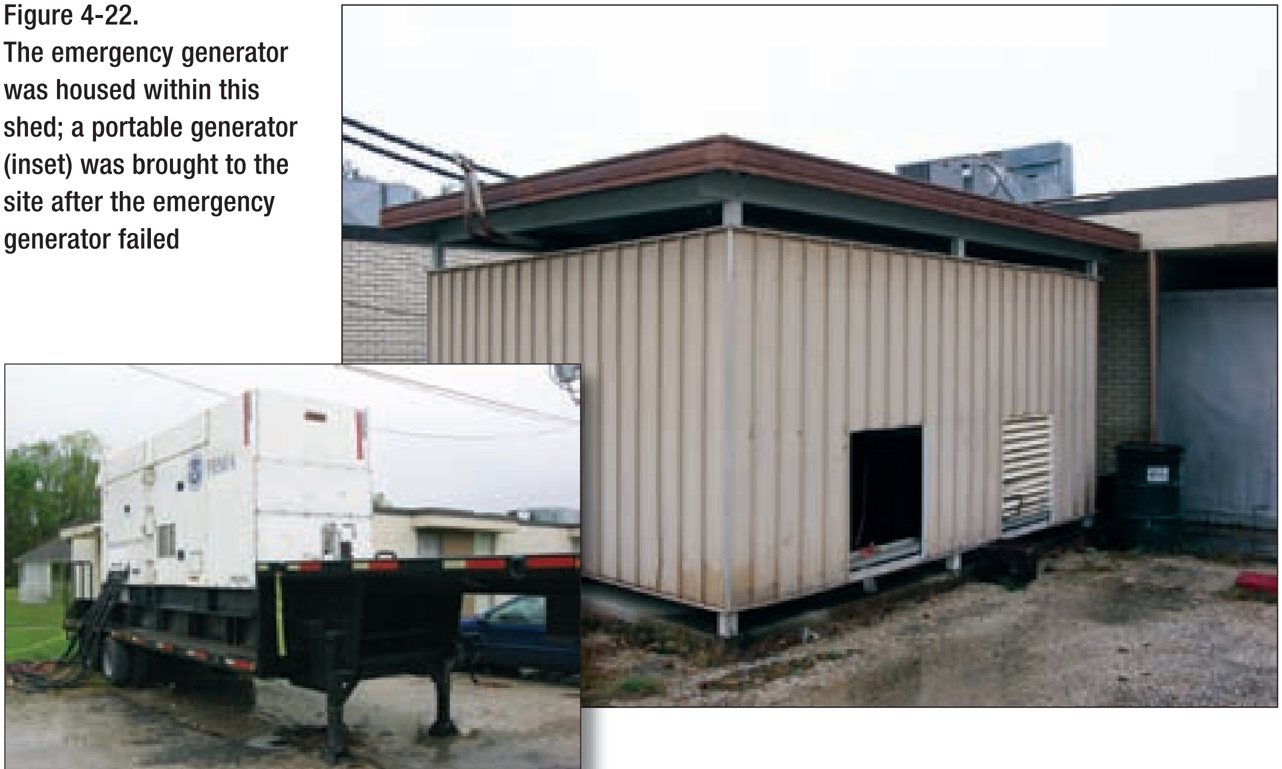
Functional Loss. At the time the hospital was reoccupied, municipal power was out, so power was provided by the hospital's emergency generator. After 2 days, the generator's governor failed, leaving the hospital without power and unable to provide urgent care services. The generator failure caused a power surge, which damaged several pieces of hospital equipment (including refrigerators). This, in turn, resulted in the loss of vaccines, medications, lab reagents, and food. Equipment had to be retested to ensure that it was safe for use.

The facility had to be vacated for 4 days until a backup generator was delivered and connected. FEMA supplied the portable generator (inset at Figure 4-22) and the facility was able to reopen. Altogether, the facility ran on emergency power for about 2 weeks. During that time, the facility was periodically refueled. There was no interruption of water or sewer service.

Vulnerabilities and Other Observations. Had the winds been stronger, extensive damage to rooftop equipment and significant water infiltration would have been likely due to roof membrane blow-off and punctures associated with edge flashing and rooftop equipment failures.

The generator was outdoors, with a roof and walls that were open at the top and bottom for air circulation (Figure 4-22). Although the generator was not damaged by wind or windborne debris in this event, the enclosure does not provide sufficient protection for the generator.

Figure 4-22.
The emergency generator was housed within this shed; a portable generator (inset) was brought to the site after the emergency generator failed



4.2.3 University of Texas Medical Branch (Galveston, TX)

The University of Texas Medical Branch (UTMB) in Galveston, TX, received significant flood damage and some wind damage. This teaching and research hospital complex has about 90 buildings on the main campus (a few of which are a few blocks from the fringes of the main campus). UTMB inhabitants were evacuated prior to the storm, including 260 patients, students, and staff.

> As of January 2009, FEMA had obligated $73 million to repair the damaged facilities, replace equipment, and recover documents (www.fema.gov:80/news/newsrelease.fema?id=47217).
>
> In addition to the devastation at UTMB and disruption of services, the temporary loss of jobs at the UTMB campus had a significant economic impact on the Galveston area.

Approximately two-thirds of the facility is located in flood hazard Zone A (BFE = 11 feet NGVD), with the remaining buildings located in shaded Zone X (area between the 1-percent-annual-chance flood and the 0.2-percent-annual-chance flood) and Zone X (outside the 0.2-percent-annual-chance flood area). A review of the UTMB Emergency Operations Plan map[3] shows that first floor elevations of campus buildings vary from approximately 7 to 16 feet NGVD.

According to ASCE 7-05, the basic wind speed for this location is approximately 132 mph. The estimated maximum wind speed during Hurricane Ike was approximately 108 mph.

3 http://www.utmb.edu/emergency%5Fplan/pdfs/Emergency%20Plan%20-%20rev%2013.pdf

General Flood Damage. The Ike flood elevation in the vicinity of UTMB fluctuated above and below approximately 12.5 feet NGVD. A review of the Emergency Plan Map showed that approximately one-third of the campus buildings have first floor elevations greater than 12.5 feet NGVD, and virtually all buildings have subgrade areas for utilities and equipment. UTMB staff reported to the MAT that approximately 90 percent of the buildings were flooded during Hurricane Ike, and approximately 90 percent of the building damage was due to flooding.

Figures 4-23 through 4-26 show some of the water marks remaining and flood clean-up underway during the MAT visit on October 20, 2008. Flooding damaged utility lines and equipment, generators, HVAC equipment, pumps and controls, gas piping for hospital and operating rooms, the morgue, offices, laboratories, and classrooms.

Figure 4-23.
High water mark (dashed blue line) shown from the outside of UTMB Building 1. The mark was measured by the MAT and found to be approximately 69 inches above the floor of the basement area inside the building.

Figure 4-24.
Clean-up underway inside the basement of UTMB Building 1. All the laboratory equipment, office and classroom contents, and interior finishes had to be decontaminated and removed for disposal.

Figure 4-25.
The Ike flood level in UTMB Building 56 pump room was approximately 30 inches above the floor, and controls and equipment were damaged

Figure 4-26.
Replaced lower interior wall sections leading to UTMB Building 90

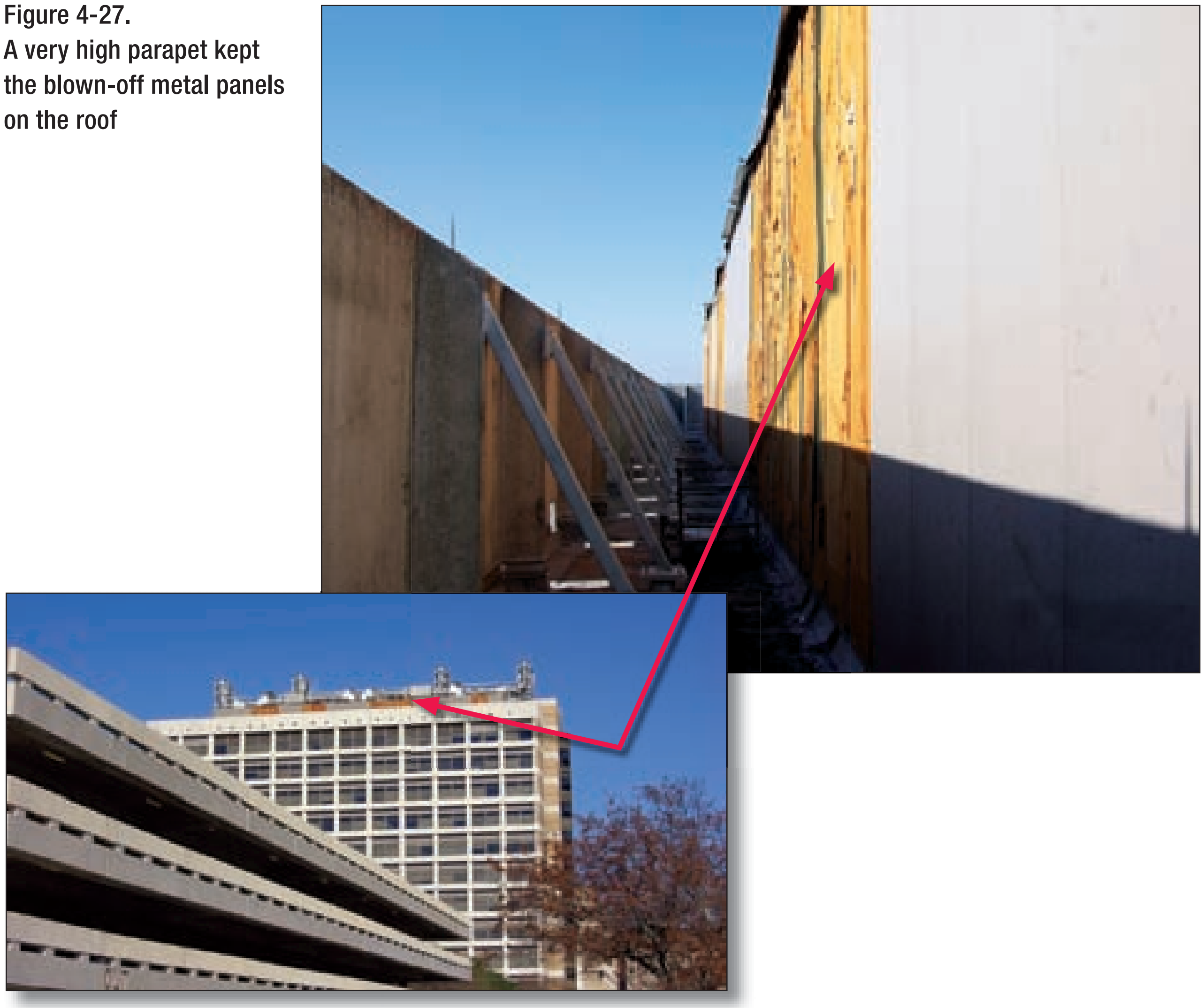
General Wind Damage. A preliminary condition assessment was conducted of the campus by a consultant (AESTIMO, INC., Facilities Engineering Consultants, Houston, TX) on September 22 and 23, 2008, to assess damage to roofs, rooftop equipment, windows, and exterior walls. To expedite the assessment process, roofs on several buildings were observed from higher rooftops. Hence, some roof membrane punctures or other types of damage may not have been identified. The report, titled *Preliminary Building Envelope Condition Assessment Report,* dated September 25, 2008, provided a list of priority buildings with 75 high priority repair items, summarized below:

- 16 buildings with broken windows (including skylights)
- 12 buildings with punctured roof membranes
- 2 buildings with roof membranes that blew off
- 5 buildings with roof system adhesion problems (i.e., the membrane did not blow off, but the insulation debonded from the deck or the membrane debonded from the insulation)
- 16 buildings with fan cowlings that blew off
- 29 buildings with fans or other rooftop equipment damage that resulted in water infiltration
- 15 buildings with flashing problems, including flashings at rooftop equipment (leakage occurred at a few flexible connectors between ducts and fans)
- 7 buildings with LPSs that detached from the roof

During their visit to UTMB in Galveston, the MAT observed the wind-induced damage described on the following page.

At the building shown in the inset of Figure 4-27, several penthouse wall panels were damaged. The panels consisted of inner and outer metal skins, with a foam insulation core. As shown in Figure 4-27, several of the outer skins blew away. The panels appeared to have been job-site fabricated, rather than having been produced as composite panels in a factory. The presence of the very high parapet prevented the metal skins from being blown from the roof and potentially damaging other parts of the facility as windborne debris. At another building, blown off EIFS was observed at a wall and at the soffits of an enclosed elevated walkway between two buildings.

Figure 4-27.
A very high parapet kept the blown-off metal panels on the roof



At the time Hurricane Alicia struck this campus in 1983, many of the buildings had aggregate-surfaced BURs and several windows on the campus were broken by wind-blown aggregate. Since Alicia, when buildings have been reroofed, they were not replaced with aggregate surfacing. However, at the time of Hurricane Ike, some aggregate-surfaced BURs still existed, such as that shown in Figure 4-28. One of the penthouse roofs was blown off during the storm. At the time of the MAT observation, that roof had been replaced by the white membrane shown by the red arrow.

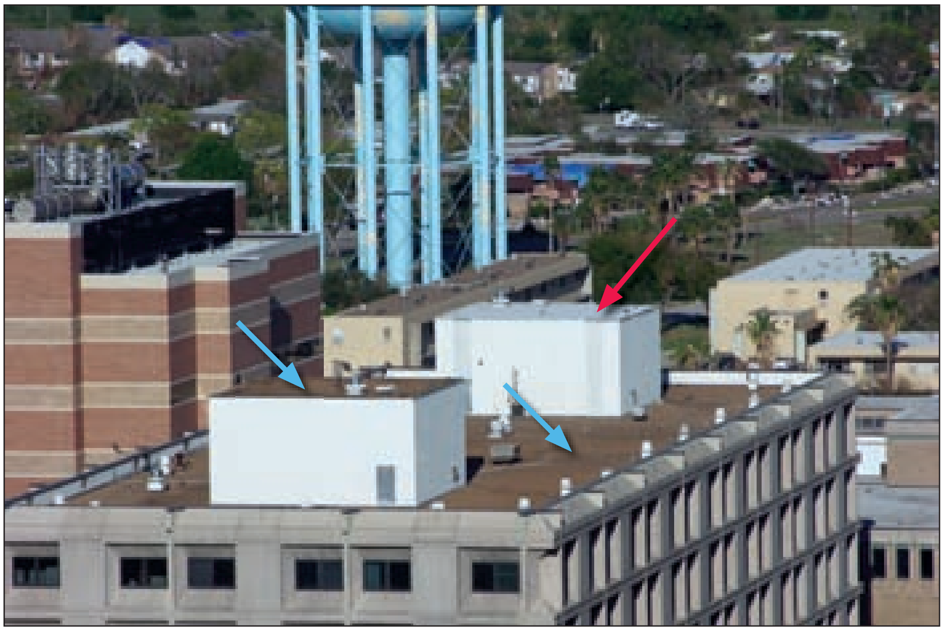


Figure 4-28.
The roofs shown by the blue arrows were aggregate-surfaced BURs at the time Ike struck; the roof shown by the red arrow is a new roof replacing one that blew off

One of the reroofing designs used by the hospital consists of a modified bitumen membrane over gypsum roof board, over rigid insulation, over a modified bitumen sheet, over a concrete deck. This is one of the roof assembly types recommended in FEMA 577. In FEMA 577, the purpose of the secondary membrane (i.e., the one over the deck) is to prevent water from leaking into the building in the event a roof membrane is punctured or blown off. However, the roof designers for the UTMB reroofing work specified the secondary membrane to avoid leakage during the tear-off and replacement of the old roof and thus, the secondary membrane fulfilled two roles.

Other rooftop equipment damage included a large stack that was blown over, even though it was guyed (Figure 4-29), and damage to two relief air hoods (Figure 4-30). One of these hoods blew off the curb.

Nine of the 32 windows in the building shown in Figure 4-31 were broken. They were likely damaged by windborne debris.

Functional Loss. The entire UTMB facility was closed following Ike. To provide emergency medical services, three portable operating rooms and a portable pharmacy were set up on the campus. Floors above the first floors of some buildings were re-opened starting in October 2008 for limited office, classroom, and laboratory use. Lower floors remain closed until clean-up and repairs are completed—some lower floors will not be reoccupied until fall 2009.

Had there been no flood damage, the wind-related damage would still have had some impact on facility functions. At one building, an emergency generator was damaged by water leakage when the roof membrane blew off.

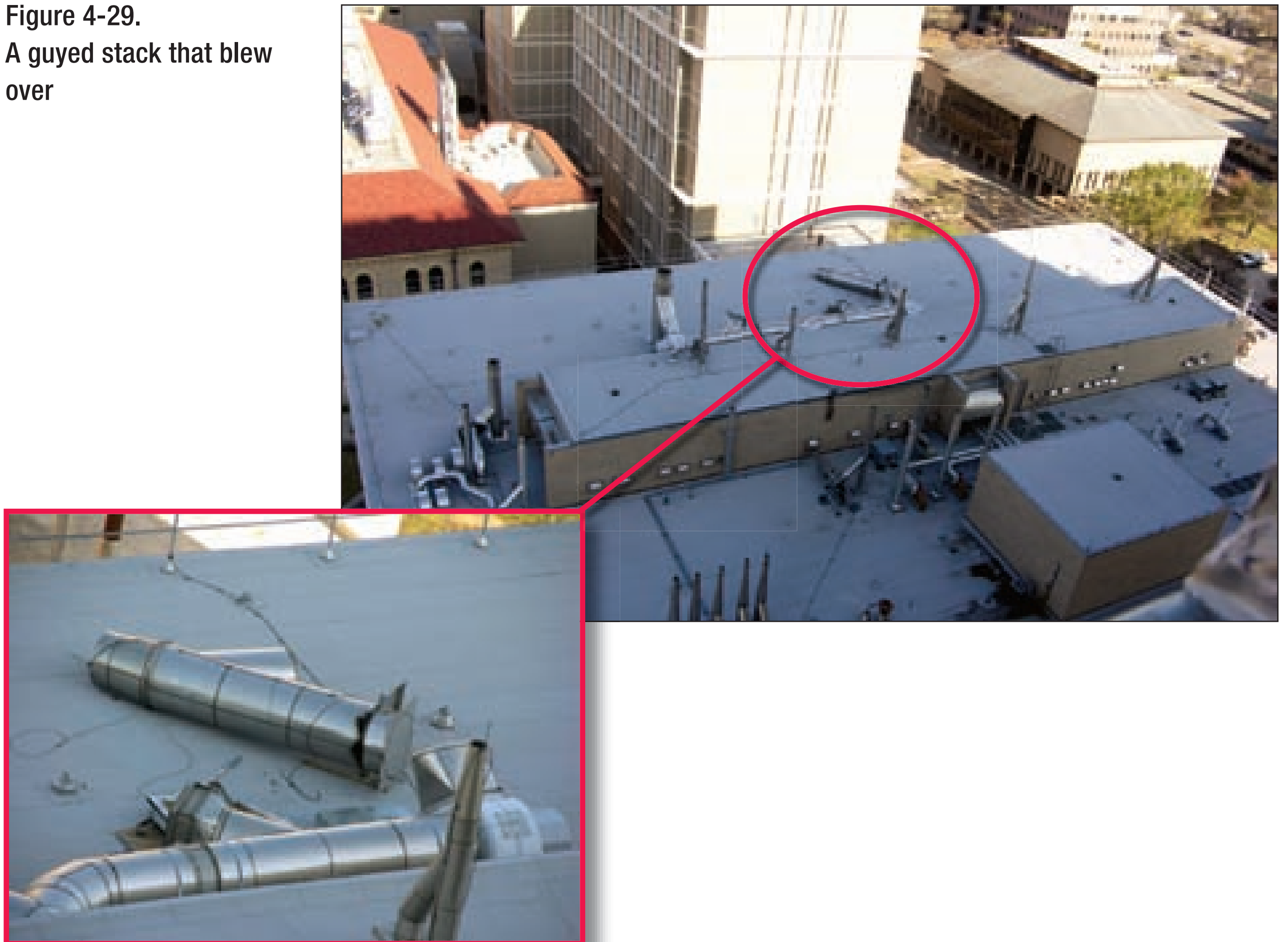


Figure 4-29.
A guyed stack that blew over

Figure 4-30.
A relief air hood blew off the curb allowing rainwater to enter the building

Figure 4-31.
Nine broken windows are shown in the red oval; the brown openings above the oval are louvers

Vulnerabilities and Other Observations. With the majority of UTMB buildings vulnerable to flooding at levels below the base flood, consideration should be given to moving critical functions and equipment to the second floor or above, or floodproofing those spaces where functions and equipment cannot be elevated. Use of flood-damage-resistant materials for repairs below the second floors of buildings would reduce future flood damages.

Hurricane Ike's maximum wind speed of 108 mph at this site was well below the current design wind speed of 132 mph. Had Ike's winds been in the vicinity of current design conditions, the wind-induced damages at this facility would likely have been significantly greater.

Considering the age of the facility and the damage experienced during Hurricane Ike and previous hurricanes, a comprehensive flood and wind vulnerability assessment should be conducted by a qualified team of professionals. Upon completion of the assessment, the vulnerabilities should be prioritized and a plan developed and implemented to mitigate the vulnerabilities in order to minimize future disruptions of healthcare delivery and expenditures for repairs.

4.2.4 South Cameron Parish Hospital (Cameron, LA)

The South Cameron Parish Hospital is located on West Creole Highway and is approximately 2.8 miles from the Gulf of Mexico shoreline. Hurricane Rita (September 2005) destroyed the original hospital on the site, and a new hospital facility was built on the same site. The new facility opened in November 2007, 10 months before Hurricane Ike struck.

When Hurricane Rita struck, the Effective FIRM for the area (1992) showed the hospital site as located in flood Zone AE, with a BFE of 9 feet NGVD. In November 2005 FEMA issued flood recovery guidance for Cameron Parish, which recommended 1 foot of freeboard above the Effective BFE. In March 2006, FEMA published ABFE Maps showing the site as Zone AE, with an

ABFE of 10 feet NGVD. The new facility was constructed with the top of the lowest floor elevation at 10 feet NGVD (Figure 4-32). Reports indicate that Hurricane Ike storm surge was just a few inches below that elevation at the site (Figure 4-33). The March 2008 Preliminary DFIRM, released by FEMA after completion of the post-Katrina and Rita flood hazard studies, shows the site will be remapped as Zone VE (Coastal High Hazard Areas) with a BFE of 15 feet. If rebuilt using the DFIRM and in accordance with ASCE 24-05, the top of the first floor of the facility would be at or above 17 feet NGVD. It should be noted that the flood hazard zone and BFE at the site were Zone V and 13 feet NGVD between 1984 and 1991, close to the 2008 preliminary DFIRM zone and BFE.

The facility also received wind damage during Hurricane Ike. According to ASCE 7-05, the basic wind speed for this location is approximately 120 mph. The estimated maximum wind speed during Hurricane Ike was approximately 70 mph.

General Flood Damage. The hospital property was flooded during Ike—surge did not enter the building but did damage conduits and piping suspended below the floor. The hospital was not fully functional until repairs were made and additional emergency power generation capacity was obtained.

The reconstructed hospital did not comply with the ASCE 24-05 elevation requirements (see Table 4-2). While the floor height satisfied the requirements in effect at the time of construction, the utilities did not—either the utilities should have been located above the lowest floor level or the entire facility should have been elevated higher to allow the suspended pipes and conduits to meet the ASCE 24-05 utility elevation requirement. The latter approach is clearly preferable since it would raise the floor level another 3 feet and provide an added factor of safety against flooding.

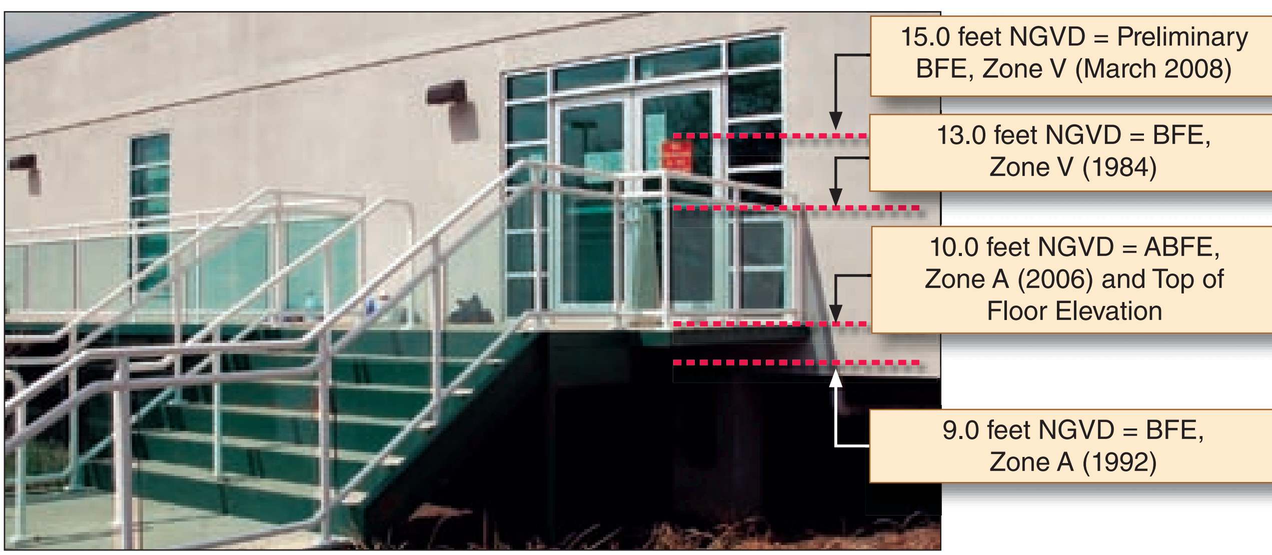


Figure 4-32.
Hurricane Ike crested approximately 6 inches below the floor of the South Cameron Parish Hospital. BFEs and flood hazard zones are shown for the site for the period 1984 to 2008 (Note: the building code may require freeboard above the BFEs shown).

Figure 4-33.
Conduits and pipes beneath South Cameron Parish Hospital. Vegetation was noted between the floor system and the steel plate of the foundation. A connection between the plate and the floor system was not visible.

General Wind Damage. The main building roof system performed well during the event. However, some damage was sustained by the canopy over the hospital's emergency room entrance driveway (Figure 4-34). The MAT also observed that some rooftop mechanical equipment was not properly fastened (Figure 4-35).

Figure 4-34.
Damage to canopy over emergency room entrance driveway

Figure 4-35.
Lack of proper fastening of rooftop equipment—a MAT member was able to easily lift this condenser unit off the curb. All equipment should be fastened to resist uplift and blow-off.

Functional Loss. The new hospital building was not flooded by Ike, and its emergency power generator was reportedly running when staff returned to the hospital several days after the storm. However, the building was not fully functional until repairs were made to conduits and piping suspended below the floor and until additional power generation capacity was brought in. The hospital's emergency generator was reported to be an in-kind replacement for the unit lost during Rita and was not sufficient to fully power the new facility. Following repairs after Ike, the Cameron Parish government temporarily relocated several of their departments into this facility.

Appropriate Mitigation in New Hospital Construction. A hospital previously located at this site was destroyed by Hurricane Rita in 2005 and replaced with the current facility. The original South Cameron Memorial Hospital was constructed using Federal funds obtained from the Hill-Burton Act, and opened in 1963, 6 years after Hurricane Audrey (1957).

The original hospital facility had a floor elevation of approximately 8 feet NGVD, and the current replacement facility has a floor elevation of 10 feet NGVD (i.e., at the ABFE established following Rita). The estimated Rita storm surge elevation at the site was 12 to 13 feet NGVD. This hospital site was also subjected to significant flooding during Hurricane Audrey (1957), whose storm surge exceeded both the original hospital floor elevation and the new hospital floor elevation.

It is not clear what, if any, influence the flood history at this site had in decisions about either choosing a site or floor elevation for the new facility. While it is true that Ike's floodwaters did not rise above the floor of the current facility, utilities below the floor were damaged by flooding and contributed to a loss of function after Ike.

The decision to rebuild a hospital at this site with the top of its floor at the ABFE of 10 feet NGVD should be re-examined. While ABFEs may represent the latest available flood level information during a reconstruction period, critical facilities should be elevated above ABFEs—especially when flood levels during a recent event have reached above the ABFE or when historical BFEs have been mapped above the ABFE, as was the case at this site.

The MAT also observed wind damage to the new facility. Specific attention to details that result in better performance in high winds should also be included in design and construction of hospitals using guidance available in FEMA 577.

Funding decisions (by communities and State, Federal, and private entities) for reconstruction of critical facilities should reward adoption of best practices by the community/owner, and discourage reconstruction to minimum wind and flood requirements.

4.2.5 Hackberry Rural Medical Clinic (Hackberry, LA)

The Hackberry Rural Medical Clinic at Hackberry, LA, is located approximately 15 miles north of the Gulf of Mexico shoreline (Figure 4-36). The medical facility received significant flooding damage from Hurricane Ike. This facility was also flooded during Hurricane Rita and the damages had been repaired.

General Flood Damage. During Hurricane Ike, the facility was inundated with 3 to 4 feet of floodwater. Interior walls were damaged, as well as contents. Water-damaged gypsum board had been removed to a height of 5 feet above the floor (Figure 4-37) and was being replaced at the time of the MAT visit.

Figure 4-36. Hackberry Rural Medical Clinic

Figure 4-37.
Hackberry Rural Medical Clinic interior repairs in progress

Functional Loss. Repairs were still underway at the Hackberry Medical Clinic and the facility remained closed at the time of the MAT visit, one month after Ike.

4.2.6 Oceanview Transitional Care Center (Texas City, TX)

The Oceanview Transitional Care Center, located in Texas City, TX, was originally built in the 1940s as a hospital. The building received wind damage during Hurricane Ike. According to ASCE 7-05, the basic wind speed for this location is approximately 125 mph. The estimated maximum wind speed during Hurricane Ike was approximately 105 mph.

Figure 4-38 is a general view of the building. The facility houses approximately 100 residents. The facility was evacuated prior to the storm because of a mandatory evacuation order for Texas City. However, the facility that they evacuated to in Houston eventually lost all power, including the emergency generator. The residents therefore returned home 3 days after the storm. The facility was powered by its emergency generator for 3 days after the residents returned until power was restored. Although the Oceanview generator did not have sufficient capacity to power the HVAC system, the residents had lights, fans, and water.

General Wind Damage. The canopy roofs and a portion of the upper roof had a low parapet. The remainder of the upper roof had metal edge flashing. The coping blew off a portion of one of the canopies and a portion of the main roof. Exposed fasteners were used to attach the inner leg of the copings. In one area, the fasteners were 3 feet 2 inches on center, which is very excessive spacing. Had the winds been stronger, roof blow-off associated with coping failure would have been likely.

Figure 4-38. General view of Oceanview Transitional Care Center

An exhaust fan on the upper roof blew off, because of an inadequate number of fasteners, and landed on a canopy roof (Figure 4-39). A temporary covering had been placed over the curb, but at the time of MAT observations, the covering was no longer in place. Two other fans also lost their cowlings, and a fan on a lower level roof blew off. There was minor water leakage to the interior of the facility (in part or solely related to this rooftop equipment damage).

The LPS became detached from several areas of the main roof. Portions of the conductors were dangling over the front and back walls (Figure 4-40). In addition to loss of lightning protection, the detached conductors had the potential to break glazing.

Functional Loss. There was no loss of function to this building as a result of Hurricane Ike.

Vulnerabilities and Other Observations. Had the winds been stronger, significant water infiltration would have been likely due to roof membrane blow-off associated with edge flashing or coping failure. Additionally, since the roofs were aggregate-surfaced BURs, aggregate blow-off would have been likely, which depending upon wind direction, may have resulted in damage to the facility's windows and/or glazing damage to automobiles or nearby buildings.

Figure 4-39.
The fan shown in the inset blew off of this curb

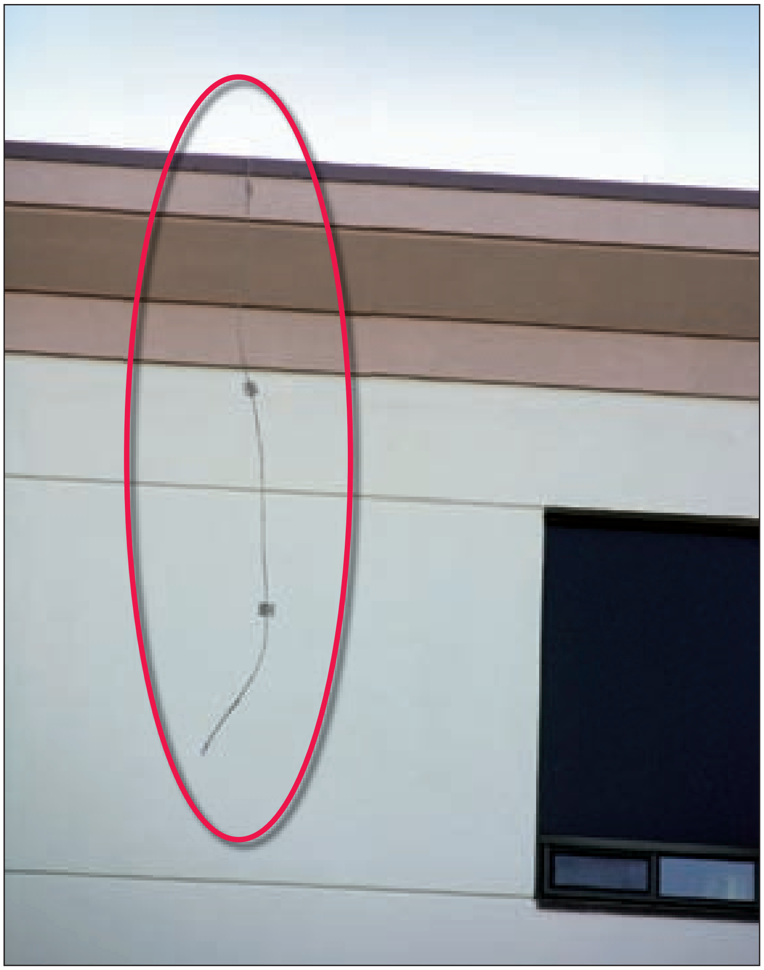


Figure 4-40.
Detached LPS conductor

4.3 First Responder Facilities (Police/Fire/EOC)

First responder facilities, including fire stations, police, and EOCs, are considered lifelines in communities. Their employees perform a community's first response function and play a critical role in ensuring the safety of all residents and protection of residences and infrastructure. For this reason, the performance of these facilities in hurricanes is of utmost importance.

4.3.1 Houston Transtar – Regional EOC (Houston, TX)

The Houston TranStar – Regional EOC is housed in a building constructed in 1996 (Figure 4-41). The Houston TranStar consortium is a partnership of four government agencies responsible for providing transportation management to the greater Houston area. In addition, it serves as a regional EOC to 14 counties. The Regional EOC building received some wind damage from Hurricane Ike. According to ASCE 7-05, the basic wind speed for this location is approximately 108 mph. The estimated maximum wind speed during Hurricane Ike was approximately 92 mph.

The roof deck for the facility is a composite concrete topping over steel decking, and the roof covering is a mineral surface modified bitumen membrane. Both the decking and the roof covering types are recommended in FEMA 543. The building originally had shutters to protect the windows. However, because of the time and expense involved with installing and removing the shutters, the windows were replaced with impact-resistant windows in 2004.

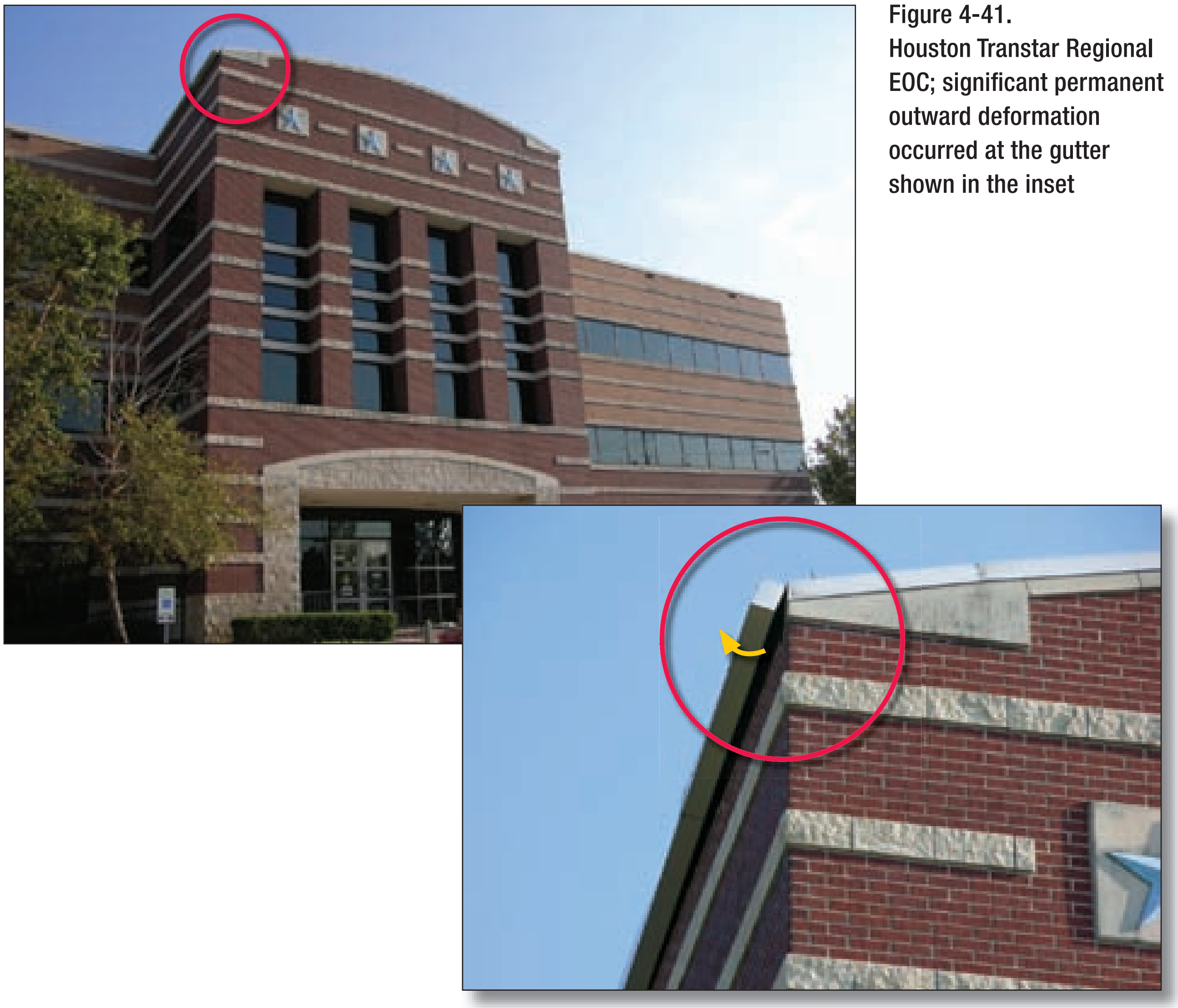


Figure 4-41.
Houston Transtar Regional EOC; significant permanent outward deformation occurred at the gutter shown in the inset

General Wind Damage. Hurricane Ike caused outward deformation of the gutter shown in the Figure 4-41 inset. Had the winds been stronger, the gutter would have likely blown off. Additionally, several pieces of coping blew off the building. The outer face of the coping is 8 inches and the inner face is 4 inches (Figure 4-42). Continuous cleats are located along both sides of the parapet. The cleats were attached with roofing nails driven through the horizontal flange (blue arrow at Figure 4-42). In addition, a few widely-spaced nails were driven through the vertical flange (red arrow in Figure 4-42). The nailing provided very little resistance to outward deflection of the cleat and coping. While most of the continuous inner and outer cleats remained on the building, several sections of coping and at least one cleat blew off once the amount of deflection was sufficient for the coping to disengage from the cleat. The blown-off cleat had a face nail that was 75 inches in from the end of the cleat, hence over 6 feet of this cleat was unrestrained from outward deformation.

The wind resistance of poorly attached copings, such as the ones on this building, can be economically strengthened by face-screwing the coping as described in FEMA 543. The base flashing was stopped at the top of the parapet. It should have been run across the top of the nailer and turned down and nailed so as to provide greater watertight protection in the event of coping leakage or coping blow-off.

Figures 4-43 and 4-44 show pieces of coping that landed elsewhere on the roof. Windborne coping can easily puncture roof membranes, including tough membranes like the modified bitumen membrane on this roof (inset at Figure 4-43).

Figure 4-42.
The coping blew off because of inadequate attachment of the cleats. The blue arrow shows roofing nails driven through the horizontal flange and the red arrow shows widely spaced nails through the vertical flange.

Figure 4-43.
Coping debris (red arrow); the membrane was gouged (blue arrow) by coping debris (an ink pen shows the scale)

A substantial amount of leaf debris was observed in the vicinity of scuppers on a lower roof (Figure 4-44). During hurricanes, heavy leaf loss and accumulation on roofs has the potential to block roof drains and overflow drains and scuppers. Increasing the size of scuppers and downspouts minimizes the potential for scupper/downspout blockage.

Figure 4-44.
Coping debris (blue arrow) on a lower roof; note leaf debris near the scupper (red arrow)

Additional damage included minor leakage at a building expansion joint and toppling of a tall flue on a lower level roof, even though it was guyed (Figure 4-45). The tautness of guys should be checked annually to avoid toppling of flues.

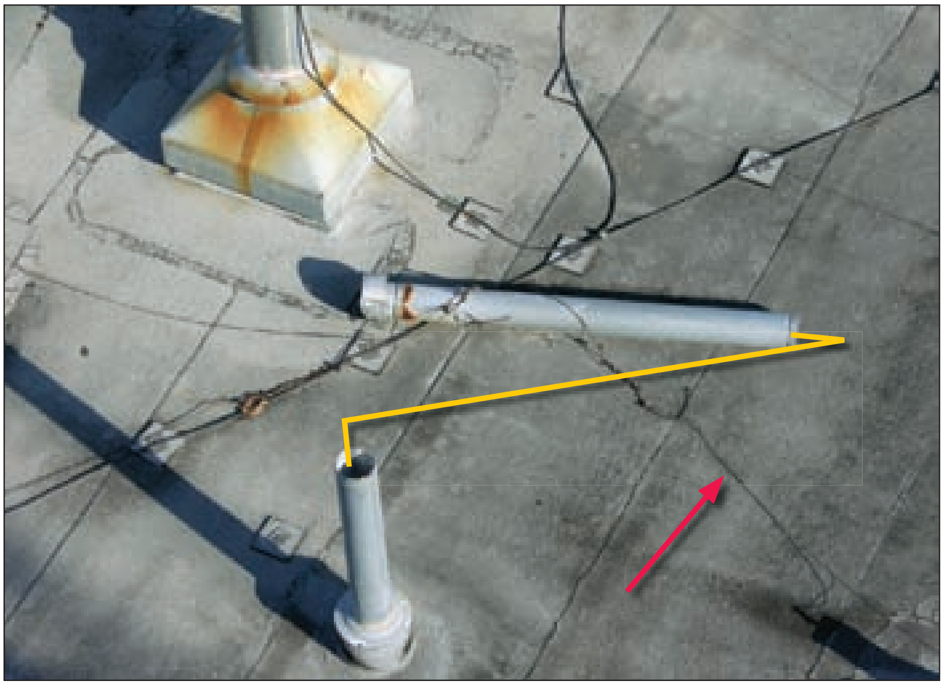


Figure 4-45.
Guyed flue blew over (red arrow indicates one of the guys)

Functional Loss. The building did not experience loss of function as a result of Hurricane Ike. However, the building experienced a power interruption when the Red Cross was allowed to connect to the building's electrical system (which at that time was being powered by the building's emergency generator). The power interruption resulted in a complete loss of electrical power to the building for approximately 15 minutes.

The building did not experience loss of water or sewer service.

Vulnerabilities and Other Observations. Had the winds been stronger, significant water infiltration would have been likely due to roof membrane blow-off associated with the coping failure. The gutters would likely have also blown off, which may have caused blow-off of the metal roof panels. Additional damage to rooftop equipment would also have occurred.

Under the right wind conditions, the emergency generator could also have been damaged because of inadequate building envelope protection. The facility's one emergency generator is housed in a separate building, shown in Figure 4-46. The coiling doors shown by the red arrow in Figure 4-46 appeared to possess little wind resistance. In addition, the louver shown by the blue arrow was not resistant to large windborne debris (which could penetrate the louver and damage the generator). Considering the importance of this facility, it would be prudent to: 1) add a back-up generator and a cam locking box (to facilitate rapid connection of a portable generator); 2) replace the coiling door with a new door rated for the design wind load and capable of resisting test missile E as specified in ASTME E 1996; and 3) replace the louver with one capable of resisting test missile E, or provide a debris-resistant shield in front of the louver. Recommendations pertaining to all three of these items are provided in FEMA 543.

Figure 4-46.
The emergency generator is housed in the circled building; the coiling door (red arrow) and the louver (blue arrow) appeared to provide inadequate protection for the generator

The facility had a very large water tank to provide potable water and water for the building's fire sprinkler system, which provides protection in the event of an interruption of municipal water.

4.3.2 Deer Park Police Station (Deer Park, TX)

The Deer Park Police Station (Figure 4-47), constructed in 2004, received wind-driven rain damage as a result of Hurricane Ike. According to ASCE 7-05, the basic wind speed for this location is approximately 112 mph. The estimated maximum wind speed during Hurricane Ike was approximately 95 mph. Shutter mitigation work was conducted after the building was constructed.

General Wind Damage. There was no apparent wind damage. However, relatively minor water leakage occurred. The building owner reported that wind-driven rain entered at the metal roof's ridge flashing.

Functional Loss. There was no loss of function at this facility from Hurricane Ike. It cost approximately $3,000 to repair the interior damage caused by the leakage.

Vulnerabilities and Other Observations. When the facility undertook shutter mitigation work, conducting a comprehensive vulnerability assessment and then mitigating the significant vulnerabilities, or alternatively, recognizing the residual risk that remains, would have been prudent (see FEMA 543). The MAT observed the following vulnerabilities.

Figure 4-47.
General view of Deer Park Police Station

The gutter brackets shown in Figure 4-48 do not provide a positive attachment between the gutter and bracket. However, the winds during Hurricane Ike were not of sufficient strength to blow off the gutters. Screwing the gutter to the brackets, as shown in the inset at Figure 4-48 (the inset photo is from an HMPG project in Port Neches), would be prudent. However, to avoid leakage at the fasteners between the bracket and gutter, the bracket should extend near or to the top of the gutter so that the fastener would be above the waterline.

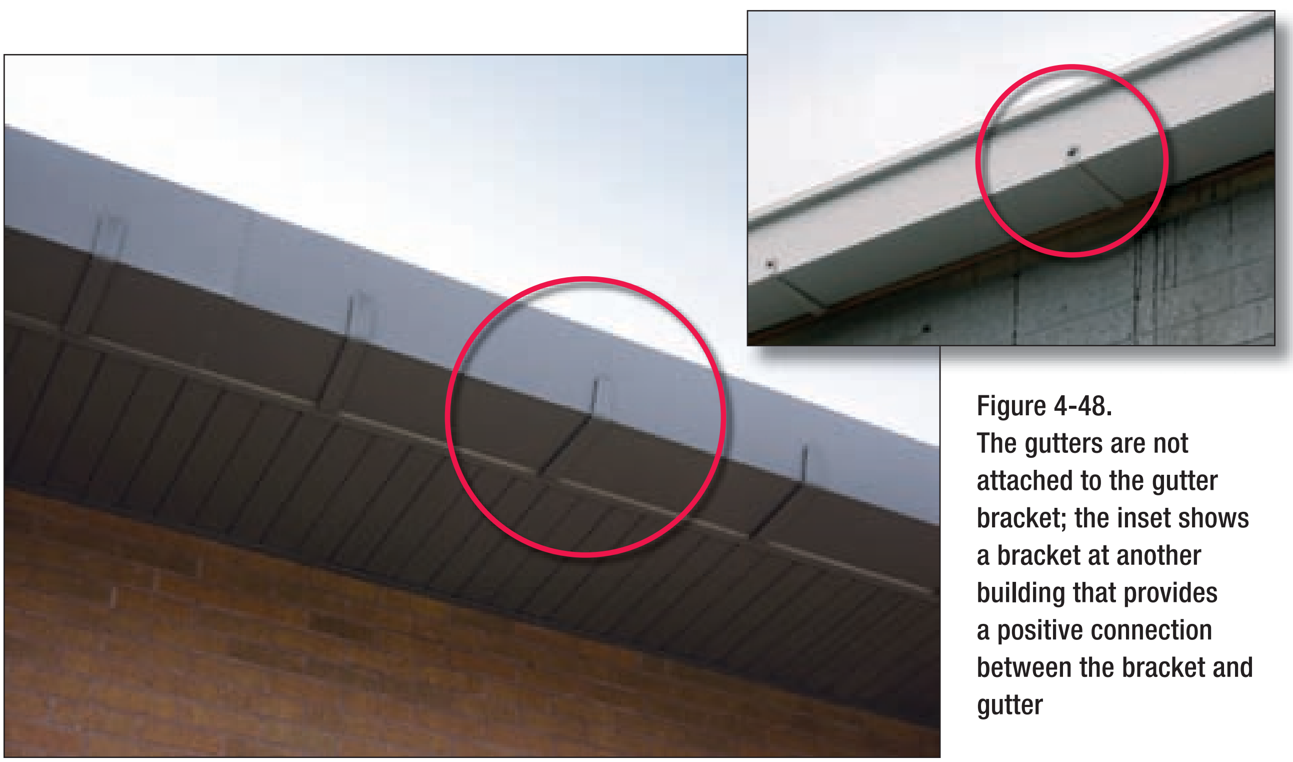


Figure 4-48.
The gutters are not attached to the gutter bracket; the inset shows a bracket at another building that provides a positive connection between the bracket and gutter

The emergency generator is shown in Figure 4-49. Although the enclosure has walls around three sides, it does not provide sufficient wind and windborne debris protection. Had the generator failed to function during the storm, lack of protection would have inhibited maintenance efforts to get the generator back online. FEMA 543 recommends providing a wind- and windborne-debris-resistant enclosure all around and over the generator.

The facility's emergency generator provided power during intermittent municipal power outages. There was no interruption of water or sewer service.

Figure 4-49.
The emergency generator is inadequately protected from wind and windborne debris

4.3.3 Port Neches Fire Station (Port Neches, TX)

The Port Neches Fire Station (Figure 4-50) was constructed in 1972. In the aftermath of Hurricane Rita (2005) and at the time that Hurricane Ike struck, this building was being mitigated using HMGP funds. The mitigation work consisted of replacing all six apparatus bay sectional doors, adding window and door shutters (Figure 4-51), and installing a new modified bitumen roof system. At the time of Hurricane Ike, all the work had been completed except installation of some of the metal edge flashing. According to ASCE 7-05, the basic wind speed for this location is approximately 116 mph. The estimated maximum wind speed during Hurricane Ike was approximately 90 mph.

General Damage. This facility was not damaged during Hurricane Ike.

Functional Loss. There was no functional loss to this facility during Hurricane Ike.

Vulnerabilities and Other Observations. The MAT observed vulnerabilities that make the building susceptible to: 1) leakage due to roof membrane puncture from windborne debris, 2) fan and/or fan cowling blow-off, and 3) emergency generator damage from windborne debris.

Performance of HMGP Mitigation Work. When the facility undertook mitigation work, it would have been prudent to conduct a comprehensive vulnerability assessment and then mitigate the significant vulnerabilities, or alternatively, recognize the residual risk (see FEMA 543).

Figure 4-50.
General view of Port Neches Fire Station

Figure 4-51.
View of a new motorized shutter; the toggle in the red circle allows the shutter to be manually raised

Replacing the sectional doors, adding the shutters, and replacing the roof system were appropriate actions for the mitigation project. However, the new roof system does not provide leakage protection in the event the membrane is punctured by windborne debris. Although the roof membrane choice was appropriate (and one that is recommended in FEMA 543), the new roofs do not have secondary membranes, as recommended in FEMA 543, to avoid water leakage in the event the membranes are punctured by windborne debris.

Neither the exhaust fan cowlings nor the fans were anchored as recommended in FEMA 543. The contract documents specified two screws per side, with a maximum spacing of 16 inches on center; however, for this size fan, FEMA 543 recommends four screws per side.

The emergency generator is not located in a protected enclosure (Figure 4-52). The nearby non-reinforced masonry screen wall (red arrow) could collapse on the generator, and the generator could be damaged by windborne debris. Had the generator failed to function during the storm, lack of protection would have inhibited maintenance efforts to get the generator back online. As part of a comprehensive mitigation project, providing a wind- and windborne-debris-resistant enclosure all around and over the generator as recommended in FEMA 543 would have been prudent.

Figure 4-52.
The emergency generator is susceptible to windborne debris and damage caused by collapse of the masonry screen wall

4.3.4 High Island Fire Station (High Island, TX)

The High Island Fire Station is an older pre-engineered metal building (Figure 4-53). The facility received wind damage during Ike. According to ASCE 7-05, the basic wind speed for this location is approximately 131 mph. The estimated maximum wind speed during Hurricane Ike was approximately 110 mph.

General Wind Damage. All four apparatus bay doors blew away when the door rollers disengaged from the tracks (Figure 4-53).

At the back of the building, the bottom of the wall blew outward (Figure 4-54). The metal walls were attached to an angle that was poorly attached to the concrete slab. The angle was attached at the door jamb, but there was a 10-foot gap to the next adjacent fastener. Some wall insulation near the door was also blown away. In addition, some of the metal wall panels peeled back at a corner of the building.

Functional Loss. There was no functional loss to this facility during Hurricane Ike.

Vulnerabilities and Other Observations. The apparatus (trucks) appeared to be left in the fire station during the storm. Older buildings such as this are quite susceptible to damage (including collapse of the structural frame if winds are quite high). When apparatus are left in a station such as this, they can be damaged by building collapse.

Figure 4-53. General view of High Island Fire Station

Figure 4-54.
The metal wall at the red oval area was pushed outward because of inadequate attachment of the wall angle to the slab

4.3.5 Louisiana Fire Stations

If fire stations cannot remain operational during or after an event, the community loses a valuable and important part of its emergency response capability. The MAT visited and inspected five fire stations in Louisiana:

- Grand Caillou Volunteer Fire Station, Terrebonne Parish
- Bayou Dularge Volunteer Fire Station, Terrebonne Parish
- 7th Ward Volunteer Fire Department, Vermilion Parish
- Hackberry Volunteer Fire Station, Cameron Parish
- Grand Isle Volunteer Fire Station, Jefferson Parish

The MAT also saw, but did not inspect, flood damage to metal building systems and fire equipment at other fire stations (e.g., Muria Road Fire Station and East Creole Highway Station, Cameron Parish). A summary of the observations for each facility is included in Table 4-3.

Table 4-3. Observations of Louisiana Fire Stations

Fire Station	Parish	Ike Damage	Comments
Grand Caillou Volunteer	Terrebonne	None	Elevated above ABFE (Figure 4-55); manned during Hurricane Ike, no loss of function
Bayou Dularge Volunteer	Terrebonne	Foundation undermined	Sited along the bank of a canal, rear of building was undermined by bank erosion during Ike (Figure 4-56); erosion also occurred during Rita and had been repaired before Ike; manned during Ike, no loss of function; bank stabilization required. The Parish Council agreed to condemn the station in February 2009, and its operations will move to another station.
7th Ward Volunteer	Vermilion	Flood	Approximately 8 inches of flooding above the floor during Ike; repairs underway during MAT visit (Figures 4-57 and inset); previously flooded during Rita; station was not in use during Ike.
Hackberry Volunteer	Cameron	Flood	Flooded during Ike; previously flooded during Rita, after which the station had been cleaned but not fully repaired; station was not in use during Ike, although vehicles and equipment were damaged by flooding; replacement HVAC units from Rita were not elevated (Figure 4-58).
Grand Isle	Jefferson	Flood	Facility sustained wind and flood damage during Katrina that had not been repaired at the time of Ike (Figure 4-59); facility sustained additional flood damage during Ike, but was not in operation at the time and is now used only as a garage.
Muria Road	Cameron	Flood	Obvious flood damage to the metal building was evident during a drive-by.
East Creole Highway	Cameron	Flood	Obvious flood damage to the metal building was evident during a drive-by.

Figure 4-55. The Bayou Grand Caillou Fire Station is elevated above the ABFE and sustained no damage

Figure 4-56.
Rear of Dularge Fire Station; note canal bank erosion sustained during Hurricane Ike

Figure 4-57.
7th Ward Fire District No.1 Fire Station; wall repairs were in progress during MAT inspection

Figure 4-58.
Condenser units were installed at Hackberry Fire Station after Ike and are vulnerable to future flooding

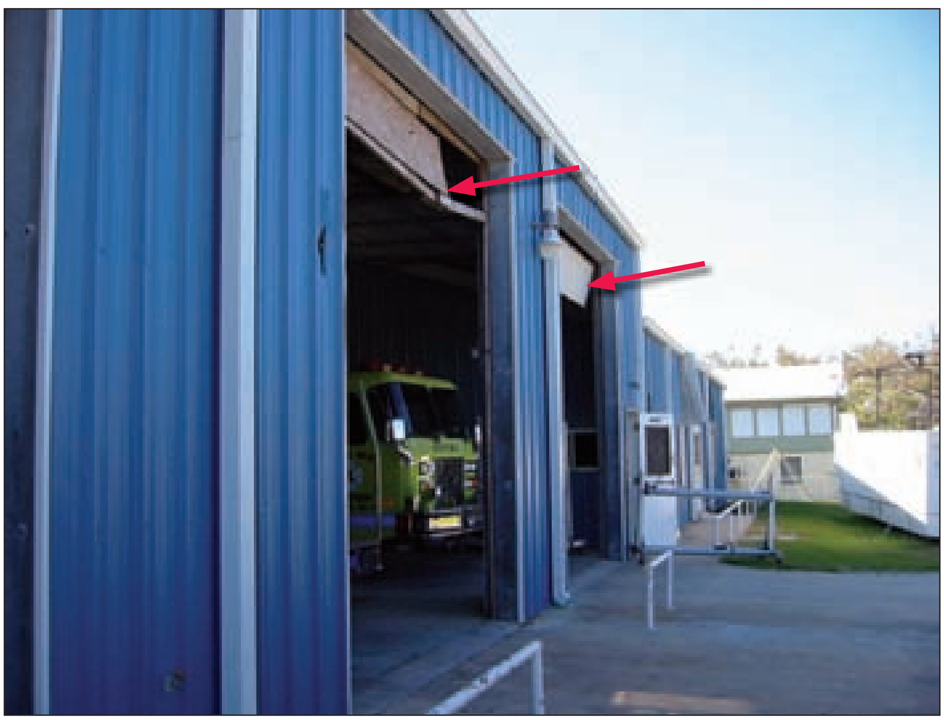


Figure 4-59.
Wind damage (red arrows) to Grand Isle Fire Station remaining from Hurricane Katrina

4.4 Other Government Buildings

Although few government buildings are categorized as critical facilities in ASCE 7-05 (i.e., Category III or IV buildings), many government buildings play a vital role in delivering various services during and/or after a hurricane and should receive additional design attention to avoid or resist flood and wind loads.

4.4.1 U.S. Army Corps of Engineers Administration Building (Galveston, TX)

The USACE Administration Building (Figure 4-60), constructed in 1991, is located in Galveston, TX. Although the building was not damaged by flooding, floodwater surrounded the building during Hurricane Ike. Had the water been a few inches higher, it would have wetted the first (lobby) floor. The building experienced wind damage from Hurricane Ike. The exterior walls are precast concrete. According to ASCE 7-05, the basic wind speed for this location is approximately 132 mph. The estimated maximum wind speed during Hurricane Ike was approximately 108 mph.

Figure 4-60.
General view of the USACE Administration Building in Galveston, TX

General Wind Damage. Some minor leakage occurred at a few windows; facility staff reported that minor leakage had also occurred during previous thunderstorms. Additionally, some fan cowlings and louvers at condensers were blown off, and some of the LPS conductors detached from the roof membrane. A sheet metal cover over a curb was blown off (Figure 4-61). The presence of the 3-foot 2-inch high parapet was the likely reason the sheet metal was not blown from the roof. The roof membrane is a mineral-surface modified bitumen membrane (which is relatively tough and one of the membrane types recommended in FEMA 543). Although the sheet metal scuffed the roof, the membrane was not punctured or torn.

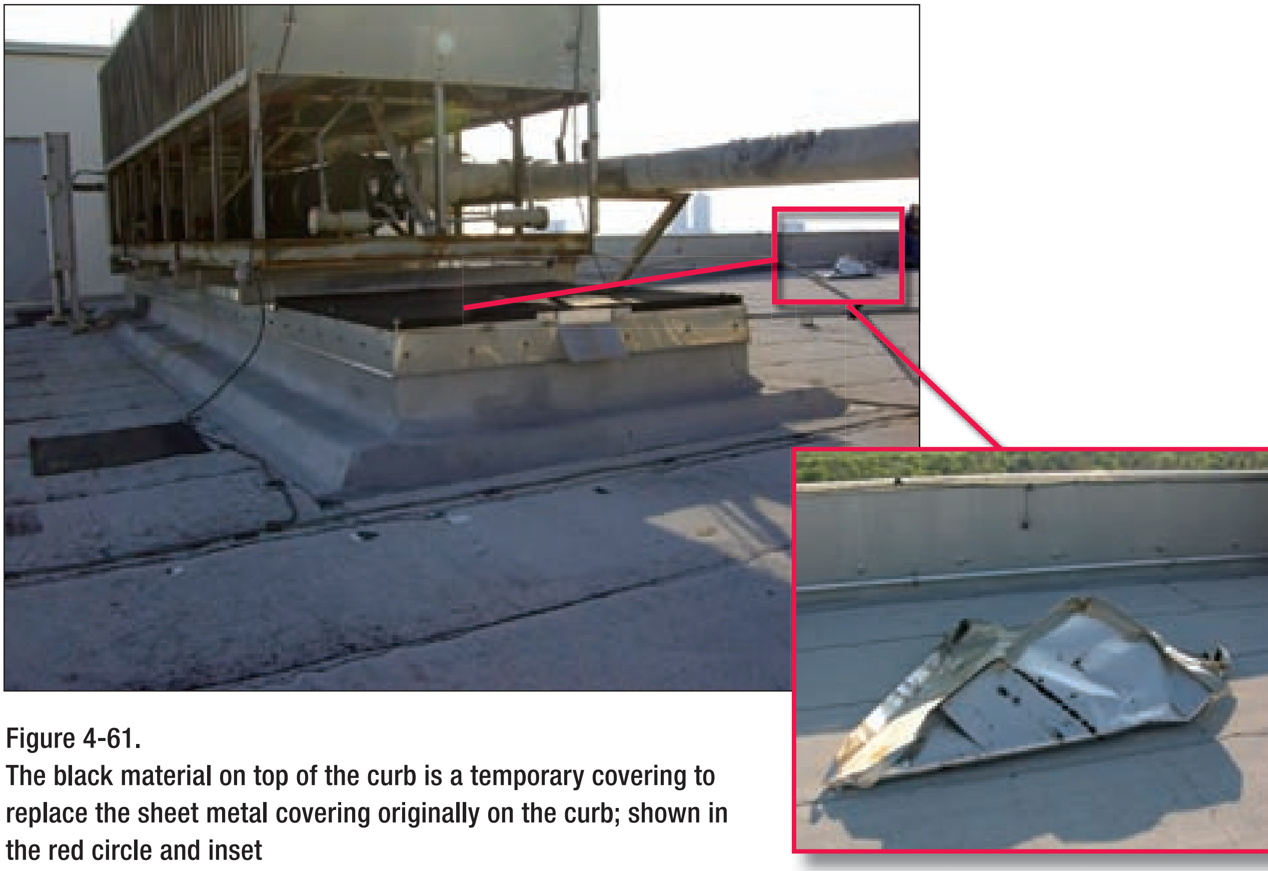


Figure 4-61.
The black material on top of the curb is a temporary covering to replace the sheet metal covering originally on the curb; shown in the red circle and inset

Functional Loss. The emergency generator for the facility is fueled by natural gas. The gas supply was shut down prior to the storm by the gas supplier. The facility was without power until a portable generator was supplied by FEMA on September 21. Municipal power was restored on September 30. Additionally, the building was without potable water until October 2. The building was reoccupied on October 6.

Vulnerabilities and Other Observations. The incorporation of many sound design elements (e.g., precast concrete walls, a modified bitumen membrane, and a parapet in excess of 3 feet) makes this a relatively wind-resistant building. However, strengthening the attachment of the rooftop equipment and the LPS, constructing a wind- and debris-resistant enclosure around the exposed emergency generator, and providing a contingency for future natural gas interruption (see Chapter 7, Recommendations) would be prudent.

4.4.2 Federal Courthouse and Post Office (Galveston, TX)

The Federal Courthouse and Post Office (U.S. Postal Service) facility (Figure 4-62), constructed circa 1935, is located in Galveston, TX. The facility received some flood damage. The facility also had minor wind damage. According to ASCE 7-05, the basic wind speed for this location is approximately 132 mph. The estimated maximum wind speed during Hurricane Ike was approximately 107 mph. The upper level roof is composed of two types. The steep-slope portion is tile. All of the tails of the tiles are hooked (red circle in Figure 4-63). The sloped roofs surround a low-slope area that has a mineral-surface modified bitumen membrane.

This building is on the site of the former Federal Courthouse and Post Office designed by Nicholas Clayton, a prominent Galveston architect (the first professional architect in the State), and was built between 1888 and 1892. In 1993, during construction of 4- to 5-foot deep foundation trenches for the new generator building, the upper portions of a 3- to 5-foot foundation and the remains of a marble floor were exposed. The exposed foundation and marble floor were determined to be the northwest corner of the former courthouse/post office/customs building.

Figure 4-62. General view of Federal Courthouse and Post Office; some flashing damage occurred during Hurricane Ike (shown by red arrow)

Figure 4-63. All of the tile tails were hooked

General Flood Damage. Floodwater inundated the basement, which caused major damage to mechanical equipment and the main electrical switchgear room.

General Wind Damage. In one of the offices, there was damage to ceilings and interior partitions. The MAT assumption is that the damage was caused by wind entering the office through a window that became unlatched and opened during the storm.

No roof covering damage was observed. Some roof flashing damage occurred along a small area on the front of the building (red arrow, Figure 4-64) and similarly along the back of the building. Minor rooftop equipment damage was observed. An access panel at a condenser was nearly blown off (red arrow, Figure 4-64). The condenser had two supplementary anchor straps (yellow arrows). Supplementary anchor straps are recommended in FEMA 543.

Figure 4-64.
The access panel (red arrow) nearly blew away; the yellow arrows indicate supplementary anchor straps

Functional Loss. At the time of the MAT visit, the facility was closed due to flood damage to the mechanical equipment and switchgear in the basement.

Vulnerabilities and Other Observations. A good practice observed at this facility is the location of the emergency generator in a wind- and windborne-debris-resistant building and elevation above the floodwater level (Figure 4-65). Hence, although flooding damaged the switchgear in the basement, the emergency generator was functional and, therefore, able to be reconfigured to power portable equipment used to dry the interior of the building.

Figure 4-65.
The emergency generator is housed in a separate wind- and windborne-debris-resistant building (red arrow)

4.4.3 Tiki Island City Hall (Tiki Island, TX)

The Tiki Island City Hall (Figure 4-66), constructed around 1986, is located on Tiki Island, a barrier island between the mainland and Galveston Island. In the aftermath of Hurricane Rita, the building was mitigated in 2008 using HMGP funds. The mitigation work consisted of adding motorized shutters at all glazed openings. The facility received wind and flood damage during Hurricane Ike. According to ASCE 7-05, the basic wind speed for this location is approximately 130 mph. The estimated maximum wind speed during Hurricane Ike was approximately 103 mph.

Figure 4-66.
One of the shutters at the Tiki Island City Hall is shown in the red oval; blue arrows indicate breakaway walls that performed successfully by breaking away

General Flood Damage. Breakaway walls failed under flood forces and ground level space was inundated (blue arrows in Figures 4-66 and 4-68).

General Wind Damage. A portion of the ridge flashing was blown off the metal roof (Figure 4-67). Leakage did not occur, so the roof underlayment was apparently correctly lapped over the ridge. However, loss of flashing can make roof panels more susceptible to blow-off.

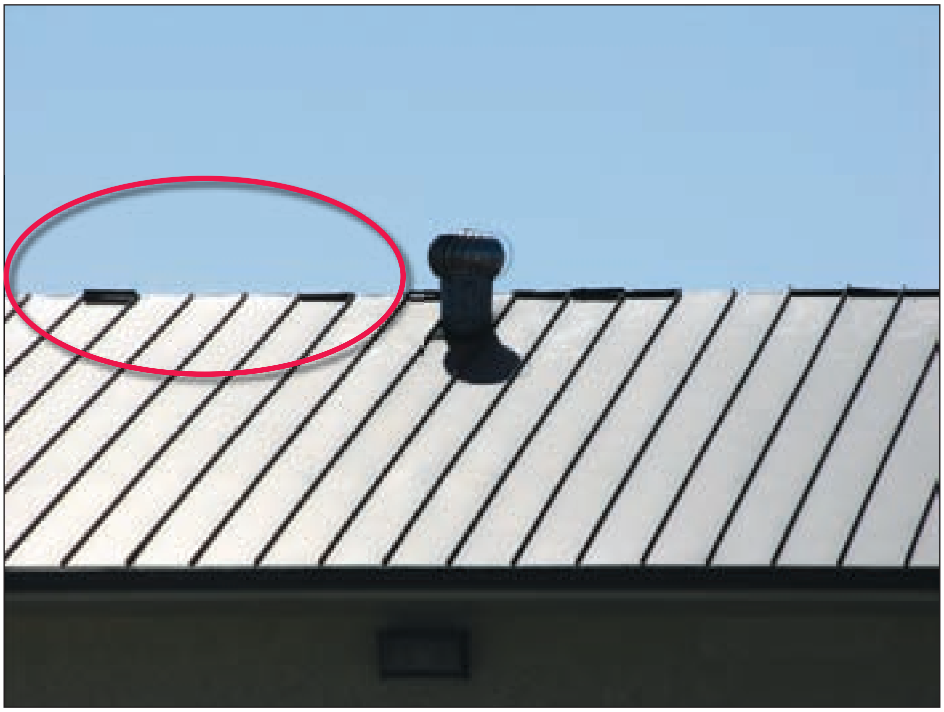


Figure 4-67.
The oval shows where ridge flashing blew away

Functional Loss. There was no loss of function at this facility. A few of the breakaway walls broke away as intended, but that damage did not significantly affect facility operations.

An exposed emergency generator that powers the City's sewage treatment facility failed due to corrosion in the electronic controls. This was an older generator that was scheduled for replacement in a year or two, so less attention had been given to maintenance. Municipal power was restored within 5 or 6 days, which allowed the sewage treatment facility to come back online. This generator also supplied power to the City Hall.

Vulnerabilities and Other Observations. The building design incorporated a very sound practice regarding entrance of electrical service. Normally when power is provided by overhead lines (as is the case with this building), the lines come into a weatherhead that penetrates the roof. If nearby power poles collapse or move significantly, the power lines pull the weatherhead, which often tears the roof and allows leakage. However, at this building, the conduit from the weatherhead (circled in Figure 4-68) runs along the wall and then enters the building through the wall (red arrow). With this installation, movement of the power lines may have caused some damage at the wall penetration had the power lines moved significantly; but if wall damage had occurred, leakage would have been much less problematic than if the conduit penetrated the roof.

Performance of HMGP Mitigation Work. When the facility undertook mitigation work, it would have been prudent to conduct a comprehensive vulnerability assessment and then mitigate the significant vulnerabilities, or alternatively, recognize the residual remaining risk (see FEMA 543). The addition of shutters via the HMGP mitigation project was prudent; however, other building vulnerabilities (i.e., the roof ridge flashing and emergency power) were not addressed.

Figure 4-68.
The electrical service entered through the wall rather than the roof; the blue arrows indicate missing breakaway walls

4.4.4 Terrebonne Parish Criminal Justice Complex (Houma, LA)

The Terrebonne Parish Criminal Justice Complex located in Houma, LA, houses approximately 600 inmates. It is a relatively new facility but received approximately 18 to 24 inches of flooding due to Hurricane Ike (Figure 4-69).

The facility was also flooded during Hurricane Rita in 2005. The 1985 FIRM showed the site as being in flood Zone C (outside the limits of the 500-year flood), but the February 2006 (post-Rita) flood recovery map shows the area as advisory flood Zone A with an advisory flood elevation of 6 feet NGVD, approximately comparable to the elevation of Hurricane Rita flooding.

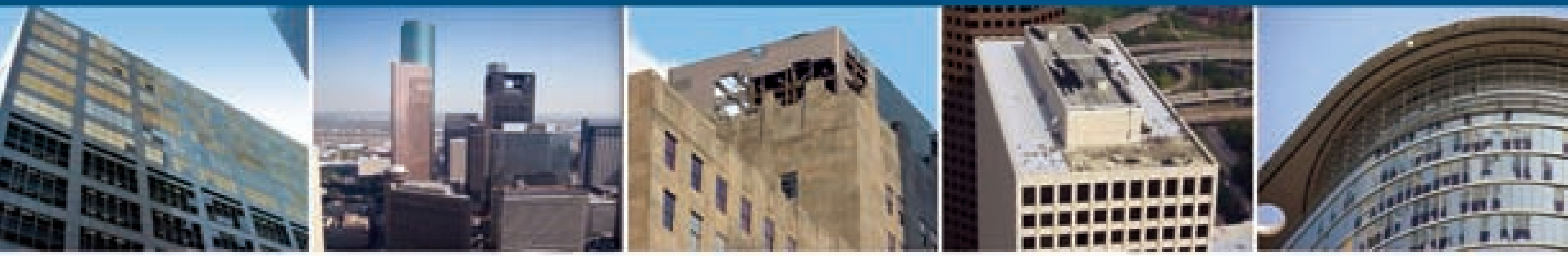
General Flood Damage. Utility service, which runs beneath the slab foundation, was damaged and disrupted by Ike's flooding. In addition to the inundation problems, the facility became unusable because controls were either damaged or inoperable (virtually all of the functions of the prison are operated by electric switches, relays, and motors, including the communications, prison monitors, lights, and cell doors). Parish records also indicate that the criminal complex electronic security system was damaged by Hurricane Rita and required repair and replacement in 2006.

Functional Loss. Flooding damaged essential equipment and required that prisoners be relocated to a State corrections facility.

Vulnerabilities and Other Observations. ASCE 7-05 and ASCE 24-05 designate jails and detention facilities as Category III facilities, which require additional design consideration beyond building code requirements for typical commercial and residential construction. Correctional facilities should be located outside the floodplain or elevated to the 500-year flood elevation. If 500-year flood elevations are not available, elevate above the BFE with sufficient freeboard to prevent damage and loss of use. Some States have mandated special permit requirements and freeboard for correctional facilities located in or near flood hazard areas (e.g., Commonwealth of Pennsylvania, 2001). Federal agencies with involvement in funding, permitting, and constructing critical facilities should follow these guidelines for protecting correctional facilities in accordance with Executive Order 11988 Floodplain Management.

The U.S. Department of Justice (DOJ), National Institute of Corrections provides specific guidance for planning for emergencies, including natural disasters. All correctional facilities in hazardous areas can conduct a self-audit using the convenient checklists in the DOJ publication (Schwartz and Barry, 1996), and should identify retrofit opportunities and procedures to reduce damage and overcome operational issues related to natural disasters.

Figure 4-69.
Terrebonne Parish Criminal Justice Complex



Tom Smith
David Conrad

5 Performance of Buildings in Houston's Central Business District

Although Hurricane Ike's winds were not as high as the current design wind speed, some buildings received extensive exterior envelope damage.

The MAT observed various types of building envelope damage at several buildings in downtown Houston. According to ASCE 7-05, the basic wind speed for downtown Houston is approximately 108 mph. The estimated maximum speed during Hurricane Ike was approximately 94 mph. Although Hurricane Ike's winds were not as high as the current design wind speed, some buildings received extensive exterior envelope damage. Most of the damage was to glazing and roof coverings. Sections 5.1 to 5.3 describe the types of buildings and building damage observed by the MAT. Vegetative roofs are discussed in Section 5.4.

HURRICANE ALICIA (1983)

Downtown Houston is infamous for glazing damage during Hurricane Alicia. More downtown glazing was broken during that hurricane than during or since any other U.S. hurricane. Extensive glass breakage was documented at six high-rise buildings (Savage et al., 1984 and Kareem, 1986). The number of broken windows and glass spandrel panels was reported on three buildings as follows: 1,100 to 1,200 units, 630 units, and 80 to 100 units. More than 80 percent of the glazing damage in the central business district was attributed to windborne debris impact. Aggregate from BURs was identified as a major contributor of the debris.

Good structural system performance is critical to avoid injury to occupants and minimize damage to a building and its contents; however, good structural system performance alone does not ensure occupant or building protection. Good performance of the building envelope is also critical. Glazing can be very expensive to replace, as is replacing a roof system. In addition, once a building envelope is breached, costs are incurred due to wind and/or water damage to interiors and contents (Section 5.2.1). Interruption of businesses when businesses are forced to vacate because of damaged buildings can result in even greater costs. The costs associated with interruption and temporary relocation often exceed the direct costs of repairing the damaged buildings and their contents.

Following Hurricane Alicia in 1983, a committee of the Houston Construction Industry Council—with participation from the City's building department—recommended a code change to the City of Houston Building Code that prohibited the use of aggregate on roof surfaces over 55 feet above grade (Smith, 1997). However, the City Council did not accept the recommendation and local code continued to allow aggregate surfacing on BURs. In January 2006, the City of Houston adopted the 2003 edition of the IBC (with local amendments). One of the local amendments (1504.8) was a response to changes in the 2006 edition of the IBC prohibiting aggregate (referred to as "gravel or crushed stone") roof surfaces. Although the 2006 IBC prohibits all roof aggregate (regardless of size) in hurricane-prone regions, Houston's building department does not interpret the local amendment as applicable to 1 ½-inch or larger aggregate (which is used on aggregate ballasted single-ply roof membranes). As a result, after nearly 23 years, the local code prohibits installation of aggregate-surfaced BURs, but continues to allow installation of aggregate-ballasted roof systems and does not require abatement of existing aggregate-surfaced roofs.

The MAT observed commercial high-, mid-, and low-rise buildings in downtown Houston. The building ages ranged from several decades to just a few years old. Figure 5-1 shows an aerial photograph of a portion of downtown Houston. There was significant building envelope damage in areas indicated by the blue and red circles on Figure 5-1; the red circle denotes buildings that are discussed as cluster A (Section 5.2), and the blue circle denotes buildings discussed as cluster B (Section 5.3). Random isolated envelope damage was observed in the areas outside the clusters, as described in Section 5.1.

5.1 Areas Outside Clusters A and B

Several of the buildings outside of the clusters had limited glazing damage, ranging from one or a few broken windows to several broken windows as shown in Figure 5-2. At the building shown

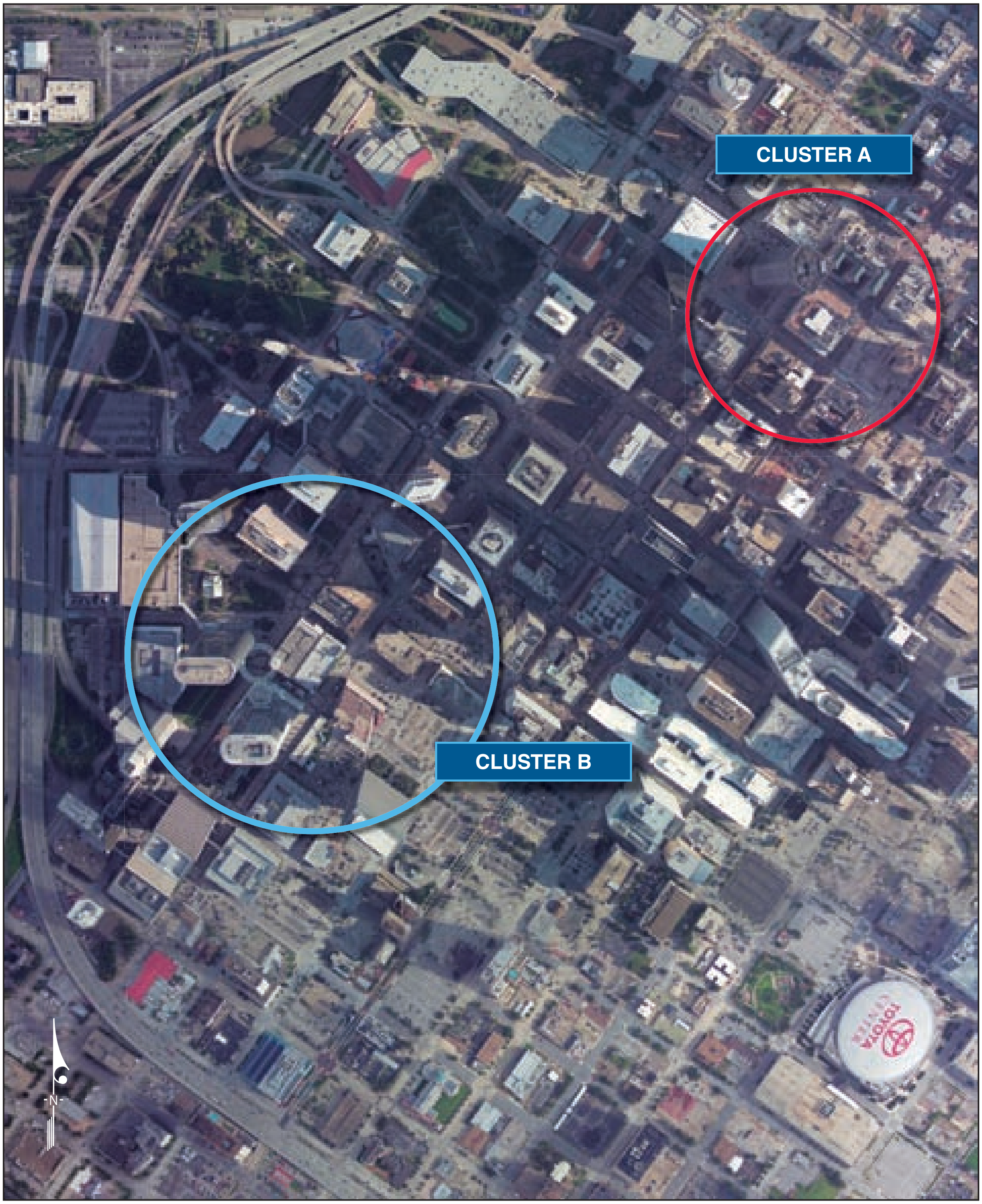


Figure 5-1.
View of a portion of downtown Houston. The red circle denotes cluster A and the blue circle denotes cluster B.
SOURCE: NOAA, SEPTEMBER 17, 2008

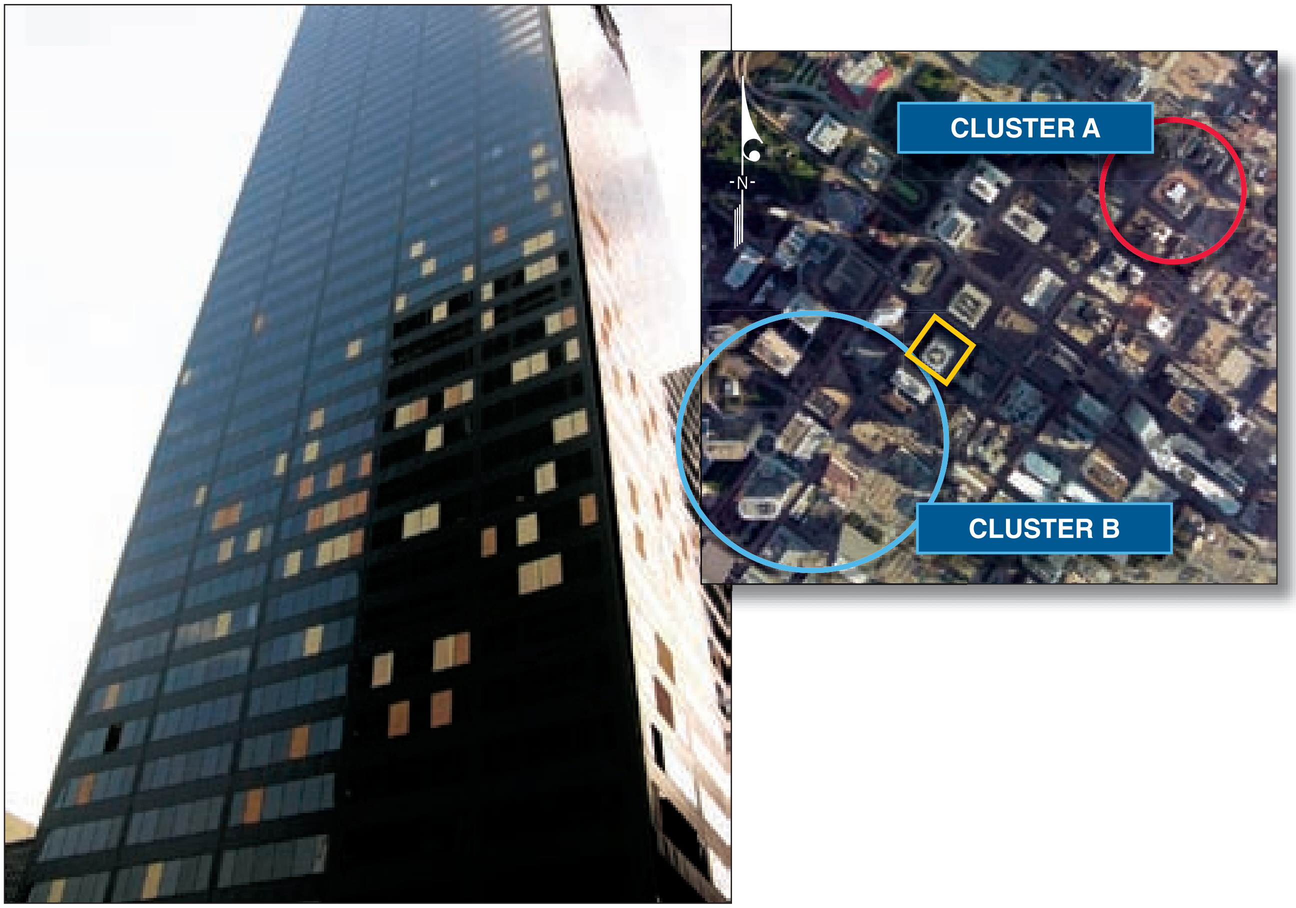


Figure 5-2.
Building with glazing damage; location shown by yellow square in inset

in Figure 5-2, 79 windows on one face were boarded up (presumably both the inner and outer panes were broken). For at least five other windows, the outer pane was also broken on this façade (these windows were not boarded).

Glazing breakage also occurred several floors above grade at other buildings. There was also random breakage at or near street level at some buildings, as shown in Figure 5-3. Exterior glazing is very susceptible to windborne debris breakage unless it is impact resistant (via use of laminated glass or shutters). Since Houston is not in a windborne debris region, protected glazing is not commonplace. The probability that any one window will be struck by windborne debris is typically small (unless the glazing is downstream from an aggregate-surfaced roof). 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. Glazing can also be broken by overpressurization via either high negative or positive wind loads, but this damage is not as common as debris-induced damage. Older glazing is more susceptible to wind-load damage because it is often weakened by scratches. In addition, much of the older glazing on low-rise buildings was installed when little attention was given to wind resistance.

Figure 5-3.
Random breakage of first floor glazing

Windborne debris in the downtown area included glass shards, rooftop mechanical equipment, roof aggregate, wall coverings (Figure 5-4), building signage, and tree limbs. Some of the debris was of relatively high momentum (Figure 5-5).

Figure 5-4.
Portions of the mechanical equipment screen wall blew away. Location shown by yellow box in bottom inset.

Figure 5-5.
The wire mesh of this stucco wall was penetrated by windborne debris. The impact location is about 5 feet above the sidewalk.

5.2 Cluster A – JP Morgan Chase Area

An enlarged view of cluster A is shown in Figure 5-6. The JP Morgan Chase Tower and Center are part of cluster A.

- **JP Morgan Chase Tower.** Built in 1982 and standing 75 stories (1,000 feet), this is the tallest building in Houston. The building never lost power during the event, as power is fed from two vaults from two different substations. This building sustained significant glazing damage (Section 5.2.1).
- **JP Morgan Chase Center.** Built in 1982, this is a 20-story (240-foot) building. Floors 1 through 13 are a parking garage. Floors 14 through 20 are offices. Virtually all of the glazing on one façade was damaged (Section 5.2.1) and the main roof covering was blown off (Section 5.2.4).

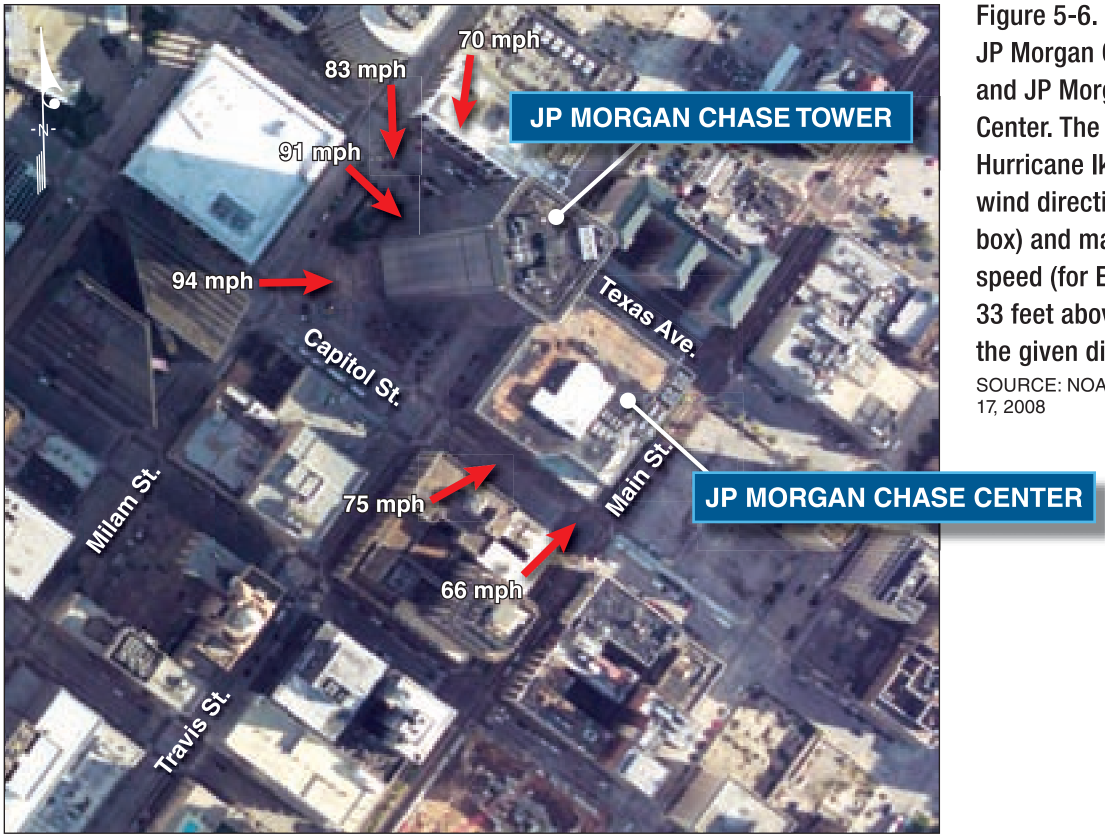


Figure 5-6.
JP Morgan Chase Tower and JP Morgan Chase Center. The arrows show Hurricane Ike's primary wind directions (see text box) and maximum gust speed (for Exposure C at 33 feet above grade) for the given direction.[1]

SOURCE: NOAA, SEPTEMBER 17, 2008

WIND DIRECTIONS AND SPEEDS IN DOWNTOWN HOUSTON

The variation in wind speeds and wind directions shown in Figures 5-6 and 5-16 were derived from measurements obtained from a Florida Coastal Monitoring Program 10-meter tower located on the University of Houston Campus. The magnitudes of the wind speeds were adjusted in two ways, as follows:

(1) Since the measurements were taken in an area with a terrain exposure best described as suburban, the wind speeds were converted to equivalent open country exposure conditions to facilitate comparison with basic design wind speeds specified in the 2006 IBC / ASCE 7-05. The terrain conversion resulted in an increase of 17 percent in the gust wind speeds over the actual measurements.

(2) The tower data represent measurements at a single point. However, the wind field model developed by ARA (2008) considers data from many sources and represents a smoothed estimate of wind speeds throughout the area. Therefore, the open terrain wind speed estimates computed from the actual tower measurements were increased by an additional 7 percent to be consistent with the ARA wind field estimates for downtown Houston.

1 All estimated speeds in this Chapter are peak gust, Exposure C at 33 feet taken from *Estimates of Maximum Wind Speed Produced by Hurricane Ike in Texas and Louisiana* (ARA, 2008)

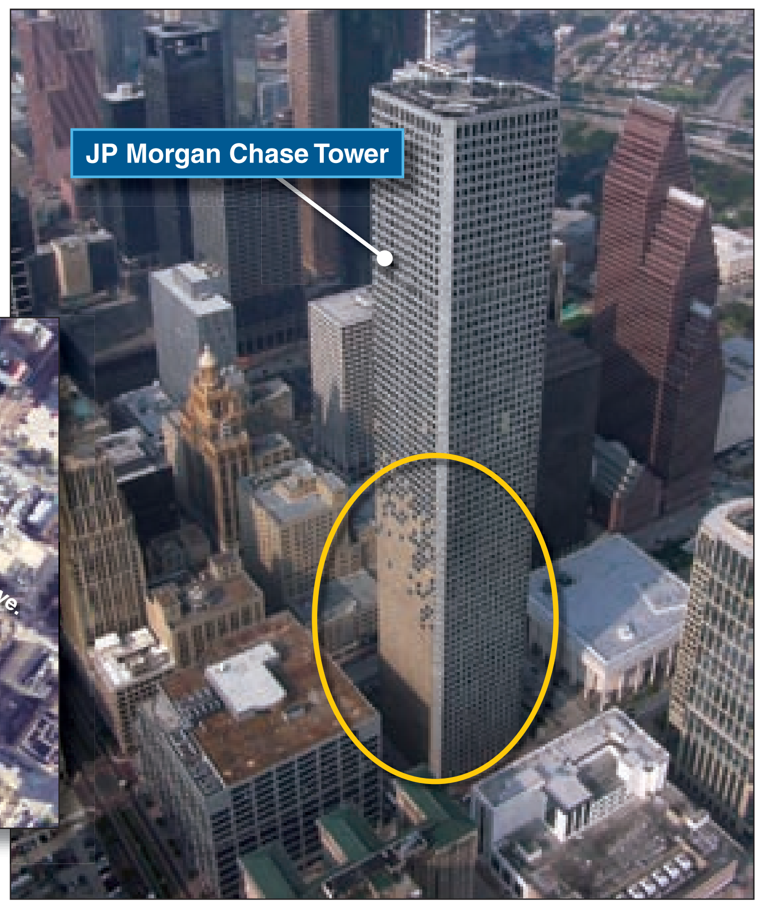
5.2.1 Glazing

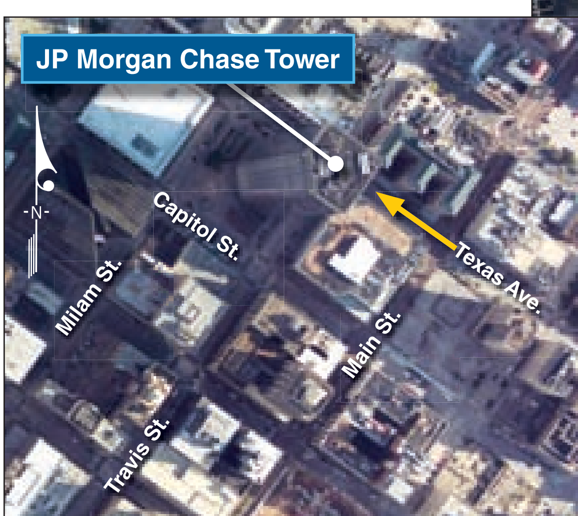
JP Morgan Chase Tower

The glazing panes of the JP Morgan Chase Tower are ¼-inch thick each, inner and outer, with a ½-inch air space between the panes. The glazing units are tinted and annealed. There was significant damage on the southeast façade, which was on the leeward side of the building during the time of the strongest winds (yellow circled area in Figure 5-7 and yellow arrow in inset), where both the inner and outer panes of approximately 463 windows were broken. On that façade, all windows in the first 22 floors were broken. The highest broken window was on the 47th floor. The southwest façade had 23 windows with broken inner and outer panes, and the northeast façade had two. The temporary protection and glazing replacement costs were significant.

For most of the southeast façade, very little wind and rain was driven into the offices. However, because of localized wind effects, some offices had significant amounts of rain and wind infiltration, which blew out ceiling boards and toppled office partitions. The MAT was advised that some furniture blew out of offices in this building and landed on the roof of the JP Morgan Chase Center across Travis Street. Because few of the broken windows were on windward façades, there was relatively little interior damage (Note: an explanation of the observed damage pattern is provided later in this section).

Figure 5-7.
Most of the glazing in the yellow oval was broken (JP Morgan Chase Tower). Inset shows location in cluster A; the yellow arrow shows the southeast façade where most of the damage occurred.

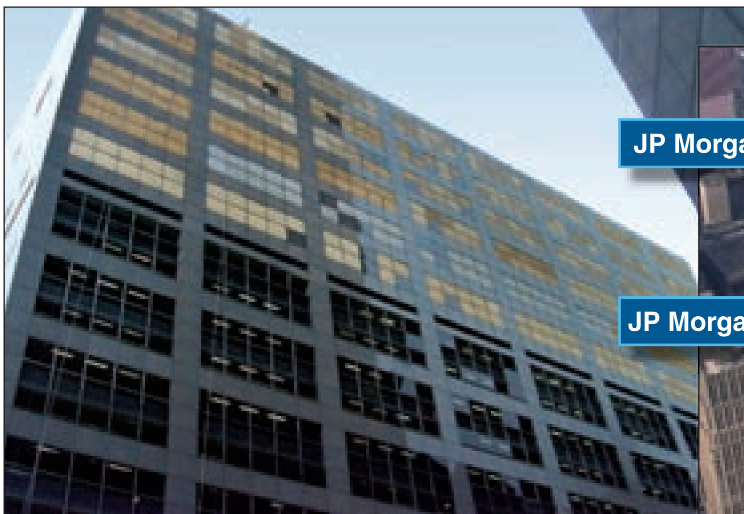




JP Morgan Chase Center

The JP Morgan Chase Center utilizes single-pane, heat-strengthened glazing. Virtually all of the penthouse glazing and the glazing on the northwest façade, which was the windward side of the building during the time of the strongest winds (Figure 5-8), was broken. At least 16 windows were broken on the façade with the yellow arrow in Figure 5-8 inset. Only a few windows were broken in the opposite façade. There was no damage in the southeast façade.

The broken glazing on the northwest façade blew approximately 50 feet into the interior of the building. Once the exterior glazing was breached, wind-driven rain penetrated into the building, causing extensive interior damage.



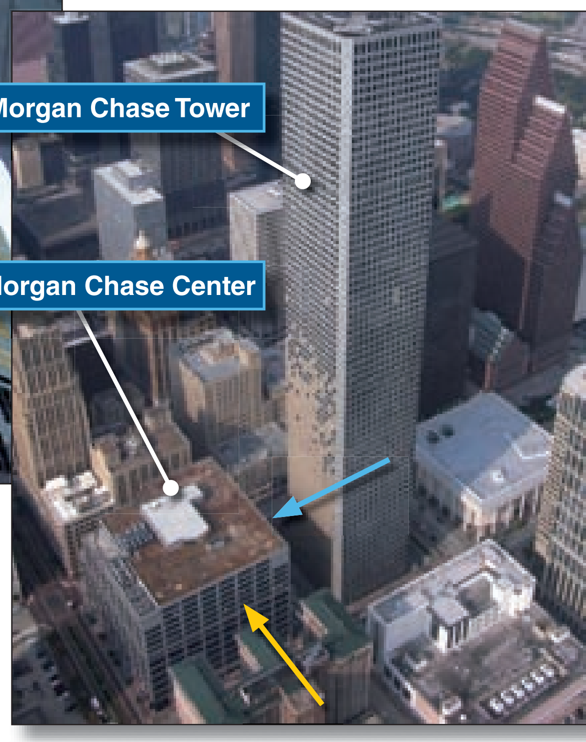


Figure 5-8.
Northwest façade glazing damage on JP Morgan Chase Center. The broken windows at the office level are boarded up, but broken windows at the parking level are not. The blue arrow in the inset indicates the northwest façade; the yellow arrow indicates a façade that also received some damage.

The extensive glazing damage at the JP Morgan Chase Center, possibly in combination with some contribution from roof damage, allowed water penetration into the offices on Floors 14 through 20, resulting in significant damage and loss of office space (Figure 5-9). On one of the floors, the MAT observed water damage that extended about 250 feet into the interior of the building. The water damaged interior walls and ceilings; some of the interior corridor walls toward the exterior fell over and touched the far wall. A computer lab, located along the exterior wall, received extensive water damage. Water damaged approximately 150 desktop computers.

Floors 18 and 19 sustained extensive damage. Water-damaged carpet and ceiling boards were removed from approximately 50 percent of the floor area that was observed by the MAT. At the time of the MAT observation, new materials were being installed, including new wiring, new data cables, and extensive HVAC work. Approximately 25 percent of the floor area on Floors 14 through 17 sustained similar damage.

Figure 5-9.
View of repairs to an office damaged in the JP Morgan Chase Center

Cause of Glazing Damage in JP Morgan Chase Tower and Center

Although the glazing damage shown in Figures 5-7 and 5-8 is indicative of damage caused by windborne roof aggregate, the MAT conclusion is that aggregate did not, in fact, cause the damage based on the following observations:

Although aggregate-surfaced BURs were present on the buildings shown in the yellow and orange circles in Figure 5-10, it is unlikely that debris from these roofs caused the glazing damage observed at the JP Morgan Tower and Center. The wind direction and relatively low speed precluded aggregate from the roofs in the orange circle from being a debris source. The speed and direction may have been sufficient to cause aggregate to be blown from the penthouse of the building shown in the yellow circle of Figure 5-10 (and discussed in Section 5.2.4), but if that occurred, the aggregate would likely only have struck the JP Morgan Center façade, which had very little damage. MAT observations from a helicopter and the roofs of the Tower and Center did not reveal any other aggregate-surfaced roofs in the vicinity.

> **OVERPRESSURIZATION**
>
> Wind speeds in downtown Houston during Hurricane Ike were below the ASCE 7-05 design wind speed. Hence, glazing failure due to overpressurization via negative (suction) or positive loading would not be expected, unless the glazing was weakened by scratches, was inadequately designed for wind loads, or glazing or frame-capture of the glazing was inadequate to meet the wind loads.

Figure 5-10.
Locations of possible debris sources that impacted the JP Morgan Tower and Center. Aggregate-surfaced roofs within cluster A area shown by yellow circles. Blue lines show location of failed metal panel veneer.
SOURCE: NOAA, SEPTEMBER 17, 2008

The MAT postulates that the glazing damage occurred as a result of the following: some glazing in the Tower or the Center failed, either due to windborne debris or overpressurization, and the resulting glass shards became enveloped in vortices that developed between the two buildings. As the shards impacted the opposing façades, additional shards were injected into the vortices. It is believed that the vortices lifted the shards upwards, thereby causing damage at the upper floors (shown in Figure 5-11). Potential initial debris sources include trees along the sidewalks and metal wall panels from a nearby building (blue lines shown in Figure 5-10; refer also to Section 5.2.4).

The MAT's postulate is consistent with initial research work on the observed glazing damage conducted by the University of Notre Dame in a paper titled *Saga of Glass Damage in Urban Environments Continues: Consequences of Aerodynamics and Debris Impact During Hurricane Ike* (Kareem, 2008).[2] A model of the JP Morgan Tower and surrounding buildings was constructed and flow visualization experiments were conducted in a wind tunnel. In addition, flow visualization was analyzed by computational fluid dynamics (CFD). The wind tunnel and CFD studies both demonstrated that a series of vortical flow structures formed between the two façades that were heavily damaged (Figure 5-11).

2 Available at www.nd.edu/~nathaz/doc/NATHAZ_Ike_Glass_Dmg.pdf

Figure 5-11.
The Tower is on the left and the Center is on the right. It is believed that vortices developed between these façades, and that glass shards entrapped within the vortices were slammed against and broke glazing in the opposing façades.

5.2.2 Granite Veneer

At least two granite veneer panels on the southeast façade of JP Morgan Chase Tower were blown off. Stone fragments reportedly punctured the roof membrane on the JP Morgan Chase Center. The MAT observed a veneer panel on the southwest façade that remained in place, but had a notable debris impact scar. The cause of failure of the two panels may have either been a result of overpressurization (influenced by panel weakness or an installation deficiency) or they may have been broken by windborne debris.

5.2.3 Roof Systems and Rooftop Equipment

According to project records, the original roof on the JP Morgan Chase Tower was a smooth-surface built-up roof over a concrete deck (Figure 5-12). It was reroofed in 1990 by fully adhering an EPDM[3] membrane directly to the BUR. The MAT did not observe any areas of membrane debonding or any damage to rooftop equipment. Some lightning protection conductors were

3 Ethylene propylene diene monomer

no longer held by some of the connectors, but it was not clear if the attachment was lost prior to or during the hurricane.

A portion of the window washing equipment on the JP Morgan Chase Tower broke loose and slammed around, damaging the equipment (Figure 5-12 inset).

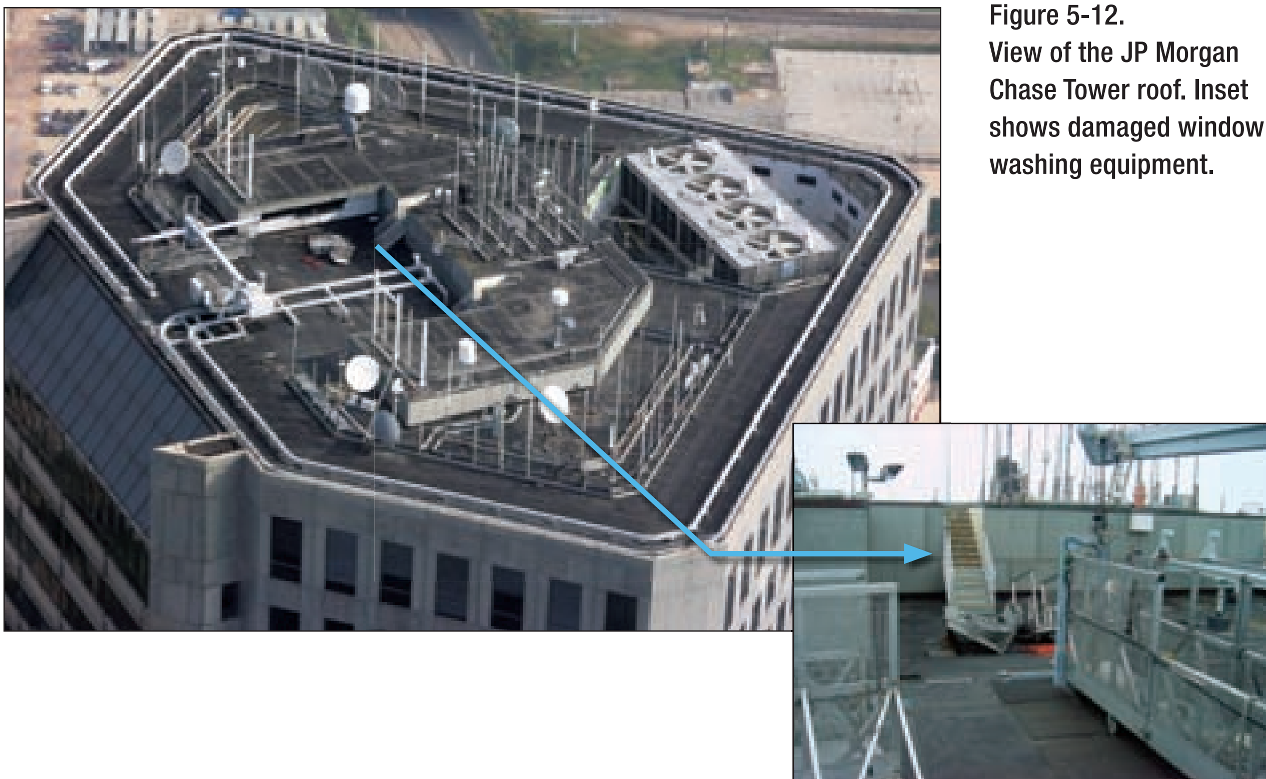


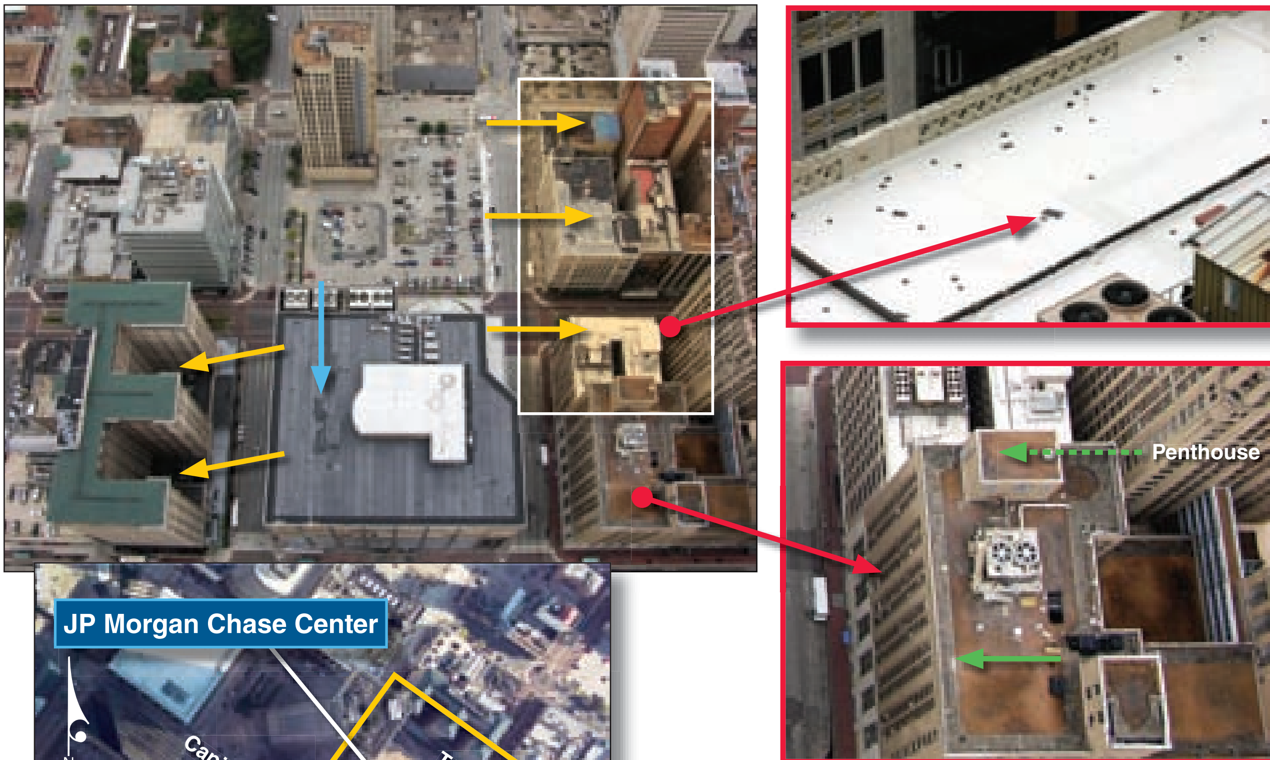
Figure 5-12.
View of the JP Morgan Chase Tower roof. Inset shows damaged window washing equipment.

5.2.4 Nearby Building Performance

There was variable performance of glazing and roof coverings at the surrounding buildings. Although some buildings were undamaged, several low-rise buildings had glazing and/or roof covering damage and one building had signage and wall covering damage.

The roofs shown by the yellow arrows in Figure 5-13 had either been blown off (i.e., the tarped roofs) or punctured by windborne debris. Much of the roof puncture and glazing damage was likely caused by windborne glass shards.

At the building shown in the bottom inset at Figure 5-13, concrete pavers had been installed around the perimeter of the main roof (solid green arrow at the inset) and at a portion of one of the penthouses as part of the original roof surfacing. However, the penthouse roof indicated with the dashed green arrow did not have pavers; its roof had a raised curb at the roof edge. Aggregate from this penthouse roof may have struck the side of JP Morgan Chase Center that had very little glazing damage.



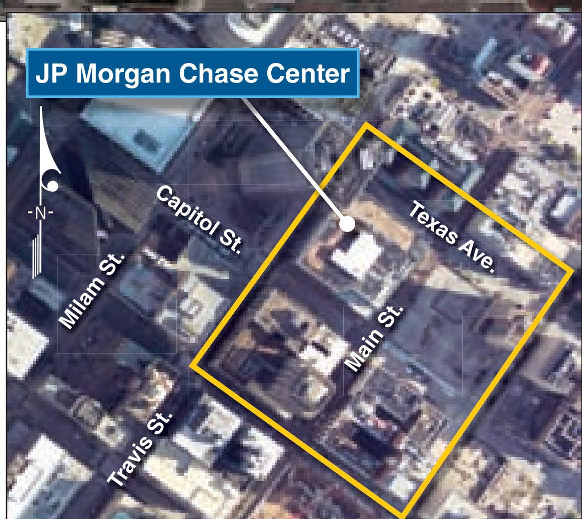


Figure 5-13.
The main roof of the JP Morgan Chase Center (blue arrow) and several other roofs (indicated by yellow arrows) were blown off or damaged by debris. Black areas at the top inset are patches. The bottom inset shows a building with built-up aggregate-surfaced roofs. The location inset shows the buildings in this figure (yellow box). See Figure 5-14 for the buildings in the white rectangle.

Figure 5-14 is a view of the roofs in the white rectangle at Figure 5-13. Blue and clear plastic tarps cover two roof areas. The green arrows show where an aggregate-surfaced built-up membrane lifted and peeled back. It is doubtful that aggregate from these roofs struck the JP Morgan Chase Tower or Center buildings. The punctured roof with the black arrow is the same as shown at the top inset of Figure 5-13. Several windows were broken in the buildings shown by the yellow arrows.

Figure 5-15 shows a building that lost several metal wall panels and a wall-mounted sign; the inset shows the building location and the façade that lost the panels (blue lines). It appears that the wall panel debris had the potential to strike either the JP Morgan Tower or Center.

In addition to the damage described above, the MAT observed a mid-rise building that had a protected membrane roof system that used extruded polystyrene insulation boards with a cementitious coating for the ballast. On-the-roof observation was not made, but analysis of high resolution photographs did not reveal any wind uplift problems.

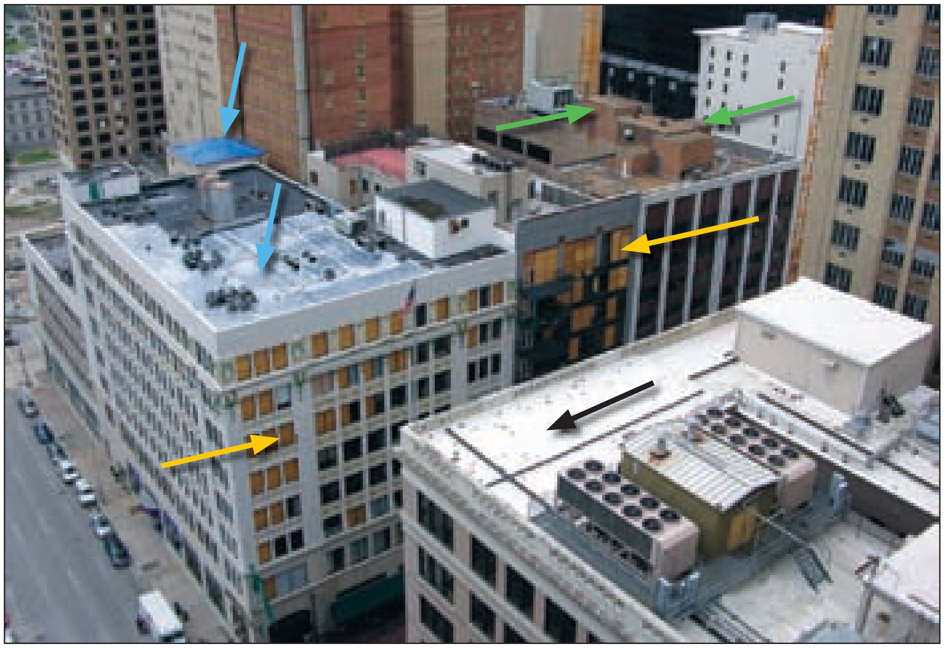
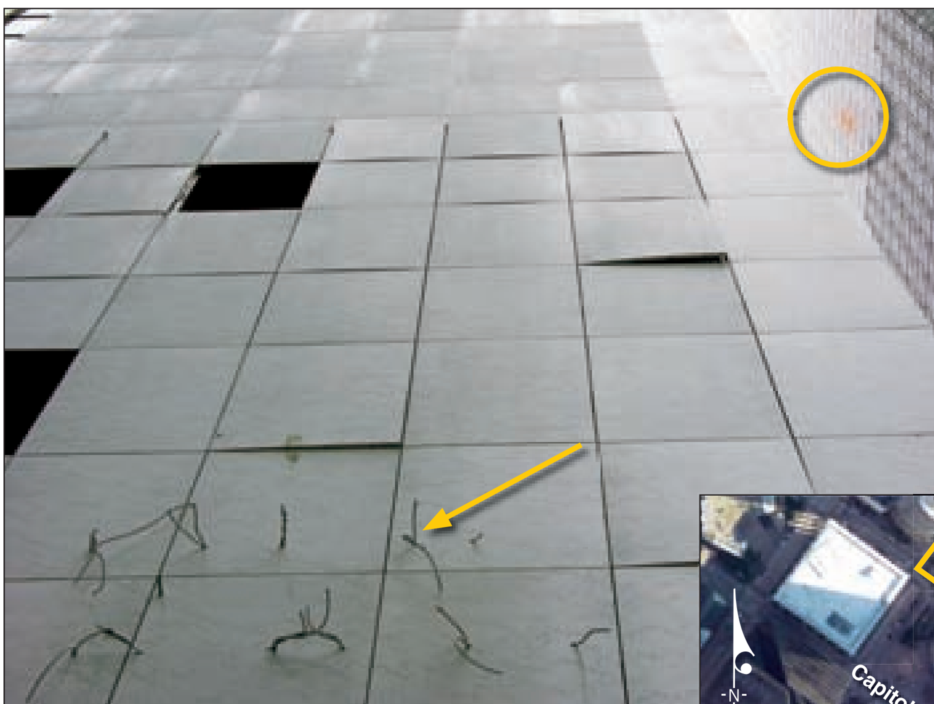


Figure 5-14.
Glazing damage (yellow arrows) at two of the buildings shown in the white rectangle in Figure 5-13. The blue, green, and black arrows indicate damaged roofs.



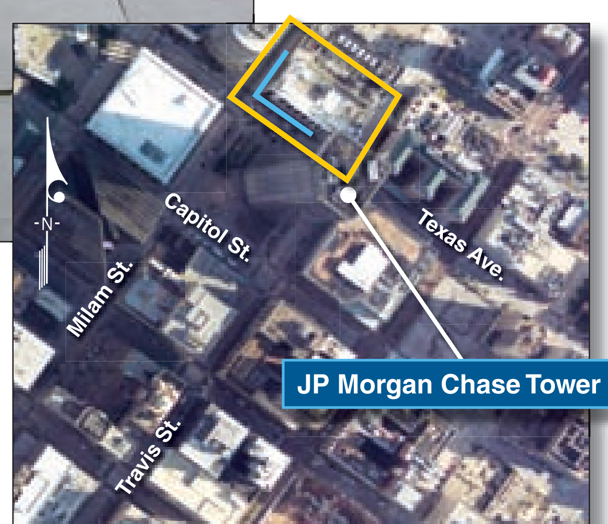


Figure 5-15.
Several metal panels blew off of two façades of this building, along with a wall-mounted sign (yellow arrow). Two broken windows can be seen in the yellow circle at the JP Morgan Chase Tower. Inset shows location of building (yellow box); blue lines indicate façades where metal panels blew off.

Loss of Function

The upper floors of JP Morgan Chase Center, Floors 14 through 20, were not operational for a substantial amount of time. The cost of the repairs is expected to be around $3.1 million. At the time of the MAT observation, the cleanup and repair crews had been at the building for about 2 months. In addition to cleanup costs, costs were incurred by the resulting loss of function of the offices. Some of the office functions were moved out of the State.

5.3 Cluster B – Chevron Center Area

An enlarged view of cluster B from Figure 5-1 is shown in Figure 5-16. The Chevron Center is part of cluster B. This 40-story building was built in 1999–2002. A large number of windows were broken on the side indicated by the yellow arrow in Figure 5-16 (refer also to Section 5.3.1). The roof membrane was blown off the end of the building indicated by the green arrow (refer also to Section 5.3.2). The building lost power during Hurricane Ike and for 2 days afterward.

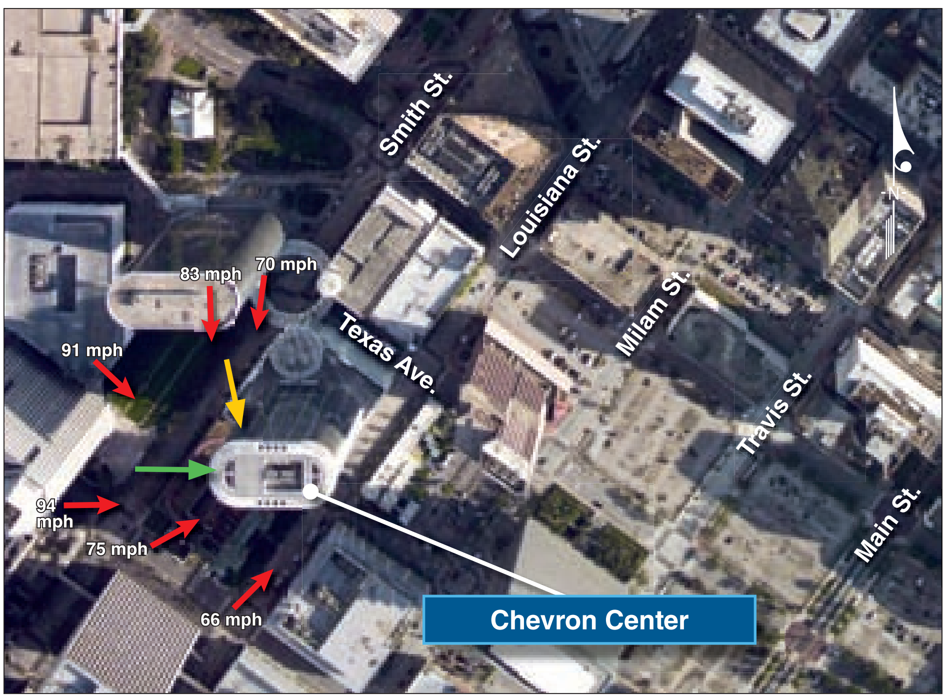


Figure 5-16. A substantial amount of glazing damage occurred to the façade of the Chevron Center, indicated by the yellow arrow. The roof membrane blew off from the end of the building (green arrow). The red arrows show Hurricane Ike's primary wind directions and maximum gust speed for the given direction.
SOURCE: NOAA, SEPTEMBER 17, 2008

5.3.1 Glazing

The area of the Chevron Center that received most of the glazing damage is shown in Figure 5-17. The outer panes of about 700 heat-strengthened windows were broken. At seven windows, both the inner and outer lites were broken.

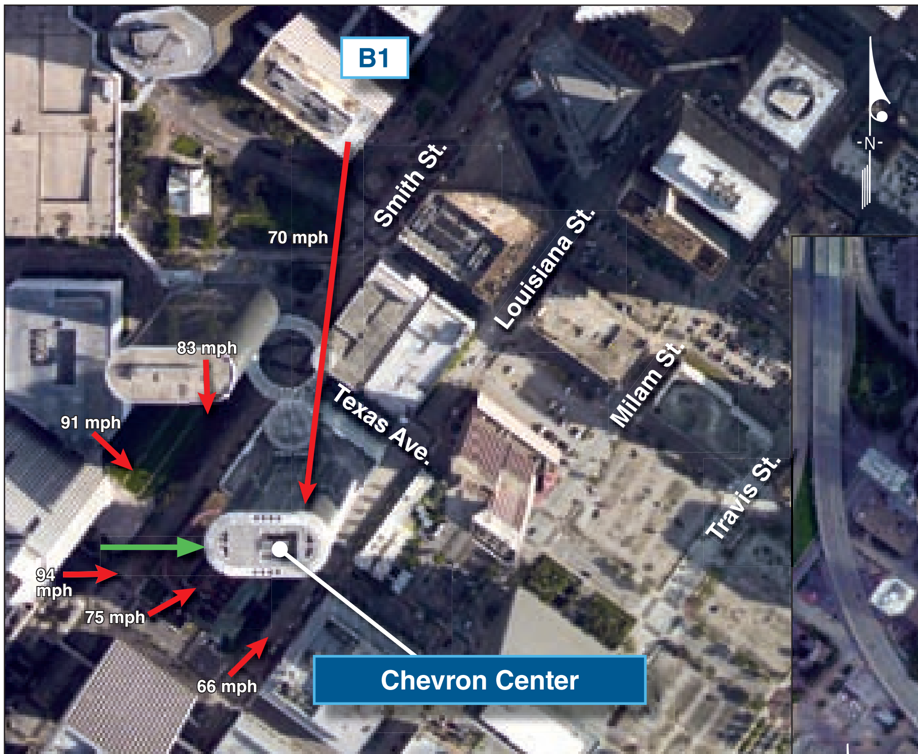
Figure 5-17.
Chevron Center glazing damage. At the building beyond (yellow circle), at least 35 windows were boarded up. Bottom inset shows location.

Shortly after the storm, the building owner retained a company to quickly install a temporary film over all of the broken glazing as a safety precaution to avoid falling shards of glass (Figure 5-18). Once the protective film was in place, work commenced on removing the broken glass that was still in place. Glass removal took considerable time, hence the initial installation of the protective film was prudent to protect pedestrians.

Figure 5-18.
Broken glazing held in place with temporary film

Cause of glazing damage: Prior to and during the MAT helicopter observations, the glazing damage at the Chevron Center had not been detected. Therefore, the high-rise roofs near the Chevron Center were not observed during the flight for potential debris sources. Subsequent analysis of the NOAA high-resolution photographs did not reveal an obvious debris source. Roof debris from the building designated as B-1 in Figure 5-19 (close up view shown in Figure 5-28) appears to have had the potential to strike the center area of the Chevron Center. Although some glazing damage occurred in the center area, the damage was primarily near the end of the Chevron Center. Also, when the wind was blowing in the direction conducive for roof debris from building B-1 to strike the Chevron Center, the wind speed was relatively low. Therefore, roof debris from building B-1 is not believed to be the primary cause of the Chevron Center glazing damage.

Two mid-rise buildings with aggregate-surfaced BURs occur to the south of the Chevron Center (yellow arrows at the inset of Figure 5-19). These buildings are shown in Figure 6-4. The closest building is approximately 250 feet from the Chevron Center, which is well within the flight capability of windborne aggregate. However, wind direction during Hurricane Ike precluded aggregate from these buildings as being potential debris sources for the glazing damage at the Chevron Center (refer to red arrows indicating wind directions shown on Figure 5-19).



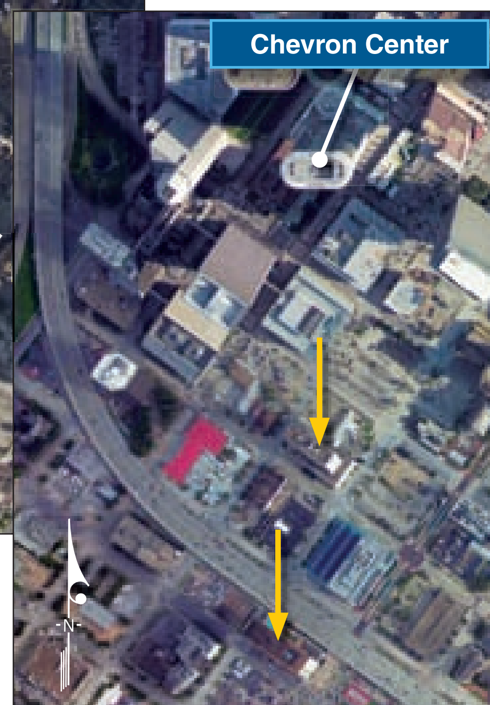


Figure 5-19.
Portions of the roof system were blown off building B-1. Winds blowing roof debris in the direction shown by the long red arrow may have had potential to strike the Chevron Center. The green arrow indicates where a portion of the roof membrane blew off the Chevron Center. The yellow arrows at the inset show locations of buildings that had aggregate-surfaced roofs.
SOURCE: NOAA, SEPTEMBER 17, 2008

The LPS conductor around the perimeter of the Chevron Center detached from the conductor connectors. It is conceivable that the conductor dangled over the side of the building (similar to that shown in Figure 4-40) and caused some glazing damage. Also, as discussed in Section 5.3.2, some of the lightweight insulating concrete roof deck blew off and landed on a roof area that was just a few floors below the main roof. It is conceivable that some of the deck debris caused some glazing damage.

Additional study, which is beyond the scope of the MAT, is needed to more definitively assess the primary cause of glazing damage on this building.

5.3.2 Roof Systems and Rooftop Equipment

The perimeter of the Chevron Center roof had a PVC membrane fully adhered to lightweight insulating concrete. The main roof is surfaced with 16-inch by 16-inch lightweight interlocking concrete pavers.

A portion of the PVC roof membrane was blown off in the vicinity shown by the green arrow in Figure 5-19 and as shown in Figure 5-20. The concrete deck was gouged in many locations (Figure 5-20). The gouging may have been due to roof membrane flutter, or it may have been caused by the detached lightning protection conductor.

Figure 5-20.
The lightweight insulating concrete deck was gouged in many locations

As a result of the roof membrane damage, the window washing track (Figure 5-21) was damaged. Apparently, membrane fluttering caused the nuts on the ½-inch stainless steel bolts to loosen. The galvanized T-shaped window washing track is 4 inches high and 5 ½ inches wide, with a ¼-inch thick head and a ⅜-inch stem.

Figure 5-21.
View of the damaged window washing track (green arrow). The concrete pavers (blue arrow) were not damaged.

5.3.3 Damage at Nearby Buildings

In addition to the glazing and roof covering damage at the Chevron Center, several other low-, mid-, and high-rise buildings shown in Figures 5-22 and 5-23 had various types of building envelope damage as described below.

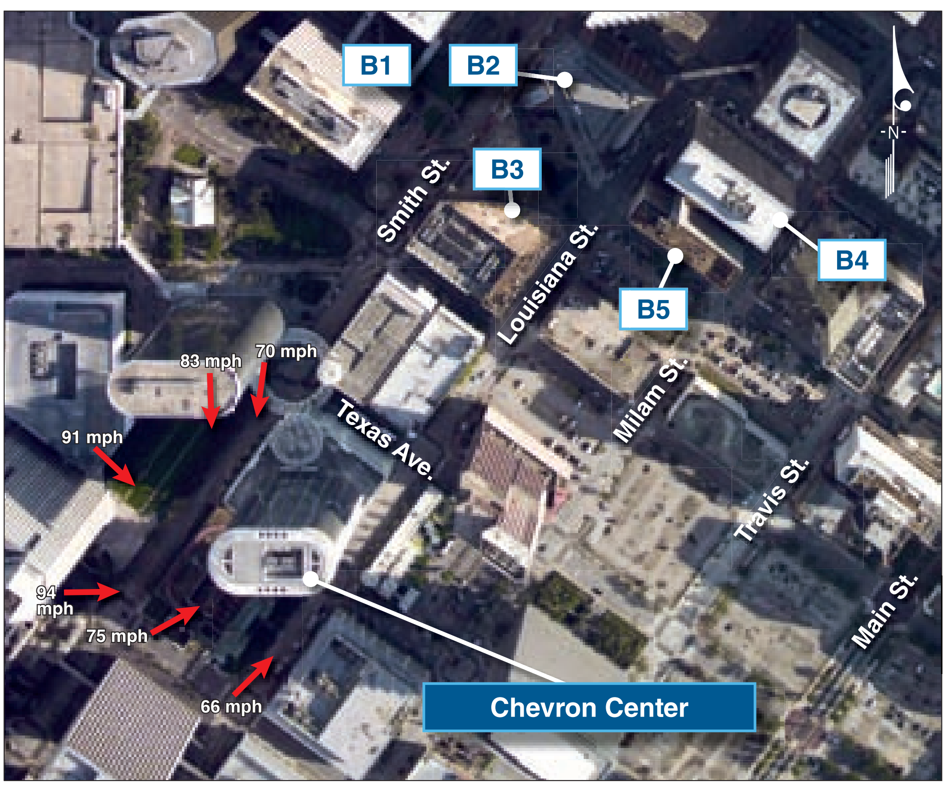


Figure 5-22.
Locations of nearby damaged buildings
SOURCE: NOAA, SEPTEMBER 17, 2008

The view in Figure 5-23 is looking northeast from the roof of the Chevron Center. Yellow arrows indicate two broken windows in the high-rise beyond. There was extensive roof covering damage at building B-3, including exterior wall collapse (green arrow).

Figure 5-23.
View of buildings with glazing, roof and wall covering, and rooftop equipment damage

At building B-2, as shown in Figure 5-24, there was roof puncture damage at the three roof areas shown by the blue arrows, metal wall panels were blown off (yellow arrow), skylights were damaged (green arrow), and a fan cowling was blown off the upper round roof. According to a Hurricane Alicia investigator, this building experienced similar damage during that hurricane.

Building B-5 had an aggregate-surfaced BUR with low parapets (likely less than 12 inches high). The aggregate from this roof was a debris source for the building B-4 glass damage (Figure 5-25; close-up shown in Figure 5-26). The red arrow in Figure 5-25 indicates the generalized likely flight path of the aggregate debris. At least two fan cowlings blew off the building B-5 roof. On the back side of building B-5, a few stone veneer panels were damaged (Figure 5-27). According

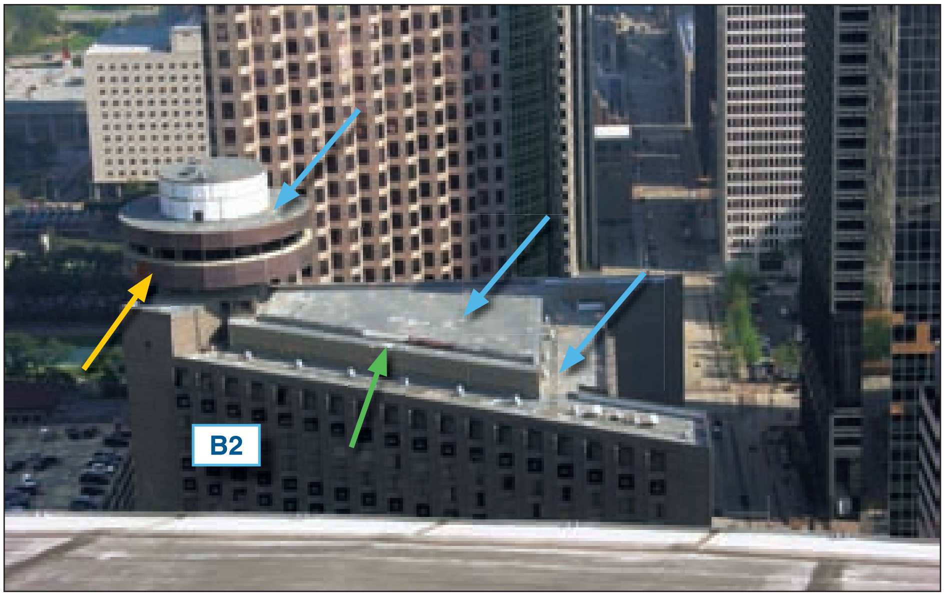


Figure 5-24.
Roof and wall covering, skylight, and roof-top equipment damage at building B-2

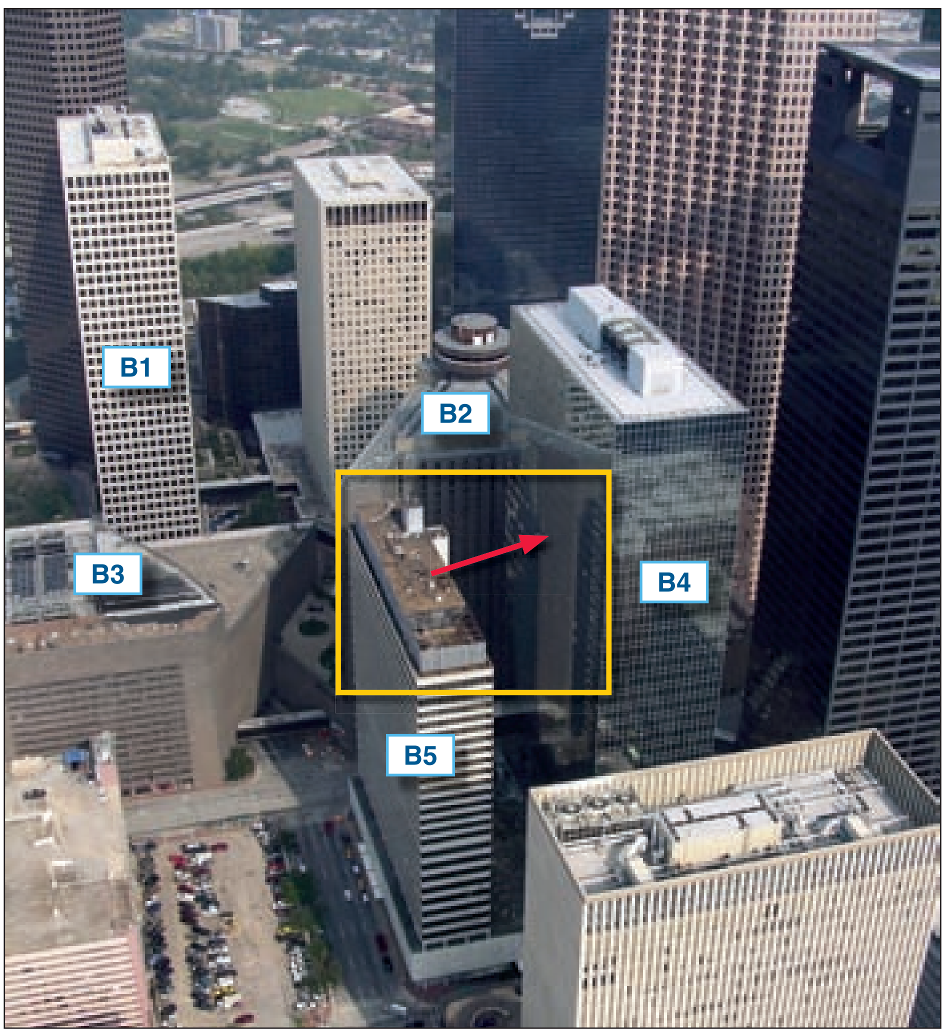


Figure 5-25.
Roof aggregate from building B-5 was the likely cause of the majority of the building B-4 glass damage. The area in the yellow box is shown in Figure 5-26.

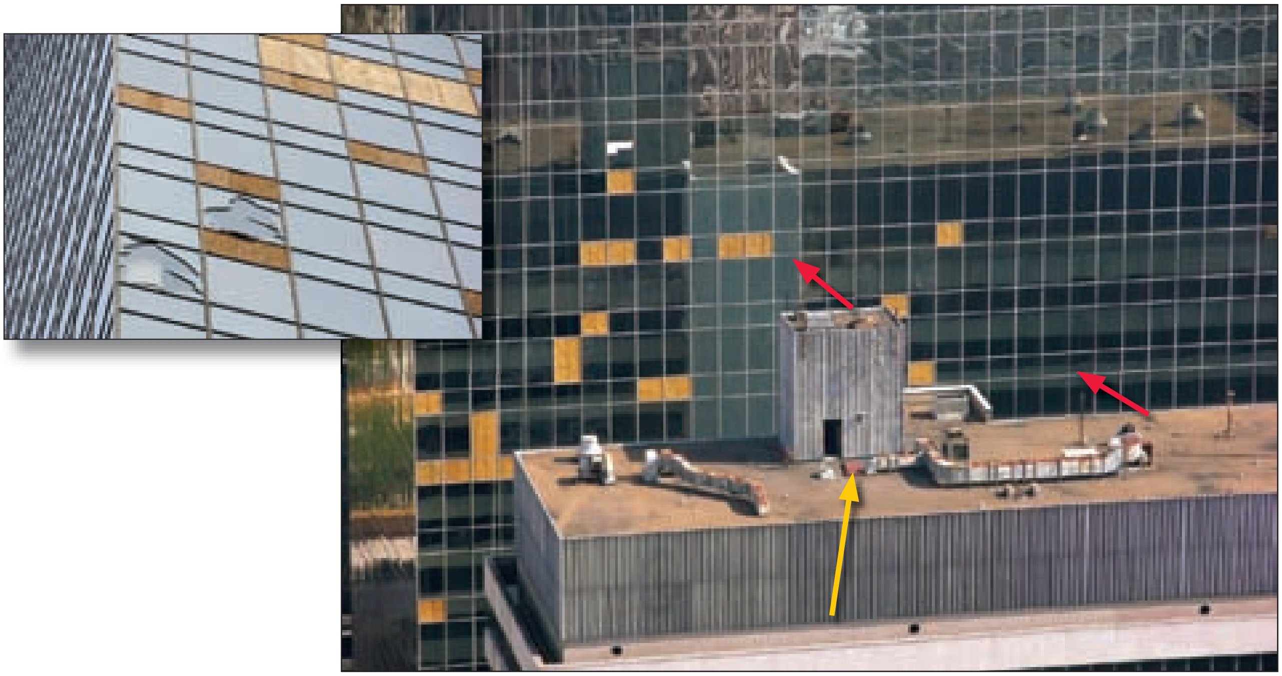


Figure 5-26.
View of the aggregate-surfaced roofs on building B-5 and broken glazing on building B-4 beyond. Red arrows indicate generalized aggregate flight path. The yellow arrow shows a penthouse door that blew off. Inset shows damage on a portion of building B-4 below the area shown in the main photograph.

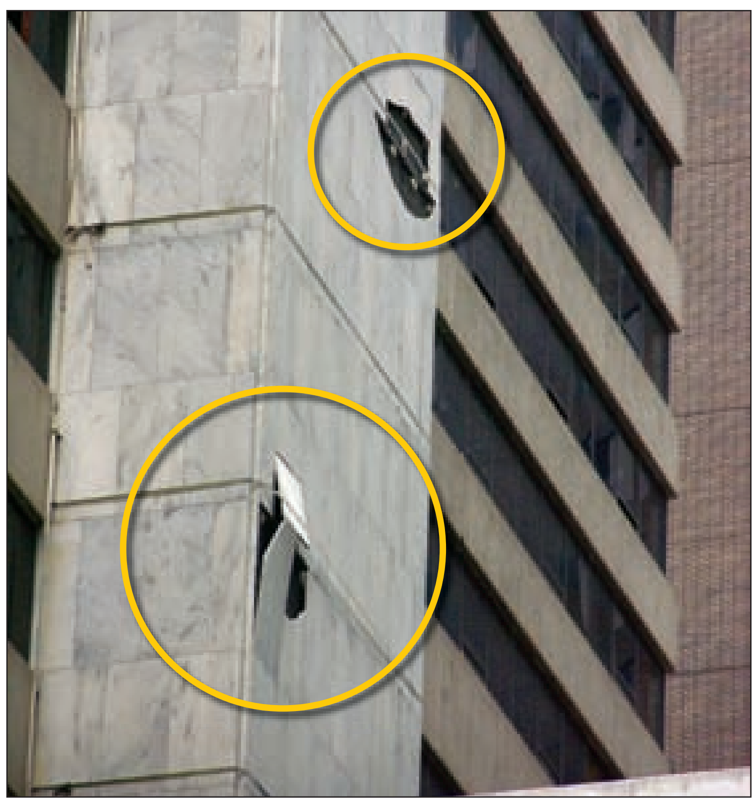


Figure 5-27.
Stone veneer damage on backside of building B-5 (side facing B-4)

to a Hurricane Alicia investigator, buildings B-4 and B-5 had somewhat similar damage during that hurricane. However, the rooftop penthouse performance on building B-5 was better during Hurricane Ike.

Figure 5-28 shows roof covering damage to building B-1, which was a possible debris source for some of the glazing damage to Chevron Center, as discussed in Section 5.3.1. This building is one of the oldest high-rise buildings in the downtown area.

Figure 5-28.
Roof covering damage on the main and penthouse roofs of building B-1

5.4 Vegetative Roofs

In the downtown area, the MAT observed three vegetative roofs (also known as garden roofs and green roofs). Vegetative roofs had not been observed by previous MATs. The MAT is not aware of previous documentation of wind performance of vegetative roofs. Currently, there are no consensus wind design guides or wind-related code requirements for this type of roof.

Vegetative roofs can either be "extensive" (with very low plants) or "intensive" (which allows for the planting of shrubs and trees). All three of the vegetative roofs observed by the MAT had trees, as shown in Figure 5-29. The MAT did not perform on-the-roof observations at any of the vegetative roofs, but it was apparent that few, if any, tree limbs were blown away. Lack of limb damage may have been prevented by sheltering from nearby buildings. Also, the low-level wind speeds in the downtown area were not sufficiently high to cause substantial loss of limbs. The concern with limbs is their potential to damage glazing if they are blown away, particularly when trees are placed many floors above grade.

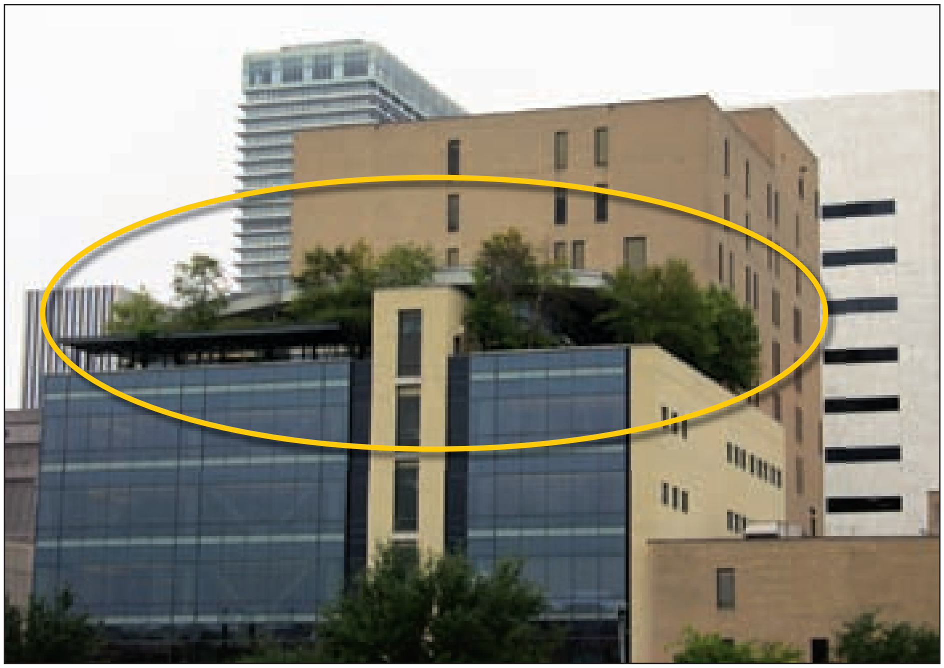
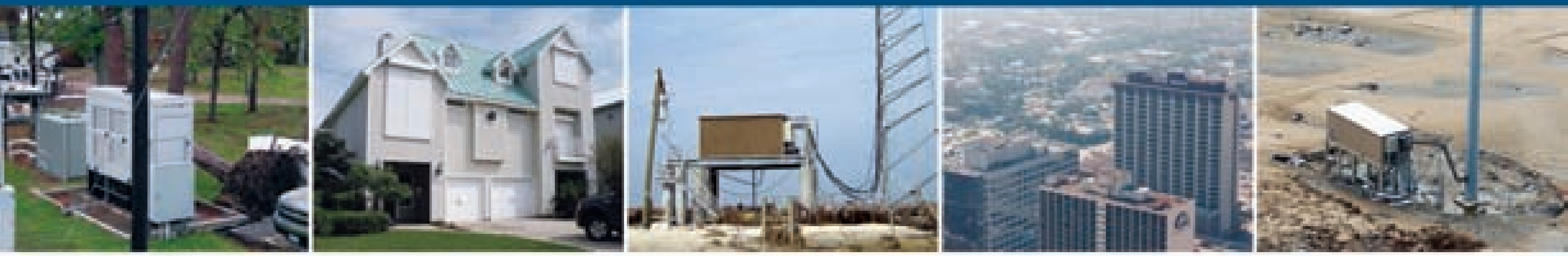


Figure 5-29.
View of a vegetative roof in the downtown area



6 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 a meeting with State and local officials, business and trade associations, contractors, and other interested parties. These conclusions are intended to assist the States of Texas and Louisiana, communities, businesses, and individuals in the reconstruction process, and to help reduce future damage and impacts from flood and wind events similar to Hurricane Ike. The report and recommendations will also help FEMA assess the adequacy of its flood hazard mapping and floodplain management requirements, and determine whether changes are needed or additional guidance is required.

The conclusions presented in Sections 6.1 (residential), 6.2 (critical facilities), and 6.3 (Houston's Central Business District) relate to recommendations made in Section 7 to ensure that designers, contractors, building officials, and coastal populations understand what is necessary for disaster-resistant construction in hurricane-prone regions.

6.1 Residential

6.1.1 Flood

Flood-related damage was severe and widespread, especially along the Texas shoreline east of the entrance to Galveston Bay. High storm surge levels, waves, scour and erosion, and floodborne debris contributed to the damage.

On Bolivar Peninsula, wave damage to floor systems of surviving homes revealed that wave crest elevations probably reached 2 to 5 feet above the BFE. Along western Galveston Island and along Follets Island, wave crest elevations appear to have been below the BFE. Flood levels in some communities adjacent to Galveston Bay or Sabine River were several feet above the BFE. In southwest Louisiana and in the Sabine Pass region of Texas, flood levels were above Hurricane Rita elevations in many places, below in others, but were generally above BFEs shown on FIRMs.

The MAT observed a much greater incidence and severity of scour around Gulf-front building foundations during Hurricane Ike than during other recent Gulf coast hurricanes (e.g., Opal, Ivan, and Katrina). The reason for the prevalence and magnitude of foundation scour during Ike is not known at this time.

Most structural failures observed by the MAT and associated with flooding appeared to be the result of one or more of the following: inadequate elevation of the building, inadequate pile embedment, unanticipated levels of scour and erosion around the foundation, improper load path connections from the elevated building to the foundation to the ground, or inadequate foundation resistance to flood loads.

Building Elevation Relative to Flood Level. Flood damage to buildings was generally consistent with expectations, given the observed flood levels. Flood damage to commercial facilities was generally similar to flood damage at nearby residential structures.

1. In areas where flood levels exceeded the BFE, newer construction elevated several feet above the BFE on strong foundations generally survived with little flood damage, except in instances where unanticipated scour or floodborne debris led to foundation failures. Nearby newer construction elevated only to the BFE was heavily damaged or destroyed. Older, lower construction was often damaged or destroyed as well.
2. In areas where flood levels were below the BFE, flood damage to NFIP-compliant buildings was generally minimal, with a few exceptions where scour and erosion or foundation-related deficiencies led to damage.

3. In areas subject to Coastal A Zone conditions during Ike, apparently compliant Zone A construction was sometimes damaged by waves and velocity flow. The NFIP practice of allowing construction of floor systems below the BFE leads to building damage.
4. Buildings behind the Galveston seawall were subject to flooding from Galveston Bay and to Gulf-side flooding due to wave overtopping, but were not exposed to direct wave attack.

Buildings that were built according to minimum standards and code, with the lowest floor elevation at the BFE, sustained significant damage or destruction when the flood level exceeded the BFE.

Many houses were elevated to the BFE and survived Ike—they were not subject to base flood or design wind conditions during the storm. However, some of these houses will fail if they are ever subject to base flood conditions or design winds. The MAT observed houses that were not attached to their foundations or were elevated on foundations that lacked load path continuity to the ground. This problem was also noted in cases where the MAT observed houses in Louisiana that were elevated with Federal funds, including HMGP grants and flood policy Increased Cost of Compliance payments.

Several houses visited by the MAT in Galveston County were advertised as, or known to be, enhanced code construction (refer to Section 2.4 for discussion of enhanced code construction). While it is true that these houses were elevated above the BFE and incorporated certain wind-resistive features that exceeded code requirements, some of these houses sustained flood damage. The flood damage observed by the MAT was typically a result of scour and erosion exceeding the ability of the pile/column foundation to remain vertical, or lateral loads and bending moments exceeding the material properties of the foundation piles/columns.

The Federal Communications Commission studied communications related to response activities following Hurricane Katrina; this study included a consideration of emergency power requirements for cell towers. The MAT noted and benefited from the elevation of cell phone tower equipment and powering by emergency generators on Bolivar Peninsula (Figure 6-1). When the MAT was in the field 5 days after Hurricane Ike, it had cell phone coverage and was able to access maps and other information from the Internet, despite the fact that much of the commercial and residential development on the Peninsula lay damaged or in ruins.

Foundation Design. Based on the failures observed by the MAT, foundation design does not receive adequate attention from design professionals. Specifically, the MAT observed:

1. Some buildings exposed to severe foundation scour collapsed, some suffered differential settlement, and some survived without damage.
2. Some buildings were elevated above the BFE and would have been expected to survive Ike's flood loads and conditions without damage. However, the MAT observed connection failures or bending failures in piles and columns that led to collapse of otherwise successful buildings.

Figure 6-1.
Two examples of elevation of equipment above grade on pile/column foundations, a good practice that ensured continuity of cell phone service on Bolivar Peninsula, TX

Parking Slab Failures. The MAT observed a wide range of parking slab performance, and a range of slab effects on foundation performance.

The MAT observed instances where parking slab failures led to timber pile failures at elevated houses. Where broken slabs remained connected to foundation piles, they transferred loads to the piles that the piles could not resist—racked foundations and broken piles resulted. Some people might argue that constructing thicker and stronger slabs would prevent this problem, but the MAT also observed instances where intact parking slabs beneath elevated houses appeared to contribute to foundation and building settlement by increasing scour around the foundation (as water flowed between the bottom of the slab and the eroded ground) and by placing additional vertical load on the foundations. Foundation success requires adequate embedment into the ground, after accounting for erosion and scour; while a slab may help to stiffen a foundation, it is not a substitute for adequate embedment.

The MAT also observed instances where unreinforced, frangible slabs had been constructed beneath elevated houses, in conformance with Galveston County requirements. These slabs collapsed, as intended, with no apparent harm to the elevated houses or their foundations.

Siting. MAT observations regarding siting effects on building damage were consistent with observations following past storms. Buildings situated the closest to the Gulf of Mexico shoreline, either by intent or because of long-term erosion effects, are at greatest risk to erosion and wave effects and sustained the greatest damage during Ike. While building elevation and foundation strength can overcome some of the risk associated with siting a building close to the shoreline, typical design practice cannot compensate for prior land planning and development decisions that result in small lots close to an eroding shoreline.

Breakaway Wall Performance. Generally, solid breakaway walls performed as expected—they broke free when subjected to lateral flood loads. However, below-BFE elements constructed of lattice or louvers may be preferred over solid breakaway wall panels. While the latter tended to break away (as designed) when exposed to flood depths of a few feet and small waves, the louver and lattice wall panels, subjected to the same flood conditions, allowed water to flow through the panel without damage to the panel or building, thereby reducing repair costs for the owner.

As homes are elevated to higher and higher elevations above the BFE (which FEMA encourages), one unintended consequence is that breakaway wall panels are becoming taller and taller, resulting in larger and larger floodborne debris elements.

Manufactured Homes. Manufactured homes generally performed in a manner consistent with their performance in prior storms. Those that were elevated on strong foundations and tied down to resist wind effects survived intact as long as flood levels remained below the chassis frame and wind speeds were low. Those not installed and restrained on adequate foundations were damaged or destroyed once flood levels reached the floor system. Those homes not properly tied down often shifted due to lateral wind loading.

In some locations in Louisiana, manufactured housing installed after Hurricane Rita was not elevated at or above the BFE. This may have occurred in existing manufactured housing parks where an NFIP exception allows homes to be elevated 3 feet above grade, even where this is lower than the BFE, or it may have occurred through incorrect application of the 3-foot exception. Whether this was allowed by the NFIP exception or not, the result was the same—manufactured housing installed below the BFE after Hurricane Rita was completely destroyed by Hurricane Ike.

6.1.2 Wind

The observed and modeled wind speeds of Hurricane Ike were less than the design wind speeds required by ASCE 7-05 for the areas of Texas and Louisiana affected by the storm. Damage to buildings and other structures was therefore generally associated with wall cladding and roofing materials.

Due to Ike's lower wind speeds, most of the homes were spared the devastating high wind pressures that cave in walls and doors, and remove large sections of roofs. The observed damage from Ike related to debris impacts and wind pressures appeared to be the result of the use of building products not intended for hurricane-prone regions, poor installation practices, and poor code enforcement, all of which are correctable. In Texas, where specific independent review and inspection practices were provided by TDI, the required construction practices were well understood and complied with by the builders. However, questionable building practices of new construction in unincorporated areas that fall within the purview of the TRCC was observed.

Roof Systems. In the areas observed by the MAT, roof covering damage was common and quite variable, which is consistent with what was observed by the Hurricanes Charley, Ivan, and Katrina MATs (see FEMA 488, 489, and 549).

- Very little sheathing damage was observed. However, the damage observed was related to unsupported large overhangs and poor construction practices.
- Roofing damage to older homes appeared to be a function of the age of the roof, whereas roofing damage to newer homes was a function of poor installation and failure to follow guidelines for installations in high-wind zones.
- Several houses visited by the MAT in Galveston County were advertised as or known to be enhanced code construction. While it is true that these houses were elevated above the BFE and incorporated certain wind-resistive features that exceeded code requirements, some of these houses sustained wind damage. The wind damage observed by the MAT was typically roof covering loss, roof sheathing loss, or water penetration through soffits and vents or around windows and doors.

Non-Load-Bearing Walls and Wall Coverings. An extensive amount of wall covering was damaged by Hurricane Ike. The majority of this damage was to vinyl siding and fiber cement siding. In most cases, the failures were related to installation of products not rated for the high-wind zones and installers not utilizing industry recommendations for high-wind zone installations. It was further observed that some cladding failures associated with attics were related to the use of sheathing that was not attached in accordance to high-wind zone procedures. These attachment failures made the sheathing/cladding system incapable of independently withstanding design wind pressures behind the system, which led to failures.

Doors, Windows, and Shutters. Few impact-resistant glazed window units were observed by the MAT. Most houses observed by the MAT had some form of shutter to provide debris impact protection. The shutter type varied from simple plywood to expensive roll-down shutters. The MAT observed numerous instances where plywood shutters were not properly anchored to the building structure, but rather to window frames and wall cladding. Though few debris impacts were observed, it appeared that most shuttering was effective in this less-than-design wind event. It was further observed that some homeowners chose not to shutter all windows (Figure 6-2). In some instances, shutters were only placed on the seaward facing windows, and the unshuttered north facing windows left vulnerable to Ike's backside winds.

Figure 6-2.
The upper windows on this Seabrook, TX, residence were not shuttered and were vulnerable to windborne damage

Roof Soffits, Fascias, and Gable Vents. The MAT observed many instances where vinyl soffits and aluminum fascia covers failed, thereby allowing water infiltration into the homes, resulting in damage. At least one gable end vent was observed to have blown from its mounting. All of these failures appeared to be installation issues.

Exterior-Mounted Equipment. All observed HVAC units mounted on the outside of the homes were elevated, per the guidelines contained in FEMA 55.

6.2 Critical Facilities

6.2.1 Flood

Critical facilities generally performed as expected. Those that were elevated higher than the minimum permitted elevation and on stronger foundations sustained less damage to structural and non-structural components. Those that were constructed in a manner similar to nearby, minimally compliant residential and commercial structures sustained more damage.

Building Elevation Relative to Flood Level. At least one critical facility, a hospital destroyed by Hurricane Rita and rebuilt prior to Ike, does not appear to have sufficient elevation and will likely be flooded again. The facility was rebuilt with the top of its lowest floor 1 foot above the BFE. While Ike flooding did not enter the building (the flood level was reported to be just a few inches below the floor's walking surface), below-floor utilities were damaged by Ike and facility function was lost for a period of time. Critical facilities such as this should be elevated such that the floor system and all below-floor utilities are several feet above the BFE to reduce the likelihood of future flood damage and loss of facility use.

Another critical facility—a relatively new jail and criminal justice complex—was flooded during Hurricane Rita and was flooded again during Ike (18 to 24 inches of flooding was reported during Ike). The electronic equipment and controls for the jail security and communications systems were damaged during both Rita and Ike, and prisoners had to be transferred temporarily to a State facility. The 1985 FIRM (the most recent FIRM at the time of construction) showed the site in Zone C (outside the 500-year floodplain). This example points out that flood hazard evaluations for proposed critical facilities should involve more than reading an old FIRM; designs for proposed critical facilities should involve a careful assessment of potential damage and operational interruptions in the event that flooding exceeds the flood level shown on the FIRM. Self-audit guidelines have been published for existing correctional facilities and could also be used to help inform siting and design decisions for proposed facilities.

Given the nature of critical facilities, a higher level of flood protection is needed. Loss of facility function due to flood damage can have far-reaching consequences for community response, recovery, and reconstruction. ASCE 7-05 and ASCE 24-05 designate jails and detention facilities as Category III facilities, which require additional design consideration beyond building code requirements for typical commercial and residential construction. Correctional facilities should be located outside the floodplain or elevated to the 500-year flood elevation. If 500-year flood elevations are not available, elevate above the BFE with sufficient freeboard to prevent damage and loss of use. Some States have mandated special permit requirements and freeboard for correctional facilities located in or near flood hazard areas (e.g., Commonwealth of Pennsylvania, 2001). Federal agencies with involvement in funding, permitting, and constructing critical facilities are required to adhere to the requirements of Executive Order 11988, Floodplain Management (refer to Section 4.0 for additional information).

Equipment and Utilities. Critical facilities with equipment and utilities in basements, at ground level, or above ground but below the flood level, sustained flood damage to these support systems that either prohibited post-Ike resumption of operations, or delayed or reduced operational capabilities.

Mitigation Project Performance. The MAT observed critical facilities that had received Federal mitigation grant funds to address previous damage or known vulnerabilities. However, the mitigated facilities were still vulnerable, either to the hazard against which they had presumably been mitigated, or against other hazards.

6.2.2 Wind

All of the critical facilities exposed to Hurricane Ike were subjected to wind speeds that were less than the design wind speeds given in ASCE 7-05. Hence, while most of the critical facilities observed by the MAT experienced relatively little or no wind damage, had Hurricane Ike delivered current design wind speeds, poor wind performance would have been likely at many of the facilities.

Many critical facilities in the area impacted by Hurricane Ike (as well as in other hurricane-prone regions of the United States and its Territories) have significant wind vulnerabilities and are therefore in need of mitigation. This is particularly the case with those facilities older than 10 to 15 years, when codes, standards, design, and construction practices did not adequately address wind, windborne debris, and wind-driven rain issues. Older buildings with significant vulnerabilities were observed by the Ike MAT.

The recommendations in FEMA 424, *Design Guide for Improving School Safety in Earthquakes, Floods, and High Winds* (January 2004), FEMA 543, and FEMA 577 were largely based on field observation research. The research was conducted on numerous critical facilities that were struck by nine hurricanes dating back to 1989. The buildings were exposed to wind speeds ranging from around 100 to 160 mph (peak gust, Exposure C at 33 feet). The majority of that research was conducted by FEMA teams. None of the Hurricane Ike MAT observations refuted the recommendations in FEMA 543 or 577. Hence, it is still believed that the recommendations in these design guides are valid. (Note: The wind recommendations in FEMA 424 are out of date—refer to the wind chapter in FEMA 543 for more current guidance on schools.)

The Hurricane Ike MAT observations revealed issues that led to new recommendations in Section 7.3 regarding roof drainage, flexible ductwork connectors, and emergency generators.

> In addition to providing redundancy for the emergency generator, another advantage to a back-up generator is that it can be sized to carry electrical loads that are truly needed for long-term functioning of a facility. For example, at the hospital discussed in Section 4.2.2, the emergency generator only carried the minimum loads required by code—the generator did not power the HVAC system.

Emergency Generators. Maintaining adequate power during and after a hurricane is vital to the functioning of many critical facilities. The Ike MAT observed several notable deficiencies.

Location and Protection. In general, the MAT observed a lack of protection of emergency generators from wind and windborne debris at the vast majority of critical facilities that were observed. The majority of the generators were located outdoors and were susceptible to wind and windborne debris damage. For critical facilities that need to be operational during a hurricane, it is beneficial to house the generators within a building. The advantage of doing so is that if there is an equipment failure, repairs can be performed during the storm. Conversely, when generators are located outdoors, it is often unsafe to work on them during an event. Also, when housed within a building that is resistant to wind, windborne debris, and tree-fall (as recommended in FEMA 543 and 577), the generator is protected from these hazards (Figure 6-3).

Figure 6-3.
The tree shown by the red line nearly fell on the hospital's emergency generator (red arrow). The tree hit and damaged a metal roof that was over the compressed gas cylinders (blue arrow).

For critical facilities where a total loss of power for several days is tolerable (for instance, a community center that serves to house emergency workers brought in after a storm), it can be appropriate to save money and locate the generator outdoors. For facilities where loss of power is not tolerable (such as hospitals and EOCs), however, it is very unwise to place them outdoors or in enclosures that lack sufficient wind and windborne debris resistance.

Generator Capacity and Redundancy. Code requirements for emergency generators generally provide adequate capacity for life-safety equipment, essential equipment, and power required for the orderly shut-down of critical operations. However, the amount of emergency power required for a facility to provide needed services during a prolonged power outage generally exceeds that dictated by code. For critical facilities where power for some services cannot be interrupted (such as hospitals and EOCs), additional generator capacity, beyond that dictated by code, is needed. For example, most codes and standards do not require air conditioning to be powered by emergency generators. However, temperature and humidity levels can rise rapidly in critical facilities located in hurricane-prone regions if air conditioning equipment is not supplied by emergency power, thereby preventing performance of many critical functions.

> To help ensure the reliability of emergency and back-up power, it is important that generators be well maintained and tested frequently. Also, for critical facilities that need to be functional during a hurricane, it is important to have maintenance personnel on site during the event so that if the emergency power generation system malfunctions, repairs can commence immediately. For example, on-site maintenance personnel were instrumental in the quick restoration of emergency power at the EOC discussed in Section 4.3.1.

For critical facilities that must remain operational during prolonged power outages, provisions should be made to supply adequate generator power for operations during and after a hurricane. Providing power from two or more generators offers benefits and should be considered for critical facilities where loss of power is not tolerable. However, for critical facilities where loss of power for several days is tolerable, it can be appropriate to save money by not installing multiple generators.

Having multiple generators provides several advantages. When power is supplied from multiple generators, each generator is not a redundant back-up unit, but rather a power source that can be operated alone or in conjunction with other generators to provide power. In addition, having multiple generators improves reliability. During an event when municipal power is disrupted, facilities with two or more emergency generators do not have to rely on a single unit for emergency power. This is especially important during long-duration outages that can overstress generators designed for periodic short-duration operation. Having multiple emergency generators also facilitates maintenance, as individual units can be taken out of service to perform periodic maintenance without denying the facility its emergency power source.

When a facility has only one generator, the facility will be left without power if there is loss of municipal power and if the sole emergency generator fails. This scenario occurred at a hospital observed by the Ike MAT. With the failure of the single emergency generator, the entire facility had to be evacuated for 4 days until a temporary portable generator could be brought to the site. The MAT observed only a few critical facilities that had multiple generators.

Aggregate-Surfaced Roofs. The MAT observed some critical facilities (including a hospital and nursing home) that had aggregate-surfaced roofs. Even winds of about 100 mph (peak gust, Exposure C at 33 feet) are sufficient to blow aggregate from BURs with sufficient momentum to break glazing. Also, windborne aggregate can pelt people arriving at shelters or hospitals during a hurricane. Even though the potential hazard of windborne aggregate is well documented and significant, many owners of critical facilities apparently fail to understand the importance of mitigating this potential hazard.

Mitigation Project Performance. All of the HMGP work observed by the MAT failed to address all wind vulnerabilities. In seeking to reduce damage from hurricanes, building owners do not always understand or address all the vulnerabilities of the building. The MAT observed many instances where only some of the building's vulnerabilities to disaster damage had been addressed.

The MAT observed a number of buildings where mitigation projects had been accomplished that addressed one vulnerability but left other vulnerabilities unaddressed. Obviously, before implementing a mitigation project, it is important to fully evaluate vulnerabilities. While it may not be appropriate to address all of the significant vulnerabilities, if all vulnerabilities are not mitigated, that decision should be a conscious one based on deliberation and consideration of residual risks.

The MAT also observed a lack of thoroughness and robustness in mitigation efforts. For example, putting on a new roof system that lacks a secondary membrane or reroofing work that does not adequately anchor rooftop equipment. Roof membranes are frequently punctured by windborne debris. When this occurs, water will leak into the building unless a secondary membrane is incorporated into the roof assembly. Blow-off of rooftop equipment also frequently occurs and results in water leakage.

Prior to the publication of FEMA 543 and 577, there was very limited design guidance on mitigating wind vulnerabilities. Hence, those HMGP projects that were implemented before these guides were published were handicapped by lack of guidance. However, with the publication of FEMA 543 and 577, there are extensive recommendations on a variety of issues. Some of the recommendations are quite conservative, and in some cases it could be appropriate to not implement all of them. However, if a FEMA 543 or 577 recommendation is not implemented, that decision should be based on deliberation and consideration of residual risks.

6.3 Houston's Central Business District

The MAT observed various types of building envelope damage at several buildings in Houston's central business district. Although Hurricane Ike's winds were not as high as the current design wind speed, some buildings received extensive exterior envelope damage, particularly to glazing and roof coverings.

Aggregate-Surfaced BURs. Twenty-five years ago, aggregate blow-off during Hurricane Alicia caused extensive and expensive glazing damage in Houston. Therefore, it was surprising to observe that there were still aggregate-surfaced BURs in the area (see Chapter 5). Because wind speed increases as the roof height increases, the risk of aggregate blow-off also increases with roof height. It was therefore particularly surprising to observe aggregate surfacing on mid-rise buildings (such as those shown in Figure 6-4), where their presence presents enhanced opportunity for damage to surrounding buildings.

To avoid aggregate-induced glazing damage in urban areas in hurricane-prone regions, aggregate should be removed from built-up and sprayed polyurethane foam roofs.

Figure 6-4.
Aggregate-surfaced BURs on two mid-rise buildings on the periphery of Houston's central business district. The roof membrane blew off the penthouse roof, shown by the blue arrow (Figure 5-19 inset shows building locations).

Pedestrian Protection. In downtown Houston, the MAT observed remnants of unprotected broken glass several floors above grade at a few buildings (as illustrated by the inset at Figure 5-26). Those remnants had the potential to be dislodged during light winds and cause injury. At the time of the observations, many pedestrians were in the area. However, some building owners had taken quick action to mitigate the injury potential. For example, as discussed in Section 5.3.1, one building owner retained a company to install temporary film over the broken glazing as a safety precaution to avoid falling shards of glass. That appeared to be a prudent course of action. Boarding up windows can also be effective, provided it is done before people return to the downtown area.

Vegetative Roofs. As discussed in Section 5.4, the MAT observed three vegetative roofs. A decade ago, vegetative roofs were seldom installed in the United States. Although this type of roof system only captures a small percentage of the current inventory of roofs, over the past few years there has been great increase in interest, awareness, and installation of this type of system. Unfortunately, currently there are no consensus design guidelines or building code requirements pertaining to their wind performance. Although no wind-related problems related to these vegetative roofs were observed by the MAT, wind-blown tree limbs are capable of breaking glazing, and there is potential for scour of the soil media. Also, for those systems that employ trays, there may be potential for tray blow-off. The wind vulnerability of vegetative roofs needs to be better understood and dealt with via design guidelines and code criteria before large numbers of vegetative roofs are installed in hurricane-prone regions.





7 Recommendations

The recommendations in this report are based on the observations and conclusions of the MAT.

These recommendations are intended to assist the States of Texas and Louisiana, communities, businesses, and individuals in the reconstruction process, and to help reduce future damage and impacts from flood and wind events similar to Hurricane Ike. The recommendations will also help FEMA assess the adequacy of building codes and standards as they relate to flood hazard mapping and floodplain management requirements, and determine whether changes are needed or additional guidance is required.

In addition to these recommendations, several of the recommendations in the MAT report on Hurricane Katrina (FEMA 549) are also applicable. Specifically, most of the public outreach recommendations apply equally to Hurricane Ike.

7.1 Residential

The recommendations that follow are based on the MAT observations discussed in Sections 3.1 and 3.2, and the conclusions presented in Section 6.1.

7.1.1 Flood

Scour Around Foundations. Unexpected levels of foundation scour were observed between Surfside Beach, TX, and Holly Beach, LA. The local scour around building foundations greatly exceeded the vertical and lateral extents indicated by current design guidance. Damage from the scour was significant and widespread. Also, linear scour features that were likely associated with barrier island canals and roads were observed by the MAT. Numerous houses were undoubtedly affected by linear scour features, suffering either damage or destruction.

> ***Recommendation #1:*** FEMA should assist engineers and standards-writing organizations in developing new design and building code guidance that incorporates scour knowledge gained following Hurricane Ike.

> ***Recommendation #2:*** Coastal land development guidance and practices should be revised to minimize potential linear scour (and associated building damage), and building design and construction practices should be modified to account for potential linear scour effects.

> ***Recommendation #3:*** FEMA should study foundation scour in more detail during future post-storm investigations.

Building Elevation Relative to Flood Level. Much of the damage observed by the Ike MAT resulted from buildings not being adequately elevated to escape Ike's storm surge, waves, and flood-borne debris. Specific observations and conclusions, with related recommendations, follow.

BFEs shown on Effective FIRMs should not be used for reconstruction purposes in Ike-affected communities unless communities can demonstrate that Effective BFEs are adequate. Thousands of residential buildings were damaged or destroyed by Ike's flooding, many of them constructed at or above the Effective BFEs. New flood studies are underway in Louisiana and Texas; preliminary flood maps have been produced in parts of Louisiana, but Texas preliminary maps are not expected before the end of 2009.

Widespread damage outside the SFHA was observed; the Ike MAT recommends taking flood mitigation measures in the areas beyond the landward limit of the Effective SFHA, where there are likely to be no flood-resistant design and construction requirements (i.e., beyond Zone A and within Zones B, C, shaded X, or X), and in Zone A, which could experience Coastal A Zone or even Zone V conditions during a base flood.

> ***Recommendation #4:*** Until new DFIRMs are available and adopted, the MAT recommends requiring the following freeboard above the currently Effective BFEs for new construction, substantial improvements, and repair

ADDING FREEBOARD TO NEW CONSTRUCTION

A comprehensive study of freeboard (American Institutes for Research, 2006) demonstrated that adding freeboard at the time of house construction is cost effective. Reduced flood damage yields a benefit-cost ratio greater than 1 over a wide range of scenarios, and flood insurance premium reductions make adding freeboard even more beneficial to the homeowner. Reduced flood insurance premiums will pay for the cost of incorporating freeboard in a Zone V house in 1 to 3 years; in a Zone A house, the payback period is approximately 6 years.

of substantial damage: freeboard specified by ASCE 24-05, plus 3 feet. Once new DFIRMs are available and adopted, the MAT recommends requiring new construction, substantial improvements, and repair of substantial damage to be elevated to or above the freeboard elevation specified by ASCE 24-05.

Recommendation #5: Enforce Zone A design and construction standards in the area between the Effective SFHA landward limit and a ground elevation equal to the adjacent Zone A Effective BFE plus freeboard. This recommendation should be implemented before and following the adoption of new DFIRMs.

Recommendation #6: Enforce ASCE 24-05's Coastal A Zone design and construction requirements in areas presently mapped as Zone A on the Effective FIRM. This recommendation should be implemented before the adoption of new DFIRMs; following adoption, Coastal A Zone requirements should be adopted in the area between the LiMWA and Zone V.

Recommendations #4, #5, and #6 are illustrated in Figure 7-1.

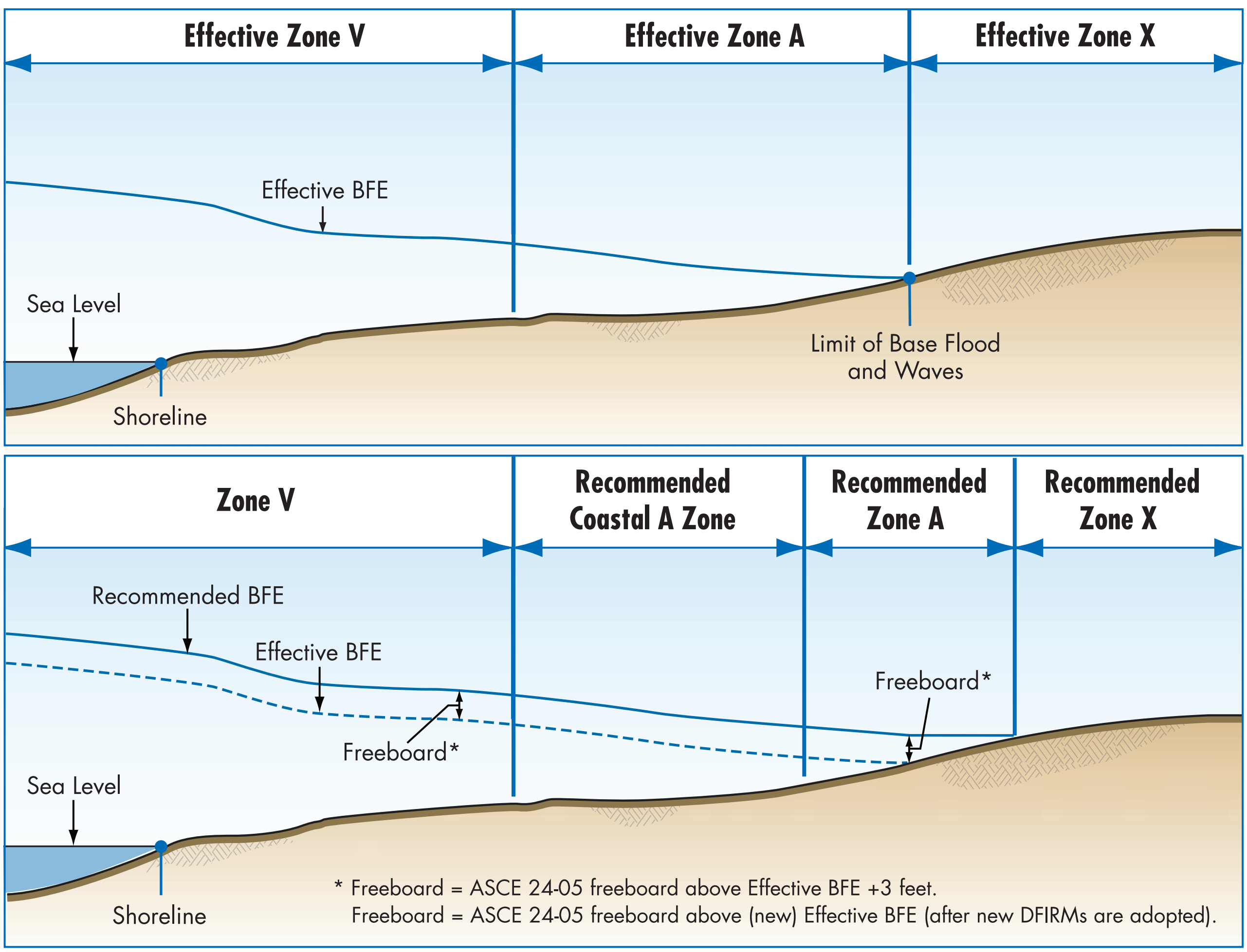


Figure 7-1. Comparison of Effective BFEs and flood hazard zones (upper figure), with MAT-recommended freeboard and flood hazard zones (lower figure)

Based on damage observed to NFIP-compliant buildings throughout the area affected by Ike, minimum floor elevation requirements in NFIP regulations (44 CFR section 60.3) are inadequate and allow flood damage in Zone A, particularly by allowing the top of the lowest floor to be set at the BFE.

> ***Recommendation #7:*** FEMA should review its lowest floor elevation requirements for consistency with the requirements contained in the national consensus standard ASCE-24, *Flood Resistant Design and Construction*, and in light of the recommendations contained in the *Evaluation of NFIP Building Standards* (American Institutes for Research, 2006). Specifically, FEMA should consider requiring freeboard such that the entire floor system is at or above the BFE for all flood hazard zones.

Even when buildings are elevated and constructed to meet minimum requirements, they are still vulnerable to flood damage when flood levels exceed the BFE.

> ***Recommendation #8:*** Property owners should be encouraged to design new and reconstructed buildings for flood levels above the BFE.

Some houses that were advertised as enhanced-code construction and intended to withstand greater-than-design level flood events sustained flood damage during Ike. Even though these buildings were elevated above the BFE, the MAT observed instances where scour and erosion exceeded the ability of the pile/column foundation to remain vertical, and instances where lateral loads and bending moments exceeded the material properties of the foundation piles/columns—the piles/columns cracked or broke.

> ***Recommendation #9:*** Enhanced-code houses should be designed for erosion, scour, and flood loads associated with flood levels above the BFE, not just elevated above the BFE on otherwise minimally flood-compliant foundations. Entities certifying enhanced-code houses should review foundation calculations before granting enhanced-code status.

Flood damage to commercial buildings was, for the most part, similar to flood damage to residential buildings.

> ***Recommendation #10:*** The MAT recommends elevating commercial buildings to the same levels and on the same types of foundations as called for in residential recommendations #4, #5, and #6. See also Section 7.3, Future Studies and Standards Revisions, recommendation #33.

Parking Slabs. A wide range of parking slab performance was observed by the MAT: a) unreinforced, frangible parking slabs collapsed, as intended, with no apparent harm to elevated houses or their foundations; b) unintended failure of non-frangible parking slabs led to timber pile failures at elevated houses where broken slabs remained connected to foundation piles and transferred loads to the piles that the piles could not resist—racked foundations and broken piles resulted; and c) intact but undermined parking slabs sometimes contributed to foundation and building settlement, by increasing scour around the foundation (as water flowed between the bottom of the slab and the eroded ground) and by placing additional vertical load on the foundations.

Recommendations #11: Coastal house foundations subject to scour and erosion should be designed to resist all loads imposed during coastal storm events, where possible, without benefit of parking slabs and grade beams to provide stiffness. Unreinforced, frangible parking slabs should be constructed under these houses when parking slabs are desired by the owner.

Recommendations #12: Where tall foundations cannot be constructed under coastal houses without added stiffness, grade beams with frangible slabs are preferred over structural slabs. This will minimize the weight that must be supported by an undermined foundation and minimize the potential of unintended load transfer from failed slabs to the foundation.

Siting. The widespread destruction and damage to houses situated closest to shorelines during Ike reinforced the principle that siting of buildings is critical to their survival during hurricanes. Siting of buildings close to eroding shorelines puts those buildings at risk and often results in erosion and flood damage to those buildings.

Recommendation #13: The State and local governments of Texas and Louisiana should encourage siting away from eroding shorelines; employ coastal restoration, where justified, to mitigate erosion effects; and acquire erosion-damaged properties and prohibit reconstruction on those properties.

Breakaway Walls. One unintended consequence of elevating houses above the BFE has been taller and taller solid breakaway wall panels, which provide larger and larger floodborne debris elements when they break away.

Recommendation #14: Lattice or louvers should be used instead of solid breakaway walls. Louver and lattice wall panels will remain intact longer than solid breakaway walls, resulting in less debris and less repair cost to homeowners. If solid breakaway walls are used, designers and owners should consider installation of flood vents in those walls. This may help to delay the failure of the walls, reduce floodborne debris, and reduce repair costs.

Manufactured Homes. Destruction of manufactured housing occurred during Ike, either because the homes were not elevated to or above the BFE (this may have occurred through proper use of the 3-foot pier exemption permitted in existing manufactured home parks, or by misinterpretation of this exemption), or because homes had not been installed on flood- and wind-resistant foundations.

Recommendation #15: All new and replacement manufactured homes should be elevated to or above the BFE using wind- and flood-resistant foundations such as those specified in NFPA 225-09. Manufactured home installations should follow the guidance contained in FEMA 85. Please note that the 1985 edition of FEMA 85 is currently under revision and is tentatively scheduled to be released later in 2009.

7.1.2 Wind

In the areas observed by the MAT, Hurricane Ike was not a design wind event; wind speeds ranged from 90+ mph[1] from the west end of Galveston Island to 110 mph on Bolivar Peninsula, 94 mph in downtown Houston, and 90 mph or less in other inland areas of Texas, 80 mph at the Texas-Louisiana border, to less than 50 mph east of Vermilion Parish, LA.

Structural. Though major wind damage to building structures was seldom observed by the MAT, wind damage to roof overhangs and sheathing was seen. This type of damage, though not pervasive, was seen from Galveston County to the affected Louisiana Parishes, including some enhanced-code construction homes.

> ***Recommendation #16:*** Roof overhangs of widths up to 2 feet are routinely designed using prescriptive standards. Roof overhangs in excess of 2 feet should be designed to withstand wind pressures calculated using ASCE 7-05 guidelines.

Asphalt Shingles. The MAT observed a substantial amount of wind-damaged asphalt shingles. To achieve good wind performance, shingles with sufficient wind resistance should be installed. TDI currently allows 110-mph-rated asphalt shingles (i.e., Class F) for all wind zones in the Designated Catastrophe Area. Products are currently manufactured to meet ASTM D 7158, which provides for testing and classification of asphalt shingles to meet 120-mph (Class G) and 130-mph (Class H) wind resistance.

> ***Recommendation #17:*** When asphalt shingles are used, it is recommended that TDI require the use of shingles complying with ASTM D 7158 Class G shingles in Inland (I) and Inland (II) and Class H shingles in the Seaward Zone.

Non-Load Bearing Walls and Wall Coverings. An extensive amount of envelope wall covering, primarily vinyl siding and fiber cement siding, was damaged by Hurricane Ike.

> ***Recommendation #18:*** Municipalities with building code authorities, along with TDI and their inspection program, should require that the installed products are on the approved and tested list and are installed in accordance to industry and manufacturer's recommendations for high wind zone installations.

Doors, Windows, and Shutters. Few impact-resistant glazed window units were observed by the MAT in either Texas or Louisiana, with homeowners and builders opting to use shutters to provide debris impact protection of building openings. TDI currently requires only homes located in the Seaward Zone and the Inland (I) to be protected by impact-resistant glazing or shutters.

---

1 All estimated speeds in this chapter are peak gust, Exposure C at 33 feet taken from *Estimates of Maximum Wind Speed Produced by Hurricane Ike in Texas and Louisiana* (ARA, 2008).

Recommendation #19: It is recommended that opening protection by TDI include Inland (II [110 mph]) within 1 mile of the coastal mean high water line where the basic wind speed is equal to or greater than 110 mph, which is consistent with ASCE 7-05 and IRC 2003 recommendations.

Roof Soffits, Fascias, and Gable Vents. Vinyl soffits and roof ridge ventilation systems frequently failed, thereby allowing water infiltration into the homes, causing damage.

Recommendation #20: The TDI and Building Inspection Program should ensure that vinyl soffits are installed in accordance to industry and manufacturers' recommendations for high wind zone installations. Ridge ventilation systems frequently allow wind-driven rain to enter the attic space and should not be allowed in Designated Catastrophe Areas.

Exterior-Mounted Equipment. All observed HVAC units mounted on the outside of the homes were elevated, per the guidelines in FEMA 55.

Recommendation #21: It is recommended that where railings are installed around elevated units, the railings either be removable or adequate space be provided on the platform to allow servicing of the units.

7.2 Critical Facilities

Critical facilities apparently continue to be designed and constructed without sufficient consideration of the guidance documents written to make critical facilities more hazard resistant.

Recommendation #22: Critical facilities should be designed in keeping with available guidance (FEMA 424, 543, and 577). Existing critical facilities should be audited using FEMA 424, 543, and 577 and retrofitted where appropriate.

Recommendation #23: Update FEMA 424, 543, and 577: See Section 7.3, Future Studies and Standards Revisions.

FEMA GUIDANCE FOR CRITICAL FACILITIES

FEMA 424, *Design Guide for Improving School Safety in Earthquakes, Floods, and High Winds*

FEMA 543, *Design Guide for Improving Critical Facility Safety from Flooding and High Winds: Providing Protection to People and Buildings*

FEMA 577, *Design Guide for Improving Hospital Safety in Earthquakes, Floods, and High Winds: Providing Protection to People and Buildings*

Mitigation Project Performance. Some critical facilities that had received Federal mitigation grant funds to address previous damage or known vulnerabilities were found to still be vulnerable, either to the hazard against which they had presumably been mitigated, or against other hazards.

Recommendation #24: Additional controls should be put in place by FEMA to ensure mitigation projects for critical facilities are properly designed and constructed/implemented.

7.2.1 Flood

Many of the critical facilities observed by the MAT were insufficiently elevated and vulnerable to flood damage. This was the case for most of the older buildings housing critical operations, but was also an issue for many recently constructed critical facilities.

Building Elevation Relative to Flood Level. New and replacement critical facilities continue to be located within the SFHA, and without freeboard.

> ***Recommendation #25:*** New and replacement critical facilities should be sited outside the 500-year floodplain, where possible; where not possible, the critical facilities should be elevated higher than the residential and commercial building elevations called for in Recommendations #4, #5, #6, and #10. At a minimum, critical facilities should be elevated above the 500-year flood level or the freeboard requirements of ASCE 24-05, whichever offers more protection to the facility.

Equipment and Utilities. The MAT continues to see critical facility equipment and utilities damaged by flooding as a result of insufficient elevation.

> ***Recommendation #26:*** Do not locate equipment and utilities in basements or ground levels of critical facilities. Locate these above the BFE-plus-freeboard elevation. If elevation of these components is not feasible for existing critical facilities in Zone A, evaluate dry-floodproofing of these areas to an elevation several feet above the BFE. If the building structure cannot accommodate flood loads associated with dry floodproofing to this elevation, consider relocating the critical facility or replacing with a new critical facility.

7.2.2 Wind

Most of the critical facilities observed by the MAT had wind vulnerabilities, some of which were quite significant. Vulnerable elements primarily pertained to building envelopes and emergency power, but for some facilities, the MWFRS were also susceptible to wind damage. The presence of large numbers of wind-vulnerable facilities has also been observed by MATs in other locations of the United States and its Territories. To avoid wind, windborne debris, and water infiltration damage that results in partial interruption of facility operations or entire evacuation of a facility after passage of a hurricane, the following are recommended:

> ***Recommendation #27:*** For existing facilities, perform a comprehensive vulnerability assessment of the MWFRS and building envelope. As part of the evaluation process, prioritize the identified vulnerabilities. FEMA 543 and 577 recommend such an evaluation regardless of building age for critical facilities located in hurricane-prone regions.
>
> The evaluation should also include assessing a facility's capability of coping with loss of municipal utilities (i.e., electrical power, water, sewer, and communications). FEMA 543 and 577 provide guidance on back-up systems and operations when loss of municipal utilities occurs, as well as guidance for performing remedial work on existing facilities.

If budget constraints prohibit timely evaluation of all critical facilities in a community, then the order of facility evaluation should be prioritized, commensurate with community needs and perceived vulnerability of the facilities. For example, EOCs, hospitals, and hurricane evacuation safe rooms are common high-priority facilities. These types of facilities would therefore normally be the type of facilities that would first be evaluated. However, if the local hospital was quite new and the community's fire or police stations were quite old, evaluation of the fire or police station would likely be of higher priority.

Upon completion of the evaluations of a community's facilities, the order in which remedial work will be scheduled should be prioritized.

Recommendation #28: The MAT recommends that design and construction of new critical facilities follow the guidance in FEMA 543 and 577 so that wind vulnerabilities are not built into new facilities. This approach is more cost effective than building to minimum codes and standards and then retrofitting a building in the future to decrease its wind vulnerability.

Emergency Equipment. The MAT observed critical facilities with significant wind vulnerabilities that were evacuated prior to hurricane landfall. However, in some instances (such as the fire station discussed in Section 4.3.4), equipment was not removed.

Recommendation #29: The MAT recommends that emergency supplies and equipment (such as fire trucks) also be evacuated, to the extent possible. Otherwise, building failure can damage supplies and equipment, thereby making them unavailable for post-storm response and recovery.

Mitigation Project Performance. As discussed in Sections 4.2.1, 4.3.2, 4.3.3, and 4.4.3, the MAT observed mitigation projects that were not sufficiently robust and/or were not sufficiently comprehensive.

Recommendation #30: Before a critical facility receives a grant from the HMGP or Pre-Disaster Mitigation Grant Program, it is recommended that a comprehensive vulnerability assessment be conducted. All significant wind vulnerabilities (including those related to interruption of municipal utilities) should be mitigated by the grant work, and for those that are not, the remaining residual risk should be recognized and documented.

Recommendation #31: It is recommended that the guidance in FEMA 577 be considered for healthcare facility mitigation projects, and that FEMA 543 be considered for all other critical facilities. Not all of the guidance is appropriate for all facilities, but if a recommendation is not implemented, that decision should be based on deliberation and consideration of residual risks.

Recommendation #32: It is recommended that a two-stage peer review be implemented for all projects. The first review should be made early in the design process to ensure that the scope and direction of the remedial work is fundamentally sound. The second review should be quite comprehensive, and should be conducted prior to bidding the construction work.

7.3 Further Studies and Standards Revisions

7.3.1 Flood

Observations by the Ike MAT revealed that additional studies, or implementation of existing study recommendations, will be required to improve design, construction, and siting practices for coastal buildings in the area affected by Ike.

> ***Recommendation #33:*** Determine the causes of and contributors to foundation scour observed by the MAT along the Gulf of Mexico shoreline between Surfside Beach, TX, and Holly Beach, LA. Incorporate any needed changes to foundation design and construction practice to minimize and counteract such scour.

> ***Recommendation #34:*** Gulf Coast States have ongoing shoreline erosion studies and coastal restoration initiatives (e.g., to characterize shoreline erosion, and to restore the habitat and storm buffer properties of marshes). Monitor the progress and review the findings of these studies and initiatives. Incorporate findings into flood hazard mapping procedures and into building siting, design, and construction requirements.

7.3.2 Wind

The Ike MAT expected to observe a high level of building and cladding performance, given that Ike's wind speeds were less than design levels. Though the MAT did not observe complete structural failure produced by Ike's winds, the poor performance of roofing materials and cladding systems are indicative of poor design, construction, and inspection practices.

Design, Construction, and Inspection for Disaster Resistance. Construction of buildings to meet the minimum disaster-resistance provisions of model building codes is necessary for sustainability of communities. Contractor knowledge of acceptable building practices, plan review and independent inspections are necessary to ensure disaster resistance. It is not clear that the current administrative processes for controlling building in unincorporated areas of Texas provide the same level of disaster resistance as building approaches taken by other States. A warranty to the owner of the building that it will perform well in future disasters provides little value in a future distant disaster event because of the lapse of time, change in owners, and builders being out of business.

> ***Recommendation #35:*** The State of Texas should evaluate its current approach in unincorporated areas and determine if it provides an acceptable level of disaster resistance and building quality.

Roof Systems. Based on Hurricane Ike observations, the MAT makes the following recommendations regarding aggregate surface roofs, asphalt shingles, and vegetative roofs.

Aggregate Surface Roofs. The MAT observed glazing that was damaged by windborne roof aggregate (Figures 5-25 and 5-26). In urban areas where there are mid- and high-rise buildings, the presence of aggregate surface roofs has great potential to cause a significant amount of glazing damage. Beginning with the 2006 edition, IBC prohibits aggregate surface roofs in hurricane-prone regions, but there are no requirements for removing existing aggregate. Therefore, the following are recommended in urban areas in hurricane-prone regions:

> Aggregate removal will normally necessitate replacement of the roof system. Consult with a qualified design professional or professional roofing contractor.

Recommendation #36: Remove existing aggregate from built-up and sprayed polyurethane foam roofs to avoid damage to other buildings from wind-blown aggregate.

Recommendation #37: For aggregate ballasted roofs, determine if the roof complies with the current edition of ANSI/SPRI RP-4 (available online at www.spri.org). If it does not, bring the roof into compliance with RP-4 or remove the aggregate.

Recommendation #38: It is recommended that criteria based on the two recommendations above be added to the ICC International Existing Building Code.

Asphalt Shingles. The MAT observed wind damage at several relatively new asphalt shingle roofs. However, because the labeling on the plastic strip on the underside of the shingles did not include wind resistance information, compliance with ASTM D 7158 could not be ascertained.

Recommendation #39: Asphalt shingle product standard ASTM D 3462 should be revised to require labeling the underside of each shingle with its wind resistance classification (i.e., D, G, or H as determined in accordance with D 7158). Doing so will facilitate future storm damage research by providing investigators information on the wind resistance rating of installed products.

Vegetative Roofs. The MAT observed three vegetative roof systems in downtown Houston. Although they were not damaged, nor did they cause damage to other buildings, they had the potential to do so.

Recommendation #40: The MAT recommends that a consensus wind design guideline and wind-related building code requirements be developed for vegetative roof systems. The following interim guidance is recommended: In hurricane-prone regions, trees and shrubs should not be planted more than approximately 30 feet above grade. (The higher the elevation, the greater the wind speed, and hence the greater potential for limb blow-off and damage to glazing.)

Non-Load-Bearing Walls and Wall Coverings. Based on Hurricane Ike observations, the MAT makes the following recommendations regarding non-load-bearing walls and wall coverings.

Recommendation #41: The TDI inspection program should ensure that cladding products are manufacturer-rated for the appropriate wind zones, and that the methods of installation are consistent with the manufacturer's recommendations. To improve the performance of the cladding system, as well as the overall strength of the house, it is recommended that TDI consider requiring that the exterior wall substrates of residences be fully clad with plywood or OSB sheathing so that the sheathing is capable of withstanding design wind pressures that produce both in-plane and out-of-plane loads. A fully sheathed house is more robust and resistant to water infiltration in the event of the loss of wall cladding or windborne debris impacts.

Windows and Shutters. The MAT observed interior water damage due to window leakage (Figure 7-2). The current minimum test pressures used to assess the resistance of windows to wind-driven rain are substantially below the design wind pressures. Hence, current minimum testing is inadequate to evaluate leakage potential during hurricanes.

Recommendation #42: It is recommended that the window/curtain wall industry re-evaluate the test pressures that are currently used to assess resistance to wind-driven rain.

Figure 7-2. Several windows at this house on Bolivar Peninsula leaked and wetted the carpet

The MAT observed a house under construction on Bolivar Peninsula (Figure 7-3) that had protected glazing in a breakaway wall. The breakaway walls and the window were destroyed by flooding. Currently, if a building is in a windborne debris region, ASCE 7, IBC, and IRC require protected glazing, including the glazing in breakaway walls. However, if the walls break away because of flooding, the windows will likely be destroyed as shown in the inset in Figure 7-3.

Recommendation #43: Because glazing in breakaway walls is far more susceptible to flood damage than windborne debris, it is recommended that an exception be added to ASCE 7, IBC, and IRC that would allow the glazing in breakaway walls to be unprotected. Such an exception would reduce the cost of providing protected glazing, yet would not significantly increase the risk of damage.

Figure 7-3.
The breakaway walls at this house were destroyed. The inset shows a window with laminated glazing that was washed away with the walls. Using protected glazing on the upper-level windows is logical, but protected glazing is of little value in breakaway walls.

7.3.3 Critical Facilities

Schools. The MAT observed schools in need of mitigation. FEMA 424 provides design guidance for new and existing schools, but the guidance is out of date.

> ***Recommendation #44:*** It is therefore recommended that the flood and wind chapters be updated to incorporate the applicable guidance in FEMA 543, as well as the new provisions presented in Recommendation #45 below.

Critical Facility Guidance. The MAT observed various types of critical facilities in need of mitigation. FEMA 543 and FEMA 577 provide guidance for new and existing facilities.

> ***Recommendation #45:*** Based on Hurricane Ike observations, it is recommended that the wind chapters in these two guidance documents be updated to incorporate the following conceptual guidance:
>
> **Roof Drainage.** Roof drains and scuppers have the potential to be blocked by leaves, tree limbs and other windborne debris during a hurricane. If primary and overflow drains/scuppers become blocked, development of deep ponding water may inundate base flashings and

cause leakage problems or lead to roof collapse. To avoid problems with blocked drains and scuppers, the following are recommended:

- *Scuppers* – Only a relatively small scupper is needed to drain a large roof area, provided the scupper opening is not blocked by debris. However, since small openings are more easily blocked than larger openings, it is recommended that scupper openings be much larger than normal. It is recommended that scupper openings be a minimum of 24 inches wide and 16 inches high. In addition, it is recommended that the distance between scuppers be such that, in the event a scupper becomes blocked, the adjacent scuppers have sufficient capacity to drain the roof.
- *Roof drains* – Avoiding blockage of drains is more problematic than avoiding blockage of scuppers. Drain lines need to be protected by domes to prevent debris from flowing into the lines and blocking them. For domes to be effective in protecting drain lines from blockage, the dome openings must be relatively small. To provide overflow protection, it is recommended that overflow scuppers be provided. Where drainage patterns necessitate that overflow protection be provided by overflow drains (rather than, or in addition to, overflow scuppers), it is recommended that additional overflow drains be installed. By doing so, if both a main drain and its nearby overflow drain become blocked, the additional overflow drain in the vicinity can provide drainage and avoid roof collapse.
- *Maintenance* – As part of pre-storm preparations, drains, scuppers, and gutters should be cleaned of debris in order to maximize their effectiveness in draining the roof and minimize the potential for their blockage during a hurricane.

Flexible Connectors. Flexible connectors between rooftop ductwork and fans may leak (as discussed in Section 4.2.3) if they are in a deteriorated condition prior to a storm or if they are punctured by windborne debris. FEMA 543 and 577 recommend placing mechanical equipment in a penthouse to avoid these types of problems. However, if equipment is exposed, the following are recommended:

- Because of their small size, the potential for a flexible connector to be punctured by windborne debris is typically very low. However, if site-specific conditions present an unusually high potential for debris damage, it is recommended that the flexible connectors be protected by equipment screens or a custom-designed shield.
- As part of annual roof inspections prior to hurricane season, it is recommended that all flexible connectors be inspected. Those found to be in a weathered condition (e.g., cracked, torn, or embrittled) should be immediately replaced.

Emergency Electrical Power. Hurricanes often cause widespread and prolonged interruptions of municipal power. Hence, because reliable power is essential to operating most critical facilities, they need emergency generators. Current codes and standards do not require emergency generators for all critical facilities and functions, nor are the requirements sufficient to ensure reliable power during prolonged power outages. In the aftermath of Hurricane Ike (as well as previous hurricanes), some critical facilities (including hospitals) had to be evacuated because of lack of power. It is for this reason that FEMA 543 and 577 provide a number of recommendations pertaining to generators.

Recommendation #46: Based on the Ike MAT's observations, FEMA 543 and 577 should be updated as follows:

- Currently, the guidance on electrical power does not differentiate between those critical facilities where power for some services cannot be interrupted (such as hospitals and EOCs) versus those where loss of power for several days is tolerable (for instance, a community center that serves to house emergency workers brought in after a storm). The current guidance to provide standby generator(s) in addition to the emergency generator(s), as well as devices to allow quick connection of portable generators, is overly conservative for facilities where loss of power for several days is tolerable. The current guidance to house generators in wind- and windborne debris-resistant enclosures is also overly conservative for facilities that can tolerate loss of power. The guidance should be differentiated based on the ramifications of loss of power to facility operations.
- The MAT observed several critical facilities that had generators fired by natural gas. One community had great success with this fuel source. Use of natural gas alleviates various potential problems associated with on-site storage of diesel fuel (such as adequate quantity of fuel for prolonged outages). However, at a facility observed by the MAT (discussed in Section 4.4.1), the natural gas supply was shut down by the gas supplier leaving the facility without power. Neither FEMA 543 nor 577 discuss natural gas-fired generators. It is recommended that this fuel type be added to the discussion, along with guidance regarding potential interruption of gas service (such as providing a diesel fuel back-up generator).
- Guidance should be developed to determine what loads need to be supplied with emergency or standby power to enable facilities to provide services needed for operations during and/or after a hurricane.

SELF-AUDIT

A self-audit of a critical facility can help identify equipment that is essential to facility operations, but vulnerable to disruption by a natural hazard. The emergency plan should be reviewed periodically and revised as necessary.

When completing this audit for electrical power, the building owner should:

1. Determine possible restoration times for municipal power during a natural disaster (restoration times will be significantly longer than those caused by more common causes of power disruption)
2. Determine emergency power and fuel source based on restoration time
3. Determine how electrical equipment that is vulnerable to flood, wind, or windborne debris damage should be modified or relocated
4. Determine what other equipment (not currently on emergency circuits) might be needed when restoration times are longer
5. Consider how portable emergency generators and switchgear will be connected if/when required

Supplemental Emergency Power Recommendations. Many generators that are used for meeting the power demands from outages are intended to provide power for a relatively short duration. These standby generators are typically designed to supply power for a minimum of a few hours to a maximum of several days, not durations of a few weeks that often follow a hurricane. Standby generators often lack redundant control systems, redundant ancillary systems like fuel filters, adequate on-site fuel storage, and redundant capacity in their cooling systems. These limitations don't significantly affect generator reliability if generators are run for short periods of time, but can greatly affect reliability if the generators are required to operate for several weeks.

Prime-power generators, on the other hand, are designed to operate indefinitely. Their nameplate ratings are typically 15 to 20 percent lower than standby units (e.g., a 1,000 KVA standby generator will have a prime-source capacity of around 800 KVA). With prime-source units, more attention is given to maintenance under load and typically at least two units are specified to allow periodic shut-downs for maintenance. This additional capacity helps alleviate overheating and improves reliability. Redundant ancillary systems (like fuel pumps and filters) allow some components of the on-site power systems to be serviced while the system is operating; this type of maintenance can greatly increase system reliability. FEMA 543 and 577 recommend the use of prime-power generators.

Power Quality. The quality of electrical power provided by on-site generation can also be a concern. While this is generally not a problem with larger fixed generators, power quality can be problematic for smaller generators (particularly smaller generators operated near their capacity) and for portable units. Voltage control and frequency control are particularly critical.

Sizing and Vulnerability. To be effective, all emergency power systems must be properly sized and be less vulnerable than the utility power system. Generators, transfer switches, fuel supplies, and control equipment should be protected from wind, windborne debris, and flooding, as recommended in FEMA 543 and 577. Generator sizing should take into account all loads required for the critical facility to function. While not required from a life-safety standpoint, mechanical equipment for temperature and humidity control should be considered critical equipment. In many hurricane-prone regions, temperature and humidity levels can increase rapidly to the point that they severely limit or prevent the delivery of critical functions. In new or renovated facilities, energy efficient equipment, such as high efficiency lighting, can be specified to reduce loads on emergency power sources. Alternative power sources, such as wind turbines or photovoltaic cells, should not be relied upon unless they are designed to resist high winds, windborne debris, and flooding.

Temporary Generators. Temporary generators may be appropriate options for supplying power during prolonged power outages for those facilities that can tolerate loss of power until the temporary generator becomes operational. Temporary generators have the benefit of not requiring the capital expense of on-site emergency generators. If temporary generators are selected to provide power, the following issues should be considered:

- *Availability of generators* – Arrangements must be made before the event to ensure adequately sized generators are available when needed.

- *Off-loading requirements* – When generators are not trailer mounted, provisions must be available to off-load the generators on site.
- *Fuel availability* – Large generators require great amounts of fuel. Facilities need to ensure that adequate amounts of fuel are available.
- *Connection to the facility* – Methods to connect temporary generators to the facility should be installed before the event. Quick disconnects with manual transfer switches (often referred to as cam locks) should be installed. The connection point should be close to the generator location to reduce voltage drop that can result from long cables.
- *Capacity and quality of power* – The generators must be large enough to serve the requirement loads (i.e., they must be large enough to start the largest motor when operating all other loads) and the quality of the power must be sufficient to prevent damaging facility equipment.

Operation and Maintenance Staff. Temporary generators require maintenance and periodic testing and monitoring. Knowledgeable staff must be available to provide those services.

7.4 Building Codes

In Sections 7.2 and 7.3, the MAT has made specific recommendations on design, construction, and inspection to improve the disaster resistance of buildings. Some of the recommendations contained in this report are incorporated by reference into recent editions of the International Building Code and International Residential Code. It is recommended that state and local officials adopt and enforce a recent edition of a model building code – keeping intact the minimum criteria established by the parent or expert document such as ASCE-7 or ASCE-24. It is also recommended that the MAT's enhanced code recommendations be reviewed carefully. States and communities should consider adopting some of these recommendations, and designers, builders, and owners should consider voluntary implementation in cases where they are not adopted by government authorities.

Janice Olshesky

HURRICANE IKE IN TEXAS & LOUISIANA

8 Planning for a Sustainable Coast

The Galveston Bay region has been struck repeatedly by hurricanes in the past and will be again in the future. Reconstruction efforts and future development that consider and address the risks will result in communities that have fewer impacts and recover more quickly from future hurricanes. Rehabilitation and reconstruction should incorporate regional strategies that meet the needs of the area's residents and businesses. Chapter 8 addresses general planning approaches.

One of the most critical aspects of establishing sustainable building practices is effective community and regional planning that takes into account the existing geological hazards and the importance of protecting the natural environment. This chapter presents some of the issues that coastal communities face.

Hurricane Ike caused severe damage, leveled many homes, and destroyed a significant amount of infrastructure. In areas where the majority of the buildings were leveled, communities are offered an opportunity to rethink their coastal planning strategies. Rebuilding exactly as before will result in similar or worse damage in future hurricanes. Rather than attempting to rebuild what was there, the residents of these areas have an opportunity to thoroughly evaluate the coastal areas, and develop a responsible approach for their reuse. Taking a holistic view of the land and the environmental conditions that affect it will increase the probability of achieving a more sustainable result.

"Before crossing the northern Gulf Coast, the counter-clockwise circulation of hurricane wind drives nearshore currents and large volumes of beach and shoreface sand alongshore. High tides, large waves, and strong currents that accompany the storms can leave semi-permanent marks on the barrier islands and beaches." For example, Hurricane Allen (1980) reoccupied more than 60 washover channels through South Padre Island, TX, destroying the main road that runs the length of the island in several places (Morton et al., 2004).

Models for community planning and housing design have changed over the last 50 years. For example, 50 years ago wetlands and marsh areas were not considered important. Over the past 40 years, there has been a growing appreciation of the pivotal environmental role wetlands and marshes play in helping to buffer storms from damaging the built environment. Community planning and building design paradigms are shifting based on current research and studies, and it is vital to disseminate this knowledge to communities to help them plan for a more sustainable future.

The first step in any effective urban planning or land-use planning is to perform a comprehensive evaluation of the site, including a complete understanding of the natural conditions and the forces acting on the site by the surrounding environment. The Gulf Coast ecosystem is dynamic, constantly changing due to the continuous and relentless ocean forces, and subject to drastic modifications during the occasional violent storm. The information that follows is intended to provide some guidelines and a description of some of the issues that coastal communities face.

8.1 Geologic Hazards and Coastal Communities

8.1.1 Geologic Hazards That Threaten Coastal Communities

Southwestern Louisiana and southeastern Texas are in the Chenier Plain, which is the western extension of the Mississippi Delta. The physical characteristics and geologic framework of the Chenier Plain, mainland beaches, barrier islands, and tidal inlets partly determine the trends and rates of shoreline movement and related coastal changes for the region (Morton et al., 2004). There are four external factors that exacerbate the already difficult environment. These include: 1) ground subsidence due to oil and gas withdrawal, groundwater pumping, and consolidation of subsurface soils; 2) rising relative sea levels (almost 1 foot, 8 inches [0.5 meter] in the past century); 3) increasing shoreline erosion resulting from human intervention in the natural system; and 4) destruction of the protective coastal dunes, saltwater marshes, and wetlands.

8.1.1.1 Subsidence and Relative Sea-Level Rise

RELATIVE SEA LEVEL

"At any coastal site the relative sea level includes the global sea-level component (eustasy), tectonic uplift or down warping, and at some locations subsidence that is the result of natural sediment compaction or subsidence induced by the withdrawal of subsurface fluids such as groundwater, oil, and natural gas." (Morton et al., 2004)

The effects of subsidence and rising sea levels are not easily differentiated. According to a USGS report, *National Assessment of Shoreline Change: Historical Shoreline Changes and Associated Coastal Land Loss Along the US Gulf of Mexico* (Morton et al., 2004), measurements on Galveston Island, TX, and Grand Isle, LA, show a relative rise in sea level of about 1 to 2 feet (0.3 to 0.6 meter) during the twentieth century, a rate approximately three times faster than the average global rise in sea level (0.6 foot [0.18 meter] per century). The relative rise in sea level is composed of both sea level rise and subsidence. Subsidence occurs as both a natural process and as a result of human activities. In southeast Texas, subsidence is attributed to natural processes, compaction of sediments, and historic withdrawal of groundwater. Most southeast Texas municipalities have now switched to surface water supplies (Ray Newby, personal communication). In Louisiana, subsidence is attributed to groundwater withdrawal and natural sediment compaction (Gabrysch, 1984). An additional manmade cause is that sediment supply to the Mississippi River delta plain has been artificially reduced by controlling the Mississippi River and preventing it from flowing into the Atchafalaya Basin. In addition, recent studies have suggested that hydrocarbon production has been partly responsible for accelerated subsidence and wetland loss (Morton et al., 2004).

Figure 8-1 illustrates the steady rise in sea level at various locations along the Gulf of Mexico. Grand Isle, LA, experienced the steepest increase, with sea level rising about 1 to 2 feet during the twentieth century. Galveston has also experienced one of the steepest increases, with sea level rising about 1 to 2 feet (0.26 foot/year [6.5 mm/year]) during the twentieth century.

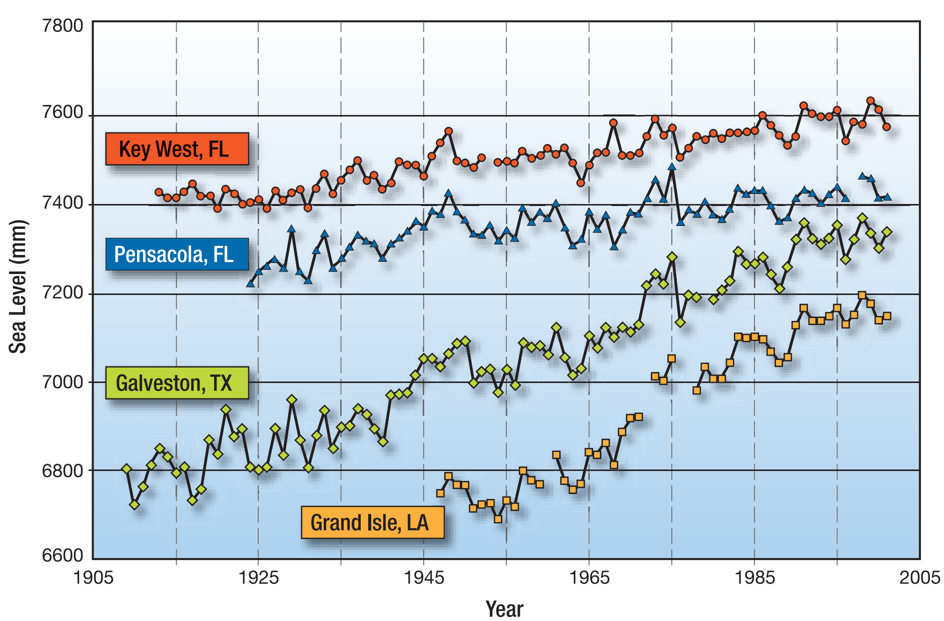


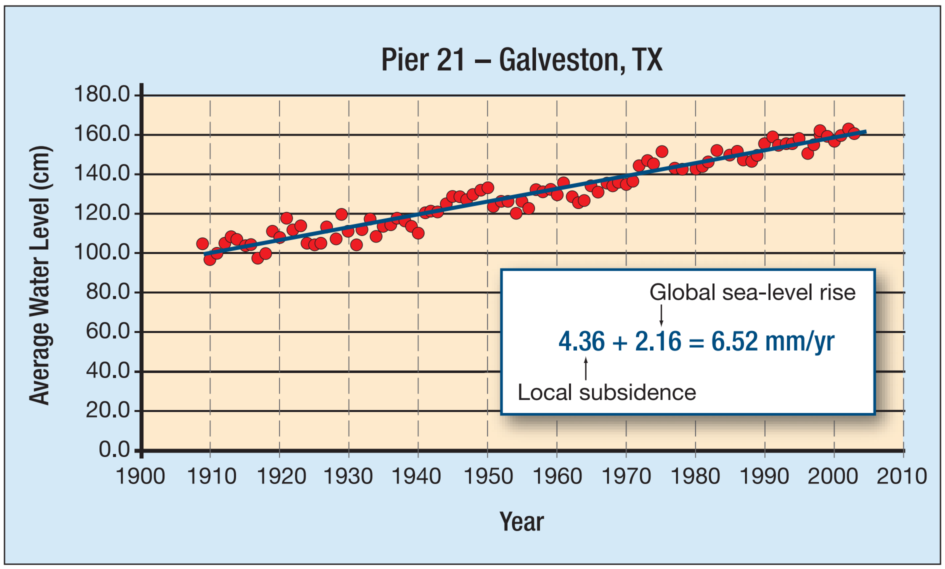
Figure 8-1. Long-term trends in average annual sea level at selected tide gauges in the Gulf of Mexico

SOURCE: MORTON ET AL., 2004

Topographic lines shown on USGS Circular 1182 indicate that Galveston has experienced approximately 1 foot of subsidence over the past 100 years (Galloway et al., 1999). Bolivar Peninsula has likely experienced similar subsidence, as it is on the southeastern edge of the Houston area subsidence bowl (Ray Newby, personal communication). Texas City has experienced 4 feet of subsidence. The east side of Houston, in the Baytown area, has experienced up to 10 feet of subsidence. A recent study conducted by the Harte Research Institute for Gulf of Mexico Studies identifies a 2-foot, 2-inch relative sea level rise at Pier 21 on Galveston over the past 100 years (Yoskowitz and Gibeaut, 2009). The authors attribute 8.5 inches (0.216 meter) of the relative sea level rise to global sea level rise and 1 foot, 5 inches (0.436 meter) to local subsidence (Figure 8-2).

Figure 8-2. Relative sea level rise at Pier 21, Galveston, TX

SOURCE: YOSKOWITZ AND GIBEAUT, 2009



The average global rate of sea level rise for the past century has been 0.6 foot (Morton et al., 2004). NOAA/National Ocean Service's (NOS) Center for Operational Oceanographic Products and Services (CO-OPS) collects and distributes observations and predictions of water levels and currents to ensure safe, efficient, and environmentally sound maritime commerce. Table 8-1 presents increases in sea level predicted for the next 100 years based on available data from 1957 to 2006.

Table 8-1. Predicted Sea Level Increases

Location	NOAA Station #	Trend based on monthly mean sea level data	Based on Data range	Change in 100 years
Galveston Pleasure Pier, TX – Gulf side of Galveston Island	8771510	1/4 inch (6.84 mm) per year with a 95 percent confidence interval of +/- 0.81 mm/year	1957 to 2006	2.24 feet
Galveston Pier 21, TX – Bay side (west) of Galveston Island	8771450	1/4 inch (6.39 mm) per year with a 95 percent confidence interval of +/- 0.28 mm/year	1908 to 2006	2.10 feet
Freeport, TX – west of Surfside Beach	8772440	5/16 inch (4.35 mm) per year with a 95 percent confidence interval of +/- 1.12 mm/year	1954 to 2006	1.43 feet
Grand Isle, LA	8761724	11/32- inch (9.24 mm) per year with a 95 percent confidence interval of +/- 0.59 mm/year	1947 to 2006	3.03 feet
Eugene Island, LA	8764311	3/8 inch (9.65 mm) per year with a 95 percent confidence interval of +/- 1.24 mm per year	1939 to 2006	3.17 feet
Average global sea level rise	Various. NOAA samples throughout the world, from Iceland to Japan	1/16 inch (1.8 mm) per year	Various. Oldest is 1832 (Sheerness, UK); most recent are typically 2006	0.6 foot

SOURCE: NOAA TIDES AND CURRENTS, http://tidesandcurrents.noaa.gov/sltrends/msltrendstablefc.htm

Grand Isle and Eugene Island, LA, are the highest and Galveston is the second highest of all the U.S. Coastal Stations NOAA is taking readings from. The average global sea level rise is only 0.6 foot. NOAA cites the Intergovernmental Panel on Climate Change (IPCC) Report, which estimates that the global sea level rise was approximately 1.7–1.8 millimeters per year over the past century (IPCC, 2008) based on tide station measurements around the world.

Sea-level rise needs to be considered when planning new houses, businesses, critical facilities, new communities, and during future renovation along the southeast coast of Texas and southwest coast of Louisiana. This is especially true for these areas, as they are experiencing significant sea-level rise compared with other coastal areas monitored by NOAA stations throughout the United States.

8.1.1.2 Shoreline Erosion

The upper Gulf Coast of Texas, which includes Galveston Bay and Bolivar Peninsula, is experiencing significant erosion, submergence, and wetland loss (Morton et al., 2004). Erosion of the Gulf shoreline at Bolivar Peninsula and Galveston Island has threatened numerous buildings in several beachfront communities. Small beach fills have been implemented, and geotextile tubes have been placed by Galveston County and private entities on the public beach to protect residences (Figures 8-3 and 8-4).

**Figure 8-3.
Broken geotextile tube at Beachside Drive, Galveston Island, TX**

**Figure 8-4.
Broken geotextile tube at Beachside Drive, Galveston Island, TX**

As of January 2009, surveys at selected locations indicated that Hurricane Ike eroded an estimated 50 to 150 feet of lateral shoreline on Galveston Island, from just west of the Galveston seawall to approximately 6 miles west, and 50 to 100 feet of lateral shoreline on Bolivar Peninsula. Additionally, surveys indicated that an estimated 5 to 10 feet of vertical loss due to shoreline erosion occurred on Galveston Island, west of the Galveston seawall (Dr. John Anderson and Ray Newby, personal communication).

According to the USGS assessment report (Morton et al., 2004), long-term rates of shoreline retreat along the Texas Gulf Coast have been measured up to 48 feet per year. Erosion rates of Gulf beaches in Texas are highest between Sabine Pass and High Island and downdrift (southwest) of the Galveston Island seawall. The most stable or accreting beaches in this area are on southwestern Bolivar Peninsula. Although short-term erosion rates are experienced by only 48 percent of the shoreline, the average short-term erosion rate of 8.5 feet per year is higher than the long-term rate, indicating accelerated erosion in some areas.

In the past decades, installation of jetties and seawalls/groins have affected the shoreline on the barrier island (Figure 8-5). Sand accumulates on the south side of the south Bolivar Roads jetty on Galveston Island, and established foredunes are abundant in that area. West of the 10-mile-long Galveston Island seawall and groin (constructed to protect the City of Galveston from storm events), the beaches are retreating, with rates of erosion at the west end of the seawall reaching 12 feet per year.

Figure 8-5.
West end of the seawall at Galveston, TX. The concrete ramp (right foreground) was the road leading to the beach in the mid-1960s. Since then, the beach has eroded more than 492 feet.

SOURCE: MORTON ET AL., 2004

8.1.1.3 Dunes and Wetland Loss

Dunes are an important natural resource for Galveston County and Chambers County, helping to protect the Texas coast from storms and flooding by dissipating the wave action of hurricanes. The dunes are dynamic, in constant change, and part of a natural cycle that stores sand and ensures the health of the beaches. Sand for the Gulf Coast barrier islands and beaches comes from eroding mainland shores, the continental shelf, and rivers such as the Rio Grande and Brazos Rivers. Historically, the Mississippi River also deposited its load of fine-grained sediments to the littoral system, which flows southwest on Bolivar Peninsula and Galveston Island; due to human intervention, the Mississippi River now deposits its load of fine-grained sediments at the edge of the continental shelf in relatively deep water, where it is unavailable to build beaches and barriers (Morton et al., 2004). Furthermore, the Mississippi River Gulf Outlet, MRGO, designed and constructed to keep channels open and direct the sediment load out to the continental shelf, acted as a funnel to focus the surge directly at New Orleans. Human intervention has resulted in subsidence, erosion, and salt water intrusion into the estuaries and bayous of coastal Louisiana (Warrick and Grunwald, 2005).

CASE STUDY – MONMOUTH COUNTY, NJ

For many years, the natural dunes in Monmouth County, NJ, were removed or altered to accommodate development. This made oceanfront properties more susceptible to damage from waves during major storms. The smaller beaches affected tourism and removed wildlife habitat. Dune restoration projects are now being initiated along the Monmouth County shoreline. These manmade dunes are once again providing storm protection and habitat, increasing the width of beaches and increasing tourism opportunities. (Source: Visit Monmouth County http://www.shore.co.monmouth.nj.us)

Estimates of historic heights of dunes on Galveston Island range from 9 feet North American Vertical Datum of 1988 (NAVD88, 6 feet above a 3-foot beach) to 13 feet NAVD88 (9 feet above a 4-foot beach) on Galveston Island and Bolivar Peninsula (Dr. James Gibeaut, personal communication) to 11 to 14 feet NAVD88 on Galveston Island based on fine-grain size (Dr. John B. Anderson, personal communication). Mean sea level at Galveston is 0.5 foot NAVD88, and the grade height along the beach is typically 3 to 4 feet NAVD88.

Most of the dunes along Galveston Island and Bolivar Peninsula were less than 5 to 6 feet NAVD88 high or non-existent before Hurricane Ike. The majority of developed areas had little to no dune development. Where developed areas were situated further back from the shoreline, the dunes were approximately 6 to 8 feet NAVD88. On the eastern end of Galveston Island, which is benefiting from sand increase trapped by jetties, the dunes were approximately 7 to 10 feet NVAD88 high and about 30 to 40 feet wide (Dr. James Gibeaut and Ray Newby, personal communication). The dunes along Galveston Island and Bolivar Peninsula have been repeatedly damaged during hurricanes and significantly altered from human intervention. Galveston Island and Bolivar Peninsula dunes could help to provide a natural defense for the area if the dunes are allowed to grow back to their former heights, thereby providing significant protection to the residences, commercial buildings, and petrochemical infrastructure in Galveston Bay. While they could still be overtopped by high-water hurricanes, dunes would help to protect the area by taking the impact of the waves (Dr. James Gibeaut, personal communication).

Marshes, swamps, and wetlands play a vital role in the coastal zone. They have tremendous biologic, economic, flood, and coastal defense value. They perform beneficial chemical and physical functions, provide habitat for fish and wildlife, are a major economic resource, and play a critical role in flood mitigation. They help reduce erosion by absorbing and dissipating kinetic wave energy, increasing sediment deposition, and reducing the flooding hazards of hurricanes and other coastal storms by helping to protect coastal and inland properties from erosion and flooding.[1]

> "Wetland losses, which constitute about 75 percent of the total land losses, have dramatically accelerated both directly in response to human activities or indirectly as a result of modifications to the coastal system. Rates of land loss around bays are highest near the heads of the largest bays where long wave fetch and high bluff elevations produce unstable conditions" (Morton et al., 2004, pg. 31).

America's Wetland Resources Center estimates that for every 3 miles of healthy coastal marsh that a hurricane crosses, 1 foot of storm surge is dissipated.[2] Tidal marshes act like a sponge to sop up water that pours in from the sea during a storm. Without marshes to absorb excess water, many low-lying areas would be prone to flooding. The Texas bay areas include wetlands that are 1 to 2 miles wide. While these wetlands are not the scale of the wetlands of Louisiana, with 30+ mile wide stretches of marsh, they do still play a role in helping to dissipate storm surges along with their other biologic and economic value.

8.1.2 Discussion of Conflicts Between Coastal Communities and Geological Hazards

Over the last 100 years, our engineering ingenuity has enabled people to live directly on the beach. More people live along the coast and more people are moving to the coast than ever in our past. According to the U.S. census figures, half of the U.S. population lives in coastal areas comprising 17 percent of the contiguous land area (Crossett et al., 2004). According to the Texas General Land Office (GLO), more than 25 percent of the Texas population lives within the 18 counties that comprise the coastal management zone. Houston is the fourth largest U.S. city, and the third largest metropolitan area close to a coast. In recent years, there has been a rapid rise in development along the upper Texas coast. In the face of increased development and increased interest in living on the coast, communities need to be more aware of the dynamic nature and dangers of the coast and the value of the natural barriers that protect it.

The trends show that more people will be moving to the upper Texas coast. The trends also show an increase in relative sea level rise. In addition, the upper Texas coast has been experiencing coastal ecosystem erosion for some time. The most important value of the natural ecosystem, wetlands and dunes, is that they provide a buffer from hurricane damage, flood control, nursery grounds for fisheries, and water supply and treatment. It is vitally important to the health of the residences, businesses, and infrastructure that the community at large begin to recognize the value of the natural ecosystem and protect it to nurture it back to health.

---

1 Coastal Texas 2020 Public Input and Scoping Document, Texas General Land Office http://wwwdb.glo.state.tx.us/res_mgmt/ct2020/scopingdocument.cfm.

2 America's Wetland Resources Center, The Basic Facts, http://www.americaswetlandresources.com/background_facts/basicfacts/FAQs.html.

As the dynamic islands change and erosion continues to remove land along the barrier islands, houses are ending up close to the water's edge, or in the water. With development this close to the water, the dunes cannot rebuild. The upper Texas coast needs to consider critical areas for the health of the ecosystem and build sustainable communities for future building. As part of the reconstruction and recovery after Ike, some questions that coastal communities should consider include:

- How do we modify existing communities and redevelop damaged communities in light of the above information?
- Is building higher and stronger the answer?
- How do we address the presence of residences built in critical areas of the ecosystem, in an area that might be considered a no-build zone?
- Should we create a buyout program for those critical areas?
- How do we protect unhealthy coastal ecosystems from further development?
- How do we allow the dunes to restore themselves?
- Are additional regulations needed to enforce dune and coastal wetland protection?
- Are joint efforts with county, State, and Federal agencies needed?

When coastal wetlands are in private ownership, decisions are typically made on the basis of what is best for the owner, not society at large. It is important that the land owners recognize the value of the coastal ecosystem—this can be accomplished through education and public outreach programs (refer to recommendations). Landowners that make wise decisions regarding the coastal ecosystem should be publicly recognized.

8.2 Existing Planning Resources and Programs

8.2.1 Texas

Land use planning is critical to Galveston Island barrier island and to the Bolivar Peninsula, and the risks and vulnerabilities of these areas need to be identified. Texas has existing programs and resources that can be used by municipalities to guide reconstruction and plan for the future.

Coastal Erosion Program and Coastal Texas 2020 Report

The Texas State coastal erosion program was initiated in 1999 when the Coastal Erosion Planning and Response Act, CEPRA, was enacted. In 1996, the Texas GLO submitted the *Texas Coastwide Erosion Response Plan*[3] to the 75th Texas Legislature describing the problems caused by erosion of the Gulf beaches and bay shorelines and the need for funding projects to mitigate

3 Texas Coastwide Erosion Response Plan, 2004 Update http://www.glo.state.tx.us/coastal/cerp/index.html

the damages. In 1999, the 76th Texas Legislature enacted the CEPRA supplying initial funding for 23 erosion response projects (Cycle 1 projects). The 77th Texas Legislature supported funding for another set of projects (Cycle 2 projects). In May 2004, the Texas Legislature supplied funding for half of the initial amount requested for the Cycle 3 projects. The Coastal 2020 report was issued in 2005 and submitted to the 79th Texas Legislature and to the 109th Congressional Delegation. The purpose of the report is to encourage lawmakers, throughout Texas, to consider that coastal issues need to be addressed and require funding.

Geohazards Map Program

Based on recommendations in a report titled "*Living with Geohazards on Galveston Island: A Preliminary Report with Recommendations, Prepared for and submitted to the Galveston, Texas City Council, July 2, 2004,*" (Gibeaut et al., 2004), the Coastal Research Group, Texas Bureau of Economic Geology (BEG) prepared a preliminary geohazards map in July 2004, and has prepared more recent versions showing current conditions for Galveston Island. The map shows low-lying areas and historical erosion rates and projects them into the future. The geohazard map presents a best-case scenario, as it uses only historical average global sea-level rise and subsidence rates, and does not reflect any increase of these rates based on new studies. The historical erosion rates presented in the Galveston Island geohazards map are based on 60 years of aerial photograph documentation that track shoreline migration. The earliest aerial photographs were taken around World War II. The elevation data is from LiDAR measurements taken by the BEG over the last 10 years. Maps such as the City of Galveston geohazard map can provide useful information for homeowners and businesses when selecting a site to locate a building.

8.2.2 Louisiana

This section describes several coastal planning programs and resources in Louisiana.

Coast 2050: Toward a Sustainable Coastal Louisiana

In 1998, Governor Foster and his administration prepared a strategic plan, Coast 2050, to establish a blueprint for comprehensive coastal restoration in Louisiana. The preparation of Coast 2050 was a joint planning initiative between the Louisiana Wetland Conservation and Restoration Authority (LWCRA), the Breaux Task Force, and the Louisiana Department of Natural Resources Coastal Zone Management Authority (LWCRA, 1998).

The development of the plan included:

- Soliciting public opinion and recommendations
- Resolving conflicts between restoration goals, coastal zone development, and infrastructure needs
- Formulating a plan that was acceptable to the public, scientifically sound, and achievable

Coastal Wetlands Planning, Protection and Restoration Act

The Coastal Wetlands Planning, Protection and Restoration Act (CWPPRA), which was submitted by Senator John Breaux and authorized by Congress in 1990, provides for targeted funds to be used for planning and implementing projects that create, protect, restore, and enhance wetlands in coastal Louisiana. The CWPPRA, also known as the "Breaux Act," provides Louisiana with approximately $40 million annually to assist in long-term conservation of Louisiana's coastal wetlands. The Louisiana Coastal Wetlands Program established a Federal task force,[4] the CWPPRA Task Force, which consists of five Federal agencies and the State of Louisiana. USACE tracks the project status of all of the CWPPRA projects. It also constructs many of them.

Coalition to Restore Coastal Louisiana

The Coalition,[5] formed in 1988, is a non-profit advocacy organization whose mission is the protection and restoration of a sustainable coastal Louisiana. The goal is to reverse the pattern of net land loss in coastal Louisiana and to reestablish a sustainable balance to its geologic processes and communities. In pursuit of this goal, the Coalition advocates the implementation of sound coastal policies and monitors coastal activities to ensure that stringent regulations and enforcement policies are maintained.

8.2.3 Nationwide Initiatives

Smart Growth

Rebuilding damaged communities in the Galveston Bay, TX, area and southwest Louisiana, provides local and State governments an opportunity to promote Smart Growth principles. Smart Growth communities promote development in ways that preserve natural lands and critical environmental areas, protect water and air quality, and reuse already-developed land. Smart Growth communities conserve resources by reinvesting in existing infrastructure and reclaiming historic buildings. Smart Growth practices are very old; this is how older urban villages, towns, and cities such as the City of Galveston were shaped.

SMART GROWTH NETWORK

The Smart Growth Network (SGN) is a partner coalition and consists of over 30 public sector, private sector, and nongovernmental organizations seeking to create smart growth in neighborhoods, communities, and regions across the United States. The SGN works to encourage development that serves the economy, community, and environment. Individual membership information, publications, and information about smart growth are available online at www.smartgrowth.org.

Infrastructure, businesses, and residences are concentrated to take advantage of walkable neighborhoods. These denser neighborhoods provide a wealth of resources. The denser neighborhoods provide solutions to concerns facing many communities about the impacts of the highly dispersed development patterns of the last 50 years. The walkable neighborhoods provide an alternative to driving long distances to get to work or to a store each day, especially as

4 http://crcl.org/stateandfederalplans/cwppra.html and http://www.lacoast.gov/cwppra/
5 http://crcl.org/aboutus.html

gas prices rise and while America is dependent on foreign oil. The denser neighborhoods are an alternative to abandoning a neglected urban site and developing instead prime farm land, thereby damaging our environment at the fringe of suburbia. Local and State policymakers, planners, architects, developers, and others are incorporating Smart Growth as a solution to these challenges (International City/County Management Association [ICMA], 2002). Good examples of Smart Growth principles in action on Galveston Island are the City of Galveston and the New Urbanism community, Beachtown (Figure 8-6). The City of Galveston is located behind the seawall. A future location for new construction or renovation could be behind the seawall in this walkable community. Beachtown, located at the east end of Galveston, is one of the few places on the island that is accreting, and new residences could take advantage of this.

Figure 8-6.
Beachtown, TX, under construction

A key element of Smart Growth principles is mixed land use. By mixing land use—such as residential, commercial, and institutional—the framework for a walkable community is in place. Another key element is to provide a mix of housing options, such as high-density residential to low-density residential. Higher density housing will support commercial and institutional uses. For example, a residential neighborhood that provides a 10-story mid-rise development, a three-story courtyard apartment complex, a townhouse development, and single-family houses will provide a mix of residential options. The denser residential buildings will sustain commercial and institutional activities, including commercial areas for groceries, pharmacies, hardware stores, restaurants; professional areas for doctors; and institutional buildings for recreational activities, community centers, and libraries. Open spaces can be preserved for uses such as parks, farmland, and critical environmental needs. A variety of transportation means can be provided, such as bike paths, sidewalks, buses, rail, and automobiles.

Implementing Smart Growth is a change to the way of doing business. It is vital to include community collaboration in decisionmaking related to Smart Growth. Local governments, lenders, community groups, zoning officials, developers, transit agencies, State governments, and others need to work together to provide the necessary changes in the way building and planning are done (ICMA, 2002). For example, there are zoning laws in place that have not caught up with these new practices. These zoning laws would need to be modified to promote Smart Growth practices. A new development called Beachtown under construction along the eastern end of Galveston Island will be a walkable community along the beach with a town center (Figure 8-7).

SMART GROWTH PRINCIPLES

1. Mix land uses
2. Take advantage of compact building design
3. Create a range of housing opportunities and choices
4. Create walkable neighborhoods
5. Foster distinctive, attractive communities with a strong sense of place
6. Preserve open space, farmland, natural beauty, and critical environmental areas
7. Strengthen and direct development toward existing communities
8. Provide a variety of transportation choices
9. Make development decisions predictable, fair, and cost effective
10. Encourage community and stakeholder collaboration in development decisions

For more information:

Smart Growth Web site, www.smartgrowth.org

Getting to Smart Growth: 100 Policies for Implementation (ICMA, 2002)

Figure 8-7. Beachtown, TX, under construction

Historic Preservation

Historic buildings are protected under the NHPA and are a recognized value to our national culture. Historic buildings are part of the history and fabric of Galveston. Additionally, older homes can provide useful information related to sustainable building practices. Older homes were designed to minimize solar gain through the use of deep porches, and overhangs, and they functioned adequately with daylight as the primary source of illumination. They were designed with high ceilings and cross-ventilation, with raised first floors to cool the buildings. Many of these homes may have had their own cisterns for rainwater catchment. With proper attention to disaster-resistant details, these practices can all support passive survivability of the building.

Reuse of existing buildings as opposed to building a new structure is one of the most effective strategies for minimizing environmental impacts. Reuse results in less habitat disturbance and typically less infrastructure development. Rehabilitation of existing buildings results in less waste sent to landfills. However, effective reuse of existing buildings requires that they be retrofitted to reduce the possibility that they will be damaged and destroyed by future hurricane winds or storm surge.

8.3 Recommendations for Rebuilding After Ike

The following are recommendations for communities and municipalities to consider as they begin rebuilding after Ike and planning for the future.

8.3.1 Specific to Local Communities

Sustainable Land Use Planning Recommendations

Coastal Counties:

Recommendation #1: Identify the risks to and vulnerabilities of the coastal communities and develop mitigation strategies to address them as part of the community's master plan. Identify zoning, land ownership, resident populations, tourism, and economic activity, and identify where and how vulnerable these assets are to natural hazards.

City of Galveston and Jamaica Beach:

Recommendation #2: Prepare a Sustainable Land Use Plan that considers that more severe hurricane impacts can be expected in the future and incorporates the geohazards map prepared by BEG, and relative sea-level rise for the next 50 years as a minimum.

Bolivar Peninsula:

Recommendation #3: Prepare a Sustainable Land Use Plan and that considers that more severe hurricane impacts can be expected in the future and incorporates a geohazards map and an additional overlay map that shows relative sea-level rise for the next 50 years as a minimum.

City of Galveston, Jamaica Beach, and Bolivar Peninsula:

Recommendation #4: Provide an overlay map accounting for the natural dynamism of the barrier peninsula. A Sustainable Land Use Plan should be a living document that changes over time. A sustainable landscape is a prerequisite for both storm protection and environmental restoration. Prepare a map showing the amount of shoreline erosion that will occur over the next 50 years if current trends are maintained.

Recommendation #5: Allow new construction and additions only in areas that are deemed safe with low risk, based on the Risks and Vulnerabilities and the Sustainable Land Use Plan, which includes future trends over the next 50 years. This will ensure that development stays out of the fragile coastal zone that needs to be protected for dune dynamism and growth.

Recommendation #6: Municipalities require that future development projects comply fully with the Clean Water Act 404 requirements before granting construction permits.

Galveston Island, Bolivar Peninsula, Galveston Bay Region, and Southeast Louisiana:

Recommendation #7: Build a coalition of municipal, community, and business partners to discuss economic investments at stake. Encourage businesses to think about their response to natural hazards over the long term, both operationally and physically. Emphasize that building codes are intended to provide a minimal level of life-safety and building performance. In coastal areas, it is prudent to design and construct more conservatively. This includes commercial buildings, in order to increase their potential for being operational after a disaster.

Recommendation #8: Using NOAA's "Coastal Resiliency Index: A Community Self-Assessment, A Guide to Examining How Prepared Your Community is for a Disaster" (Emmer et al., Date Unavailable), prepare a Community Self-Assessment and obtain a Coastal Resiliency Index rating. This rating will aid community leaders in predicting if their community will reach and maintain an acceptable level of functioning and structure after a disaster. The goal of this Community Self-Assessment is for every community to become highly resilient; the guide reviews critical infrastructure.

Recommendation #9: Modify land use maps to enable Smart Growth principles to encourage mixed land uses; institute policies to enable Smart Growth.

Protection of the Natural Environment

Local Municipalities

Increase protection of dunes on Galveston Island and Bolivar Peninsula to allow the dunes to stabilize and achieve their natural, undisturbed heights (estimated to be approximately 9 to 14 feet NAVD88). Examples of best practices include:

Recommendation #10: Conduct research into storm history and beach dynamics to determine how wide a buffer strip is necessary to maintain the dunes. These vary according to specific locations. Arbitrary dune widths are not useful and can easily be breached.

Recommendation #11: Prohibit any traffic, including foot and motorized/non-motorized vehicles. Walking on dunes jeopardizes their stability by damaging the fragile anchoring root system. While providing storm protection and habitat, dunes tend to reduce access to beaches. Provide boardwalks over the dunes to protect the vegetation. Pathways could also be designed between the dunes to limit their damage. Placing fences along the pathways will confine pedestrians to the paths.

Recommendation #12: Institute a dune revegetation program and put measures in place to allow dunes to achieve their former heights. High-elevation continuous dunes effectively block storm surges and prevent island overwash. Restoration, maintenance, and protection of dunes are vital to ensuring storm protection, beach stability, and increasing the economic health of the region.

Recommendation #13: Institute community education programs to place signage and provide literature about the importance of dunes.

Several publications are available on topics of dune planting and construction, including: *Restoration of Sand Dunes along the Mid-Atlantic Coast* (Hamer et al., 1992), *Landscaping at the Seashore* (Rutgers, 1980), and *Guidelines and Recommendations for Coastal Dune Restoration and Creation Projects* (New Jersey Department of Environmental Protection, 1985).

AMERICA'S ENERGY COAST

Residences and businesses located in the Chenier Plain—southeast Texas and southwest Louisiana—have many common interests as the alliance, *America's Energy Coast*, has found out. *America's Energy Coast* is a loose alliance of environmentalists, oil companies, government agencies, and shipping interests that is calling on the Nation to do two things that are often seen as mutually exclusive: invest in restoring a degraded ecosystem and, at the same time, protect and increase oil production. For more information, see: http://www.americasenergycoast.org/files/120208AEC-ActionFrameworkFINAL.pdf.

Galveston and Chambers Counties

Recommendation #14: Encourage local municipalities to ensure that building permits are in compliance with Texas Wetlands Conservation Plan. The Texas Wetlands Conservation Plan[6] provides a non-regulatory, incentive-based approach to wetlands management.

Recommendation #15: Initiate a local or regional wetlands protection program. According to the USGS report (2004), not many dune or habitat restoration projects had been started. It is very important that these projects be initiated as soon as possible to begin to establish basic protection. Dunes often take many years to become stable.

8.3.2 General Recommendations – State Level

Recommendation #16: Update and revise accordingly the Coastal 2020 (2004[7]) plan to include the devastation of Ike and recommendations in this Ike MAT report. Fully fund and expedite its implementation.

6 http://www.tpwd.state.tx.us/landwater/water/habitats/wetland/publications/conservation_plan.phtml
7 http://www.glo.state.tx.us/coastal/ct2020/index.html

Recommendation #17: Initiate a regional coalition including coastal communities of southeast Texas and southwest Louisiana to address coastal planning and hazard mitigation. Consider supporting the alliance of *America's Energy Coast*, which includes interests along the southeast Texas coastline (refer to text box).

Recommendation #18: Institute policies to enable Smart Growth.

8.3.3 General Recommendations – Federal Level

Recommendation #19: Federal agencies with technical expertise, such as NOAA, USACE, and others, should help communities identify the most effective protective measures to put in place for coastal wetlands to ensure wetland health.

A Acknowledgments

The Federal Emergency Management Agency would like to acknowledge the contributions of the following persons to the Mitigation Assessment Team study of the areas affected by Hurricane Ike:

J.T. Agregard
Operations Manager, Houston Transtar, Houston, TX

Dr. John Anderson
Professor of Geology and Geophysics, Rice University, Houston, TX

Barry Bergeron
Bergeron's Electric, Sulphur, LA

Mike Blount
Senior Project Manager, Crown Team Construction, Beaumont, TX

Dana Bres
U.S. Department of Housing and Urban Development, Washington, DC

Antoine Bryant
The Bryant Design Group, LLC, Houston, TX

Bill Coulbourne, PE
Director, Wind and Flood Hazard Mitigation, Applied Technology Council, Rehoboth Beach, DE

Lori Cummings
Assistant City Manager, City of Port Neches, TX

Dr. Eileen Curl
Chairperson & Professor, Dishman Department of Nursing, Lamar University, Beaumont, TX

Windell Curole
Executive Director, South Lafourche Parish Levee District, Galliano, LA

Chip Dence
East End Builders, Victoria, TX

Chad Deshotel
Majestic Homes, Lake Charles, LA

Dana Dugas
Affordable Homes, Inc., New Iberia, LA

Charles Everetts
Mayor, Village of Tiki Island, TX

Wayne Fender
Fender Homes, Lake Charles, LA

Capt. Bruce Francois
Grand Isle Police Department, Grand Isle, LA

David Franklin, PE
Aran & Franklin Engineering, Inc., La Marque, TX

Jennifer Gerbasi
Recovery Planner, Terrebonne Parish & City of Houma, LA

Ian Giammanco, PhD Candidate
Texas Tech Hurricane Research Team, Lubbock, TX

Dr. James Gibeaut
Harte Research Institute for Gulf of Mexico Studies, Texas A&M University, Corpus Christi, TX

Bill Grim
Supervisor, Operations & Maintenance, Chevron, Houston, TX

Leigh Guidry
Executive Assistant, Greater Lafourche Port Commission, Galliano, LA

Gene Hafele
Meteorologist-In-Charge, National Weather Service, Dickinson, TX

Karen Hagerman
City Secretary, Village of Tiki Island, TX

Shalia Hampton
Administrator, Winnie Community Hospital, Winnie, TX

Officer Mitch Hohensee
Greater Lafourche Port Commission Police, Galliano, LA

Darrell Hunter
Building Inspector, Village of Tiki Island, TX

John Ingargiola
FEMA HQ, Washington, DC

John S. Jacob
Texas Sea Grant, College Station, TX

Mike Johnson
Mike Johnson Homes, Bridge City, TX

Jerry Jones
City Manager, Bridge City, TX

Phil Kabza, FCSI, CCS, AIA
SpecGuy®, Charlotte, NC

Richard Keleher, AIA, CSI, LEED, AP
Richard Keleher Architect, Concord, MA

Rob Kistler, AIA
The Facade Group, LLC, Portland, OR

Chris Koerner, PE, BCEE
Environmental Network International, LLC, Oakton, VA

Michael Lege
Crown Team Texas, Beaumont, TX

Paul J. Lemoine
Chief of Police, Port Neches Police Department, Port Neches, TX

Nathan Letroise
Property Manager, Galveston Courthouse, Galveston, TX

Philip Line
American Forest and Paper Association, Washington, DC

Bill Little
Little Investments, Inc., Beaumont, TX

Jeff Mabrey
Property Manager, Hines, JPMorgan Chase Tower, Houston, TX

Wesley S. Maida
QRC Operations Manager, Flowserve Corporation, Port Arthur, TX

Mitch McDonald
Senior Planner, Terrebonne Parish & City of Houma, LA

Ray Newby, PG
Geomorphologist/Project Manager, Texas General Land Office, Coastal Resources Program, Austin, TX

Greg Ormsby
FEMA Contractor, Washington, DC

Judd Peterson, AIA
President, Judd Allen Group, Edina, MN

John Plisich
FEMA Region IV, Atlanta, GA

Dan Reilly
Warning Coordination Meteorologist, National Weather Service, Dickinson, TX

Spencer Rogers
North Carolina Sea Grant, Raleigh, NC

Ron Rohrbacher
Perry Homes, Houston, TX

Michael Scanlon, PE
President, Norex Engineering Inc., Houston, TX

John Schroeder, PhD
Texas Tech Hurricane Research Team, Lubbock, TX

Taylor J. Shelton
Public Works Director, City of Port Neches, TX

Rodney Townsend
R & D Quality Construction Home Builders Inc., Bridge City, TX

Don Veronie
Heritage Builders, LLC, Sulphur, LA

Larry Voice
FEMA Disaster Assistance Employee

Jim Walker
Construction Manager, Facilities Operations & Management, The University of Texas Medical Branch, Galveston, TX

Mark Williams
Mark Williams Home Builder, Beaumont, TX

Dewayne Willoughby
Senior Chief Engineer, JPM Realty Group, Houston, TX

Maurice Wolcott
Louisiana Sea Grant, Baton Rouge, LA

Chandra Franklin Womack
Aran & Franklin Engineering, Inc., La Marque, TX

B References and FEMA Publication List

Aestimo, Inc., 2008. *Preliminary Building Envelope Condition Assessment Report.* Houston, TX.

American Concrete Institute (ACI), 2003. *Building Code Requirements for Masonry Structures,* ACI 530-05. Farmington Hills, MI.

American Concrete Institute (ACI), 2008. *Building Code Requirements for Masonry Structures,* ACI 530-08. Farmington Hills, MI.

American Institutes for Research, 2006. *Evaluation of the National Flood Insurance Program's Building Standards.* Washington, DC, September 2006.

American National Standards Institute (ANSI)/American Society of Civil Engineers (ASCE), 1988. *Minimum Design Loads for Buildings and Other Structures,* ANSI/ASCE Standard 7-88. Washington, DC, (ANSI) and Reston, VA (ASCE).

American Society of Civil Engineers (ASCE), 1998. *Minimum Design Loads for Buildings and Other Structures,* ASCE Standard 7-98. Reston, VA. (2-12, 18)

American Society of Civil Engineers (ASCE), 2005a. *Flood Resistant Design and Construction,* ASCE Standard ASCE 24. Reston, VA.

American Society of Civil Engineers (ASCE), 2005b. *Minimum Design Loads for Buildings and Other Structures,* ASCE/SEI Standard 7-05. Reston, VA.

Applied Research Associates (ARA), 2008. *Estimates of Maximum Wind Speed Produced by Hurricane Ike in Texas and Louisiana*. Albuquerque, NM.

ASTM, 1996. *Standard Test Method for Windload Resistance of Rigid (Poly Vinyl Chloride) (PVC) Siding*, ASTM D5206. West Conshohocken, PA.

ASTM, 2008. *Standard Test Method for Wind Resistance of Asphalt Shingles (Uplift Force/Uplift Resistance Method)*, ASTM D7158. West Conshohocken, PA.

ASTM, 2009. *Test Method for Wind-Resistance of Asphalt Shingles (Fan-Induced Method)*. ASTM D3161. West Conshohocken, PA.

ASTM, 2009. *Standard Specification for Rigid Poly (Vinyl Chloride) (PVC) Siding*, ASTM D3679. West Conshohocken, PA.

Berg, R., 2009. "Tropical Cyclone Report (TCR) Hurricane Ike (AL092008)." National Hurricane Center. http://www.nhc.noaa.gov/pdf/TCR-AL092008_Ike.pdf.

Bergeron, Angelle, 2005. "Louisiana Passes New Statewide Building Code; Critics Say It May Burden Home Repairs." *Engineering News Record*, December 7.

Brick Industry Association (BIA), 1991. *Anchored Brick Veneer Wood Frame Construction*, Technical Notes 28. Reston, VA.

Brick Industry Association (BIA), 2002. *Anchored Brick Veneer, Wood Frame Construction*, Technical Notes 28. Reston, VA.

Commonwealth of Pennsylvania, Department of Community and Economic Development, 2001. *Technical Information on Floodplain Management*, Planning Series #5. Harrisburg, PA. http://www.newpa.com/get-local-gov-support/publications/download.aspx?id=340

Crossett, Kristen M.; Thomas J. Culliton, Peter C. Wiley, and Timothy R. Godspeed, 2004. *Population Trends Along the Coastal United States: 1980–2008*, Coastal Trends Report Series, National Oceanic and Atmospheric Administration (NOAA), National Ocean Service, Management and Budget Office. September 2004.

Dallas Business Journal, 2008. "Report calls for abolishing Texas Residential Construction Commission," *Dallas Business Journal*. Dallas, TX, August 21, 2008.

Elsharkawi, Mena, 2008. "Ike's Death Toll Rises to 39." Fox News, September 15. http://www.myfoxhouston.com/dpp/news/Ikes_Death_Toll_Rises_to_39.

Emmer, Rod; LaDon Swann; Melissa Schneider; Stephen Sempier; Tracie Sempier; and Tina Sanchez, Date Unavailable. *Coastal Resiliency Index: A Community Self-Assessment: A Guide to Examining How Prepared Your Community Is for a Disaster*, MASGP-08-014, Pilot Test Version.

Federal Alliance for Safe Homes (FLASH), 2002. *Blueprint for Safety: Contractors Field Manual.*

Federal Emergency Management Agency (FEMA), 1985. *Manufactured Home Installation in Flood Hazard Areas*, FEMA 85. Washington, DC, September 1985.

Federal Emergency Management Agency (FEMA), 1996. *Corrosion Protection for Metal Connectors in Coastal Areas*, NFIP Technical Bulletin 8-96, Section 2t. August 1996.

Federal Emergency Management Agency (FEMA), 2000. *Coastal Construction Manual: Principles and Practices of Planning, Siting, Designing, Constructing, and Maintaining Residential Buildings in Coastal Areas,* FEMA 55, Third Edition. Washington, DC, June 2000.

Federal Emergency Management Agency (FEMA), 2004. *Design Guide for Improving School Safety in Earthquakes, Floods, and High Winds*, FEMA 424. Washington, DC, January 2004.

Federal Emergency Management Agency (FEMA), 2005a. *Mitigation Assessment Team Report: Hurricane Charley in Florida*, FEMA 488. Washington, DC, April 2005.

Federal Emergency Management Agency (FEMA), 2005b. *Home Builder's Guide to Coastal Construction*, Technical Fact Sheet Series, FEMA 499. Washington, DC, August 2005.

Federal Emergency Management Agency (FEMA), 2005c. "Asphalt Shingle Roofing for High-Wind Regions," *Fact Sheet 20, Home Builder's Guide to Coastal Construction*, Technical Fact Sheet Series, FEMA 499. Washington, DC, August 2005.

Federal Emergency Management Agency (FEMA), 2005d. "Shutter Alternatives," *Fact Sheet 26, Home Builder's Guide to Coastal Construction*, Technical Fact Sheet Series, FEMA 499. Washington, DC, August 2005.

Federal Emergency Management Agency (FEMA), 2005e. *Hurricane Ivan in Alabama and Florida: Observations, Recommendations and Technical Guidance, Mitigation Assessment Team Report*, FEMA 489. Washington, DC, August 2005.

Federal Emergency Management Agency (FEMA), 2006a. *Summary Report on Building Performance: Hurricane Katrina 2005*, FEMA 548. Washington, DC, April 2006.

Federal Emergency Management Agency (FEMA), 2006b. *Hurricane Katrina in the Gulf Coast: Building Performance Observations, Recommendations, and Technical Guidance*, FEMA 549. Washington, DC, July 2006.

Federal Emergency Management Agency (FEMA), 2006c. "Attachment of Brick Veneer in High-Wind Regions," Hurricane Katrina Recovery Advisory 5, *Hurricane Katrina in the Gulf Coast: Building Performance Observations, Recommendations, and Technical Guidance,* FEMA 549, Appendix E. Washington, DC, July 2006.

Federal Emergency Management Agency (FEMA), 2006d. "Initial Restoration for Flooded Buildings," Hurricane Katrina Recovery Advisory 2, *Hurricane Katrina in the Gulf Coast: Building Performance Observations, Recommendations, and Technical Guidance*, FEMA 549, Appendix E. Washington, DC, July 2006.

Federal Emergency Management Agency (FEMA), 2006e. "The ABCs of Returning to Flooded Buildings," Hurricane Katrina Recovery Advisory 4, *Hurricane Katrina in the Gulf Coast: Building Performance Observations, Recommendations, and Technical Guidance*, FEMA 549, Appendix E. Washington, DC, July 2006.

Federal Emergency Management Agency (FEMA), 2006f. *Recommended Residential Construction for the Gulf Coast: Building on Strong and Safe Foundations*, FEMA 550. Washington, DC, July 2006.

Federal Emergency Management Agency (FEMA), 2007a. *Design Guide for Improving Critical Facility Safety from Flooding and High Winds: Providing Protection to People and Buildings*, FEMA 543. Washington, DC, January 2007.

Federal Emergency Management Agency (FEMA), 2007b. *Design Guide for Improving Hospital Safety in Earthquakes, Floods, and High Winds: Providing Protection to People and Buildings*, FEMA 577. Washington, DC, June 2007.

Federal Emergency Management Agency (FEMA), 2007c. *Reducing Flood Losses Through the International Codes: Meeting the Requirements of the National Flood Insurance Program*, FEMA 9-0372, Third Edition. Washington, DC, December 2007.

Federal Emergency Management Agency (FEMA), 2009. *Local Officials Guide for Coastal Construction*, FEMA P-762. Washington, DC, February 2009.

Gabrysch, R.K., 1984. *Ground-water withdrawals and land-surface subsidence in the Houston-Galveston region*, Texas, 1906–1980, Texas Department of Water Resources Report 287, 64p.

Galloway, Devin; David R. Jones; and S.E. Ingebritsen, 1999. *Land Subsidence in the United States*, U.S. Geological Survey Circular 1182.

Galveston County, 2006. *Galveston County Dune Protection and Beach Access Plan*, Galveston County, TX.

Gibeaut, J. C.; Tiffany Hepner; R. L. Waldinger; J. R. Andrews; R. C. Smyth; and Roberto Gutiérrez, 2003. *Geotextile tubes along the upper Texas Gulf coast: May 2000 to March 2003*, The University of Texas at Austin, Bureau of Economic Geology, final report prepared for Texas Coastal Coordination Council. http://www.beg.utexas.edu/coastal/geotube.htm

Gibeaut, J. C.; J. B.Anderson; and T. M. Dellapenna, 2004. *Living with Geohazards on Galveston Island: A Preliminary Report with Recommendations*, prepared for and submitted to the Galveston, TX, City Council. July 2, 2004.

Halff Associates, 2008. *Hurricane Ike Damage Assessment Letter Report*. Galveston County, TX.

Hamer, D.; C. Belcher; and C. Miller, 1992, *Restoration of Sand Dunes along the Mid-Atlantic Coast*. December 1992.

Harris County Flood Control District (HCFCD), 2008. Table of High Water Surge Elevations.

Hays, Daniel H., 2009. "More Ike Loss Revisions Arrive." *National Underwriter Property and Casualty Magazine* (NUPC). February 9, 2009. http://www.property-casualty.com/News/2009/2/Pages/More-Ike-Loss-Revisions-Arrive.aspx?k=More%20Ike%20Loss%20Revisions%20Arrive.

Institute for Business and Home Safety (IBHS), 2005. *Guidelines for Hurricane Resistant Residential Construction*. Tampa, FL.

Institute for Business and Home Safety (IBHS), 2007. *Fortified for Safer Living Builder's Guide*. Tampa, FL.

Intergovernmental Panel on Climate Change (IPCC), 2008. *Climate Change 2007 – Impacts, Adaptation and Vulnerability*. March 2008.

International City/County Management Association (ICMA), 2002. *Getting to Smart Growth: 100 Policies for Implementation*. January 2002.

International Code Council, 2000. *International Building Code,* 2000 edition. Washington, DC.

International Code Council, 2000. *International Residential Code,* 2000 edition. Washington, DC.

International Code Council, 2003. *International Building Code,* 2003 edition. Washington, DC.

International Code Council, 2003. *International Residential Code,* 2003 edition. Washington, DC.

International Code Council, 2006. *International Building Code,* 2006 edition. Washington, DC.

International Code Council, 2006. *International Residential Code,* 2006 edition. Washington, DC.

Kareem, A., 1986. "Performance of Cladding in Hurricane Alicia," *Journal of Structural Engineering*, ASCE, Vol. 112, No. 12, pp. 2679–2693.

Kareem, A., 2008. *Saga of Glass Damage in Urban Environments Continues: Consequences of Aerodynamics and Debris Impact During Hurricane Ike*. NatHaz Modeling Laboratory, University of Notre Dame. Notre Dame, IN, November 14, 2008.

Louisiana Wetlands Conservation and Restoration Authority (LWCRA) and the Coastal Wetlands Conservation and Restoration Task Force, 1998. Coast 2050: *Toward a Sustainable Coastal Louisiana. Louisiana Department of Natural Resources*, Baton Rouge, LA. http://www.coast2050.gov/2050reports.htm.

Louisiana Department of Transportation and Development (LADOTD), 2008. *Louisiana Floodplain Management Desk Reference.*

Louisiana Economic Development (LED) Agency, 2008. "LED Releases Hurricane Gustav and Hurricane Ike Economic Impact Assessment." September 18, 2008. http://www.ledlouisiana.com/news–multimedia/news-releases/led-releases-hurricane-gustav-and-hurricane-ike-economic-impact-assessment.aspx.

McDonald, James R., and Billy Manning, 1990. *Effectiveness of Building Codes and Construction Practice in Reducing Hurricane Damage to Non-engineered Construction.*

Mehta, Madan, Walter Scarborough, and Diane Armpriest, 2007. *Building Construction – Principles, Materials, and Systems.* Prentice Hall, Upper Saddle River, NJ.

Minnesota Public Radio, 2008. "Remnants of Ike blamed for 15 deaths in Midwest." September 13, 2008. http://minnesota.publicradio.org/display/web/2008/09/13/ike_saturday/.

Morton, Robert A., 2004. *An Overview of Coastal Land Loss: With Emphasis on the Southeastern United States,* USGS Open File Report 03-337. Last modified April 29, 2004. http://pubs.usgs.gov/of/2003/of03-337/global.html.

Morton, R. A. ; T. L. Miller ; and L. J. Moore . 2004. *National Assessment of Shoreline Change: Part 1: Historical Shoreline Changes and Associated Coastal Land Loss Along the US Gulf of Mexico.* U.S. Geological Survey (USGS) Open-File Report 2004-1043. http://pubs.usgs.gov/of/2004/1043/.

National Fire Protection Association (NFPA), 1999. *National Electrical Code*, NFPA 70, 1999 edition. Quincy, MA.

National Fire Protection Association (NFPA), 2003. *Building Construction and Safety Code*, NFPA 5000, 2003 edition. Quincy, MA.

National Fire Protection Association (NFPA), 2005a. *Model Manufactured Home Installation Standard*, NFPA 225. Quincy, MA.

National Fire Protection Association (NFPA), 2005b. *Standard on Manufactured Housing*, NFPA 501. Quincy, MA.

National Fire Protection Association (NFPA), 2006. *Building Construction and Safety Code*, NFPA 5000, 2006 edition. Quincy, MA.

National Fire Protection Association (NFPA), 2009a. *Model Manufactured Home Installation Standard*, NFPA 225, 2009 edition. Quincy, MA.

National Fire Protection Association (NFPA), 2009b. *Standard for Fire Safety Criteria for Manufactured Home Installations, Sites and Communities*, NFPA 501A. Quincy, MA.

National Hurricane Center (NHC), 2007. *The Deadliest, Costliest, and Most Intense United States Tropical Cyclones From 1851 to 2006*, NOAA Technical Memorandum NWS TPC-5. Updated April 15, 2007. http://www.nhc.noaa.gov/Deadliest_Costliest.shtml.

New Jersey Department of Environmental Protection (NJ DEP), 1985. *Guidelines and Recommendations for Coastal Dune Restoration and Creation Projects*. Prepared by the Bureau of Planning and Project Review, Trenton, NJ. November 1985.

Powell, M. D. and T. A. Reinhold, 2007. “Tropical Cyclone Destructive Potential by Integrated Kinetic Energy.” *Bulletin of the American Meteorological Society*, Vol. 88, Issue, 4, pp. 513–526. http://www.aoml.noaa.gov/hrd/Powell/BAMS_IKE_Paper_final.pdf.

Risk Management Solutions (RMS), 2008. “Hurricane Ike,” Final Summary. September 2, 2008. http://www.rms.com/ClientResources/Catupdates/CatUpdatePublic.asp?event_id=2658.

Rutgers Co-operative Extension, 1980. *Landscaping at the Seashore.*

Savage, R.P., J. Baker, J.H. Golden, A. Kareem, and B.R. Manning, 1984. *Hurricane Alicia, Galveston and Houston, Texas*, August 17-18, 1983, pp. 54–59. National Research Council, Washington, DC, and National Academy Press, Springfield, VA.

Schiller, Dane, 2008. “Ike death toll increases as three bodies found,” *Houston Chronicle.* September 29, 2008. http://www.chron.com/disp/story.mpl/chronicle/6029478.html.

Schwartz, J.A. and C. Barry, 1996. *Critical Analysis of Emergency Preparedness Self-Audit Materials.* U.S. Department of Justice, National Institute of Corrections, Washington, DC.

Smith, T.L., 1997. “Aggregate Blow-off from BUR and SPF Roofs: Recognizing the Potential Hazards and Avoiding Problems.” *Proceedings of the 8th U.S. Conference on Wind Engineering*, June 1997.

Southern Building Code Congress International (SBCCI), 1985. *Hurricane Resistant Residential Construction Code.*

Texas Department of Insurance (TDI), 2009. *Report on the Texas Windstorm Insurance Association.* January 23, 2009.

Texas Residential Construction Commission (TRCC), 2005. *Warranties and Performance Standard.*

United Press International (UPI), 2008. "Search for Ike missing slows to crawl," October 12, 2008. http://www.upi.com/Top_News/2008/10/12/Search_for_Ike_missing_slows_to_crawl/UPI-80791223845873/.

URS Corporation, 2008. *Texas Hurricane Ike Rapid Response Coastal High Water Mark Collection.* Prepared for FEMA, October 2008.

U.S. Department of Energy, 2008. *Hurricane Ike Situation Report # 4*, September 15, 2008. http://www.fbiic.gov/public/2008/sept/2008_SitRep_4_Ike_091508_3PM.doc.

U.S. Department of Housing and Urban Development. 2006. *Manufactured Home Construction and Safety Standards*, Title 24 Code of Federal Regulations (CFR) Part 3280. Revised as of April 1, 2006.

Warrick, Joby, and Michael Grunwald, 2005. "Investigators Link Levee Failures to Design Flaws: Three Teams of Engineers Find Weakened Soil, Navigation Canal Contributed to La. Collapses," *The Washington Post*, Monday, October 24, 2005; Page A01.

Yoskowitz, David, and James Gibeaut, 2009. "Impact of Relative Sea Level Rise on Galveston Bay," PowerPoint presentation, Harte Research Instititue for Gulf of Mexico Studies, Texas A&M University, Corpus Christi. January, 2009.

FEMA Publications and Resources

FEMA post-disaster reports available through FEMA publications: 1-800-480-2520 and at http://www.fema.gov/rebuild/mat/mat_reprts.shtm.

FEMA 55 — *Coastal Construction Manual: Principles and Practices of Planning, Siting, Designing, Constructing, and Maintaining Residential Buildings in Coastal Areas.* June 2000
http://www.fema.gov/library/viewRecord.do?id=1671

FEMA 85 — *Manufactured Home Installation in Flood Hazard Areas.* September 1985 http://www.fema.gov/library/viewRecord.do?id=1577

FEMA 320 — *Taking Shelter From the Storm: Building a Safe Room For Your Home or Small Business.* August 2008
http://www.fema.gov/library/viewRecord.do?id=1536

FEMA 361 — *Design and Construction Guidance for Community Safe Rooms.* August 2008
http://www.fema.gov/library/viewRecord.do?id=1657

FEMA 424 *Design Guide for Improving School Safety in Earthquakes, Floods, and High Winds.* January 2004
http://www.fema.gov/library/viewRecord.do?id=1986

FEMA 431 *Tornado Protection: Selecting Refuge Areas in Buildings.* November 2003
http://www.fema.gov/library/viewRecord.do?id=1563

FEMA 488 *Hurricane Charley in Florida: Observations, Recommendations, and Technical Guidance.* April 2005
http://www.fema.gov/rebuild/mat/mat_fema488.shtm

FEMA 489 *Hurricane Ivan in Alabama and Florida: Observations, Recommendations and Technical Guidance.* August 2005
http://www.fema.gov/rebuild/mat/mat_fema489.shtm

FEMA 499 *Home Builder's Guide to Coastal Construction, Technical Fact Sheet Series*, 31 sheets. August 2005
http://www.fema.gov/rebuild/mat/mat_fema499.shtm

FEMA 543 *Design Guide for Improving Critical Facility Safety from Flooding and High Winds: Providing Protection to People and Buildings.* January 2007
http://www.fema.gov/library/viewRecord.do?id=2441

FEMA 549 *Hurricane Katrina in the Gulf Coast: Building Performance Observations, Recommendations, and Technical Guidance.* July 2006
http://www.fema.gov/library/viewRecord.do?id=1857

FEMA 550 *Recommended Residential Construction for the Gulf Coast: Building on Strong and Safe Foundations.* July 2006
http://www.fema.gov/library/viewRecord.do?id=1853

FEMA 577 *Design Guide for Improving Hospital Safety in Earthquakes, Floods, and High Winds: Providing Protection to People and Buildings.* June 2007
http://www.fema.gov/library/viewRecord.do?id=2739

FEMA 9-0372 *Reducing Flood Losses Through the International Codes: Meeting the Requirements of the National Flood Insurance Program.* December 2007
http://www.fema.gov/library/viewRecord.do?id=2094

FEMA P-762 *Local Officials Guide to Coastal Construction.* February 2009
http://www.fema.gov/library/viewRecord.do?id=3647

NFIP Technical Bulletins

http://www.fema.gov/plan/prevent/floodplain/techbul.shtm

FIA-TB-0:	User's Guide to Technical Bulletins
FIA-TB-1:	Openings in Foundation Walls and Walls of Enclosures (updated 2008)
FIA-TB-2:	Flood Damage-Resistant Materials Requirements (updated 2008)
FIA-TB-3:	Non-Residential Floodproofing – Requirements and Certification
FIA-TB-4:	Elevator Installation
FIA-TB-5:	Free-of-Obstruction Requirements (updated 2008)
FIA-TB-6:	Below-Grade Parking Requirements
FIA-TB-7:	Wet Floodproofing Requirements
FIA-TB-8:	Corrosion Protection of Metal Connectors in Coastal Areas
FIA-TB-9:	Design and Construction Guidance for Breakaway Walls Below Elevated Coastal Buildings (updated 2008)
FIA-TB-10:	Ensuring that Structures Built on Fill In or Near Special Flood Hazard Areas are Reasonably Safe From Flooding
FIA-TB-11:	Crawlspace Construction for Buildings Located in Special Flood Hazard Areas

NFIP Evaluation Studies

http://www.fema.gov/business/nfip/nfipeval.shtm

Evaluation of the National Flood Insurance Program's Building Standards

http://www.fema.gov/library/viewRecord.do?id=2592

FEMA Safe Room Web Site

http://www.fema.gov/plan/prevent/saferoom/

C Acronyms and Glossary

Acronyms

A

ABFE	Advisory Base Flood Elevation
ACI	American Concrete Institute
AIA	American Institute of Architects
ANSI	American National Standards Institute
ARA	Applied Research Associates
ASCE	American Society of Civil Engineers
ASOS	Automated Surface Observation System
ASTM	American Society for Testing and Materials

B

BEG	Bureau of Economic Geology, Texas
BFE	Base Flood Elevation
BIA	Brick Industry Association
BUR	Built-Up Roof

C

CABO	Council of American Building Officials
C&C	Components and Cladding
CDT	Central Daylight Time
CEPRA	Coastal Erosion Planning and Response Act
CFD	Computational Fluid Dynamics
CFR	Code of Federal Regulations
C-MAN	Coastal Marine
CO-OPS	Center for Operational Oceanographic Products and Services, NOAA
CRTF	Catastrophe Reserve Trust Fund
CWPRA	Coastal Wetlands Planning and Restoration Act

D

DFIRM	Digital Flood Insurance Rate Map
DHS	Department of Homeland Security
DOJ	U.S. Department of Justice

E

EF	Enhanced Fujita
EIFS	Exterior Insulation Finish System
EOC	Emergency Operations Center

F

FCMP	Florida Coastal Monitoring Program
FEMA	Federal Emergency Management Agency
FIRM	Flood Insurance Rate Map
FIS	Flood Insurance Study
FLASH	Federal Alliance for Safe Homes

G

GLO	General Land Office, Texas

H

HAZUS-MH	Hazards United States Multi-Hazard
HCFCD	Harris County Flood Control District
HMGP	Hazard Mitigation Grant Program
HRD	Hurricane Research Division
HWM	High Water Mark
HUD	U.S. Department of Housing and Urban Development
HVAC	Heating, Ventilation, and Air-Conditioning

I

IBC	International Building Code
IBHS	Institute for Business and Home Safety
ICC	International Code Council
ICMA	International City/County Management Association
IKE	Integrated Kinetic Energy
IPCC	Intergovernmental Panel on Climate Change
IRC	International Residential Code

L

LADOTD	Louisiana Department of Transportation and Development
LED	Louisiana Economic Development
LiMWA	Limit of Moderate Wave Action
LPS	Lightning Protection System
LSUCC	Louisiana Statewide Uniform Construction Code Council
LWCRA	Louisiana Wetland Conservation and Restoration Authority

M

MAT	Mitigation Assessment Team
mb	millibars
MHCSS	Manufactured Home Construction and Safety Standard
mph	miles per hour
MRGO	Mississippi River Gulf Outlet
MWFRS	Main Wind Force Resisting System

N

NAHB	National Association of Home Builders
NAVD	North American Vertical Datum
NAVD 88	North American Vertical Datum of 1988
NEC	National Electrical Code
NFIP	National Flood Insurance Program
NFPA	National Fire Protection Association
NFPA 5000	NEPA Building Construction and Safety Code
NGVD	National Geodetic Vertical Datum
NHC	National Hurricane Center
NJ DEP	New Jersey Department of Environmental Protection
NOAA	National Oceanographic and Atmospheric Administration
NOS	National Ocean Service, NOAA
NUPC	National Underwriter and Casualty
NWS	National Weather Service

O

OAR	Office of Atmospheric Research
OSB	Oriented Strand Board

P

PCS	Property Claim Services
psf	pounds per square foot
PVC	Poly Vinyl Chloride

R

R.S.	Revised Statutes

S

SBC	Standard Building Code
SBCCI	Southern Building Code Congress International
SDP	Surge/Wave Destructive Potential
SFHA	Special Flood Hazard Area
SGN	Smart Growth Network

T

TAC	Texas Administration Code
TCPIA	Texas Catastrophe Property Insurance Association
TCR	Tropical Cyclone Report
TDI	Texas Department of Insurance
TRCC	Texas Residential Construction Commission
TTU	Texas Tech University
TWIA	Texas Windstorm Insurance Association

U

UBC	Uniform Building Code
USACE	U.S. Army Corps of Engineers

USGS U.S. Geological Survey

UTC Universal Time Coordinated

UTMB University of Texas Medical Branch

V

VSI Vinyl Siding Institute

W

WDP Wind Destructive Potential

Glossary

100-year flood – The flood elevation that has a 1-percent chance of being equaled or exceeded each year.

ASCE 7 – National design standard issued by the American Society of Civil Engineers, *Minimum Design Loads for Buildings and Other Structures,* which gives current requirements for dead, live, soil, flood, wind, snow, rain, ice, and earthquake loads, and their combinations, suitable for inclusion in building codes and other documents.

ASCE 24 – National design standard issued by the American Society of Civil Engineers, *Flood Resistant Design and Construction,* which outlines the requirements for flood resistant design and construction of structures in flood hazard areas.

Base Flood Elevation – Elevation of the 1-percent-annual-chance flood. This elevation is the basis of the insurance and floodplain management requirements of the National Flood Insurance Program.

Building envelope – The entire exterior surface of a building, including roofs, walls, windows, and doors, which encloses or envelops the space within.

Capillary action – Commonly referred to as "wicking," capillary action is the process by which water in liquid form climbs upward through materials in opposition to the force of gravity.

Critical and essential facilities – Facilities that, if damaged, would present an immediate threat to life, public health, and safety. Critical and essential facilities include, but are not limited to, hospitals, emergency operations centers, water systems, and utilities.

Design flood event – The greater of the following two flood events: (1) the base flood, affecting those areas identified as special flood hazard areas on a community's Flood Insurance Rate Map (FIRM); or (2) the flood corresponding to the area designated as a flood hazard area on a community's flood hazard map or otherwise legally designated.

Design wind event – An event for which the observed wind speed equaled or exceeded the design wind speed.

Design wind speed – The wind speed designated in ASCE 7 or the building code.

Eave – The horizontal lower edge of a sloped roof.

Erosion – Process by which floodwaters lower the ground surface in an area by removing upper layers of soil.

Fetch – The distance along open water or land over which the wind blows.

Floodborne debris impact – Floodwater moving at a moderate or high velocity can carry floodborne debris that can impact buildings and damage walls and foundations.

Floodwall – A long, narrow concrete or masonry wall built to protect land from flooding.

Freeboard – The height added to place a structure above the base flood to reduce the potential for flooding. The increased elevation of a building above the minimum design flood level to provide additional protection for flood levels higher than the 1-percent-annual-chance flood level and to compensate for inherent inaccuracies in flood hazard mapping.

Gable end wall – The triangular end of an exterior wall above the eaves formed under a gable roof.

Girt – A horizontal structural member that is attached to sidewall or endwall columns and supports wall paneling.

Glazing – Glass or transparent or translucent plastic sheet used in windows, doors, and skylights.

Hem – The portion of the cleat (coping or edge flashing) that bends out at about a 60-degree angle at the bottom portion of the cleat/coping or edge flashing.

Hurricane – An intense tropical weather system with a well-defined counter-clockwise circulation and sustained winds of 74 mph or higher.

Insulated concrete form construction – A construction technique for which the walls of the building are composed of hollow styrofoam blocks or foam panels, which serve as concrete forms that remain in place after they are reinforced and filled with concrete.

Levee – A manmade structure, usually an earthen embankment, designed and constructed in accordance with sound engineering practices to contain, control, or divert the flow of water so as to provide protection from temporary flooding.

Pier foundation – Vertical support member of masonry or cast-in place concrete that is designed and constructed to function as an independent structural element in supporting and transmitting both building loads and environmental loads to the ground. Typical pier foundations are constructed on footings.

Pile foundation system – Vertical support member of wood, steel, or precast concrete that is driven or jetted into the ground and supported primarily by friction between the pilings and surrounding earth. Pilings often cannot act as independent support units and, therefore, are often braced with connections to other pilings.

Pole construction – A type of construction for which the pilings extend from the ground to the roof system. It differs from platform construction for which the pilings terminate at the lowest floor.

Purlin – A horizontal structural member that supports roof covering and carries loads to the primary framing members.

Rake – The inclined edge of a sloped roof over a wall.

Reinforced concrete – Concrete with steel mesh or bars embedded in it to increase its tensile strength.

Saffir-Simpson Scale – Measures a hurricane's intensity on a 1–5 scale to give an estimate of the potential property damage and flooding expected. Wind speed is the determining factor in the scale. A Category 1 hurricane is the weakest, with winds from 74–95 mph (maximum, 1-minute sustained speeds), and a Category 5 hurricane is the strongest, with winds over 155 mph. Refer to Table 1-2.

Slab-on-grade foundation – Type of foundation for which the lowest floor of the house is formed by a concrete slab that sits directly on the ground.

Soffit – The underside of a horizontal element of a building, especially the underside of a stair or a roof overhang.

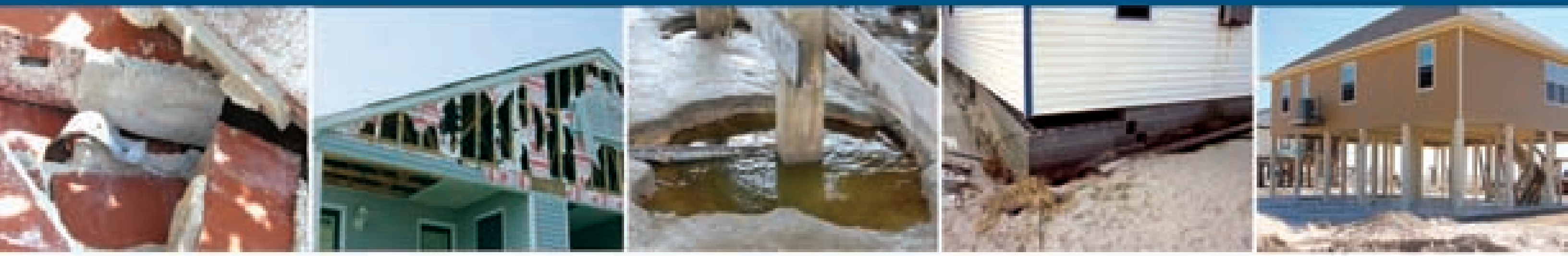
Special Flood Hazard Area – Portion of the floodplain subject to inundation by the base flood.

Steel moment frame – In steel moment frame buildings, the ends of the beams are rigidly joined to the columns so that the buildings can resist lateral wind forces without the assistance of additional braces or walls.

Stem wall foundation – A type of foundation that uses masonry block and is reinforced with steel and concrete. The wall is constructed on a concrete footing, back-filled with dirt, and compacted, and then the slab is poured on top.

Storm surge – The water that is pushed toward land from the high winds of a major storm (i.e., hurricane).

Tropical storm – A tropical cyclone with maximum sustained (1-minute average) winds of 39 to 73 mph.



HURRICANE IKE IN TEXAS & LOUISIANA

D Hurricane Ike Recovery Advisories

FEMA has prepared a series of Recovery Advisories that present guidance for design, construction, and restoration of buildings in areas subject to coastal flooding and high winds from Hurricane Ike. To date, eight advisories have been prepared and are included in this appendix:

- Attachment of Brick Veneer in High-Wind Regions ([December, 2005]; revised 2009)
- Design and Construction in Coastal A Zones ([December, 2005]; revised 2009)
- Designing for Flood Levels above the BFE ([July, 2006]; revised 2009)
- Enclosures and Breakaway Walls
- Erosion, Scour, and Foundation Design
- Minimizing Water Intrusion Through Roof Vents in High-Wind Regions
- Metal Roof Systems in High-Wind Regions
- Siding Installation in High-Wind Regions

These Advisories are also available online at http://www.fema.gov/library/viewRecord.do?id=3539 where future Advisories will also be posted.

Attachment of Brick Veneer in High-Wind Regions

FEMA

http://www.fema.gov

HURRICANE IKE RECOVERY ADVISORY

Purpose: To recommend practices for installing brick veneer that will enhance wind resistance in high-wind areas (i.e., greater than 90-mph gust design wind speed).

Key Issues

- Brick veneer is frequently blown off walls of residential and non-residential buildings during hurricanes (Figure 1). When brick veneer fails, wind-driven water can enter and damage buildings, and building occupants can be vulnerable to injury from windborne debris (particularly if walls are sheathed with plastic foam insulation or wood fiberboard in lieu of wood panels). Pedestrians in the vicinity of damaged walls can also be vulnerable to injury from falling veneer (Figure 2).
- Common failure modes include tie (anchor) corrosion (Figure 3), tie fastener pull-out (Figure 4), failure of masons to embed ties into the mortar (Figure 5), and poor bonding between ties and mortar and mortar of poor quality (Figure 6).
- Ties are often installed before brick laying begins. When this is done, ties are often improperly placed above or below the mortar joints. When misaligned, the ties must be angled up or down in order for the ties to be embedded into the mortar joints (Figure 7). Misalignment not only reduces embedment depth, but also reduces the effectiveness of the ties because wind forces do not act parallel to the ties themselves.
- Corrugated ties typically used in residential veneer construction provide little resistance to compressive loads. Use of compression struts would likely be beneficial, but off-the-shelf devices do not currently exist. Two-piece adjustable ties (Figure 8) provide significantly greater compressive strength than corrugated ties and are, therefore, recommended. However, if corrugated ties are used, it is recommended that they be installed as shown in Figures 9 and 10 in order to enhance their wind performance.

Figure 1. Failed brick veneer over plywood. Many of the ties are still attached to the substrate, but several of the tie fasteners pulled out of the substrate and the ties are embedded in the collapsed veneer. Estimated wind speed: 107 miles per hour (peak gust, Exposure C, at 33 feet).

Figure 2. The upper portion of the brick veneer at this apartment building collapsed. Pedestrian and vehicular traffic in the vicinity of the damaged wall are vulnerable to injury and damage if remaining portions of the wall were to collapse during subsequent storms.

Figure 3. Significant tie corrosion caused the brick at a fire station to fail, even though the building is not near the coast. Note that metal is missing for half of of width of the tie at two locations (red arrows). The left end of the tie was still embedded into a concrete masonry unit back-up wall. The right end is where the tie failed in tension, thus leaving a portion of the tie embedded in the collapsed brick.

- Buildings that experience veneer damage typically do not comply with current building codes. Building code requirements for brick veneer have changed over the years. Model codes prior to 1995 permitted brick veneer in any location, with no wind speed restrictions. Also, some older model codes allowed brick veneers to be anchored with fewer ties than what is required by today's standards.

  The American Concrete Institute's (ACI's) 530/American Society of Civil Engineers (ASCE) 5/The Masonry Society (TMS) 402 (ACI 530) *Building Code Requirements for Masonry Structures* is the current masonry standard referenced by model building codes. The 2006 International Building Code® (IBC®) and the 2006 International Residential Code® (IRC®) both reference the 2005 edition of ACI 530. The latest ACI 530 is the 2008 edition.

  ACI 530 addresses brick veneer in two manners: rational design and a prescriptive approach. Nearly all brick veneer in residential and low-rise construction follows the prescriptive approach. The first edition of ACI 530 limited the use of prescriptive design to areas with a basic wind speed of 110 mph or less. The 2005 and the 2008 editions of ACI 530 extend the prescriptive requirements to include a basic wind speed of 130 mph, but limit the amount of brick that can be anchored with veneer ties to 70 percent of that allowed in lower wind speed regions. Both the 2005 and the 2008 editions require rational design approaches in locations where the basic wind speeds exceed 130 mph.

  Some noteworthy distinctions exist in the requirements for anchored brick veneer between the 2005 and the 2008 editions of ACI 530. For lower wind speed regions (110 mph and below), ACI 530-05 limited the vertical spacing of ties to 18"; the 2008 edition allows vertical ties to be spaced up to 25", provided the amount of veneer anchored per tie does not exceed 2.7 square feet. In ACI's high-wind regions (over 110 mph and up to 130 mph), both editions of the code limit vertical spacing to 18". ACI 530-08 also limits the space between veneer anchored with corrugated ties and the wall sheathing to 1". This is to avoid compression failures in the corrugated ties when they are exposed to positive pressures.

Figure 4. This tie remained embedded in the mortar joint while the smooth-shank nail pulled out from the stud.

Figure 5. These four ties were never embedded into the mortar joint.

Figure 6. This tie was embedded in the mortar, but the bond was poor.

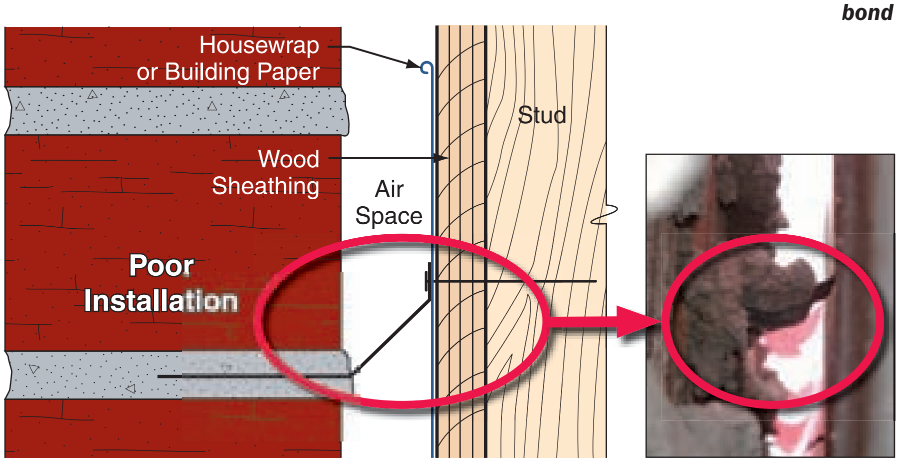


Figure 7. Misalignment of the tie reduces the embedment and promotes veneer failure.

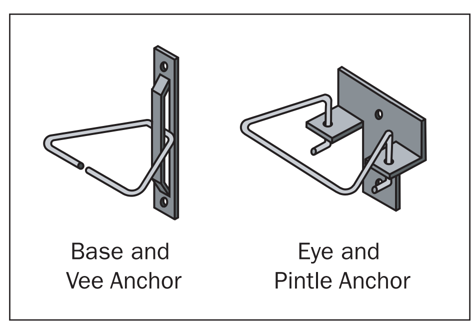


Figure 8. Examples of two-piece adjustable ties.

- The following Brick Industry Association (BIA) Technical Notes provide guidance on brick veneer: Technical Notes 28 – Anchored Brick Veneer, Wood Frame Construction; Technical Notes 28B – Brick Veneer/Steel Stud Walls; and Technical Notes 44B – Wall Ties (available online at http://www.bia.org). These Technical Notes provide attachment recommendations, but the recommendations are not specific for high-wind regions and are, therefore, inadequate.

Sustainability

Brick veneer can offer a very long service life, provided the ties are not weakened by corrosion. To help ensure that brick veneer achieves its long life potential, in addition to properly designing and installing the ties, stainless steel ties are recommended.

Construction Guidance

The brick veneer wall system is complex in its behavior. There are limited test data on which to draw. The following guidance is based on professional judgment, wind loads specified in ASCE 7-05, *Minimum Design Loads for Buildings and Other Structures*, fastener strengths specified in the American Forest and Paper Association's (AF&PA's) National Design Specification (NDS) for Wood Construction, and brick veneer standards contained in ACI 530-05. In addition to the general guidance given in BIA Technical Notes 28 and 28B, the following are recommended:

Note: In areas that are also susceptible to high seismic loads, brick veneer should be evaluated by an engineer to ensure it can resist seismic and wind design loads.

Stud Spacing: For new construction, space studs 16" on center, so that ties can be anchored at this spacing.

Tie Fasteners: Ring-shank nails are recommended in lieu of smooth-shank nails. A minimum embedment of 2" into framing is suggested.

Ties: For use with wood studs, two-piece adjustable ties are recommended. However, where corrugated steel ties are used, use 22-gauge minimum, 7/8" wide by 6" long, complying with American Society for Testing and Materials (ASTM) A 366 with a zinc coating complying with ASTM A 153 Class B2. For ties for use with steel studs, see BIA Technical Notes 28B – Brick Veneer/Steel Stud Walls. Stainless steel ties should be used in areas within 3,000 feet of the coast.

Tie Installation

- Install ties as the brick is laid so that the ties are properly aligned with the mortar joints.
- Install brick ties spaced per Table 1. Studs should be installed at 16" spacing. Veneer tie locations for 24" stud spacing are included for repairing damaged veneer on existing buildings with the wider stud spacing. In areas where the 2006 Editions of the IBC/IRC are adopted, install brick veneer ties spaced no more than 18" vertically to satisfy the requirements of ACI 530-05.
- Locate ties within 8" of door and window openings and within 12" of the top of veneer sections.
- Bend the ties at a 90-degree angle at the nail head in order to minimize tie flexing when the ties are loaded in tension or compression (Figure 9).
- Embed ties in joints so that mortar completely encapsulates the ties. Embed a minimum of 1 1/2" into the bed joint, with a minimum mortar cover of 5/8" to the outside face of the wall (Figure 10).

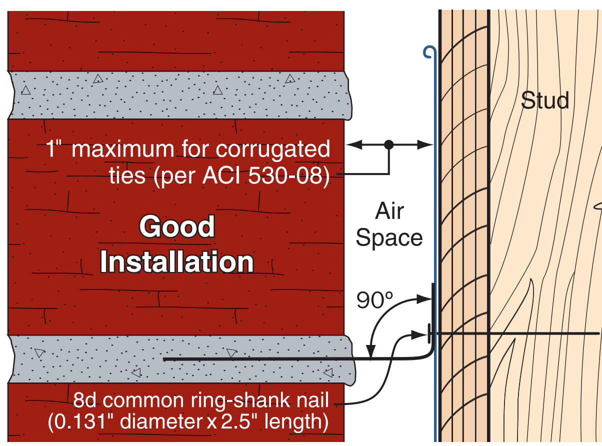


Figure 9. Bend ties at nail heads.

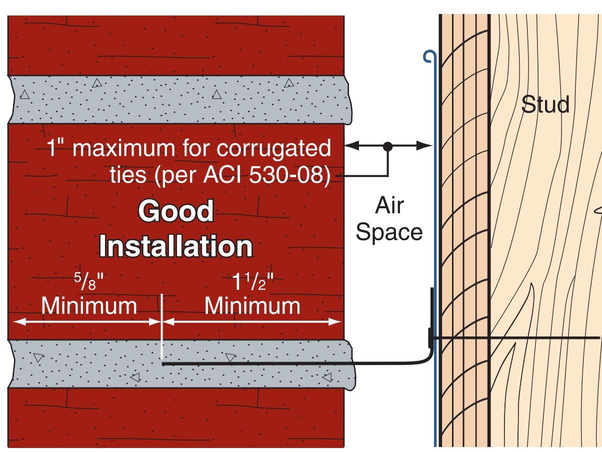


Figure 10. Tie embedment.

Table 1. Brick Veneer Tie Spacing

Wind Speed (mph) (3–Second Peak Gust)	Wind Pressure (psf)	Maximum Vertical Spacing for Ties (inches)	
		16" stud spacing	24" stud spacing
90	–19.5	24[a,b]	16[a]
100	–24.1	24[a,b]	16[a]
110	–29.1	20½ [b]	13½
120	–34.7	17	NA[c]
130	–40.7	15	NA[c]
140	–47.2	13	NA[c]
150	–54.2	11	NA[c]

Notes:

1. The tie spacing is based on wind loads derived from Method 1 of ASCE 7-05, for the corner area of buildings up to 30' high, located in Exposure B with an importance factor (I) of 1.0 and no topographic influence. For other heights, exposures, or importance factors, engineered designs are recommended.
2. Spacing is for 2½" long 8d common (0.131" diameter) ring-shank fasteners embedded 2" into framing. Fastener strength is for wall framing with a Specific Gravity G=0.55 with moisture contents less than 19 percent and the following adjustment factors, C_t=0.8; and C_D, C_M, C_{eg}, and C_{tn}=1.0. Factored withdrawal strength W'= 65.6#.
3. The brick veneer tie spacing table is based on fastener loads only and does not take into account the adequacy of wall framing, sheathing, and other building elements to resist wind pressures and control deflections from a high-wind event. Prior to repairing damaged brick veneer, the adequacy of wall framing, wall sheathing, and connections should be verified by an engineer.

a Maximum spacing allowed by ACI 530-08.

b In locales that have adopted the 2006 IBC/IRC, the maximum vertical spacing allowed by ACI 530-05 is 18".

c 24" stud spacing exceeds the maximum horizontal tie spacing of ACI 530-08 prescribed for wind speeds over 110 mph.

Design and Construction in Coastal A Zones

FEMA
http://www.fema.gov

HURRICANE IKE RECOVERY ADVISORY

Purpose: To recommend design and construction practices in coastal areas where wave and flood conditions during the base flood will be less severe than in V zones, but still cause signif cant damage to typical light-frame construction.

Key Issues

- Recent post-storm investigations have shown that typical A-zone construction techniques (e.g., wood-frame, light gauge steel, or masonry walls on shallow footings or slabs, etc.) are subject to damage or destruction when exposed to less than 3' waves, which is the current threshold for V-zone conditions.
- Coastal A-zone buildings that employ typical residential and light commercial walls to elevate and support habitable space above the flood level will be susceptible to flood damage (Figure 1). Laboratory tests and recent f eld investigations conf rm that breaking wave heights as small as 1.5' will cause failure of these types of walls (Figure 2).
- Other flood hazards associated with coastal waves (e.g., floating debris, high velocity flow, erosion and scour) also damage A-zone type construction in coastal areas (Figure 3).
- National Flood Insurance Program (NFIP) flood hazard mapping is generally divided into two categories, V and A zones. In coastal areas, the A-zone category could be subdivided into “Coastal A zone” and “A

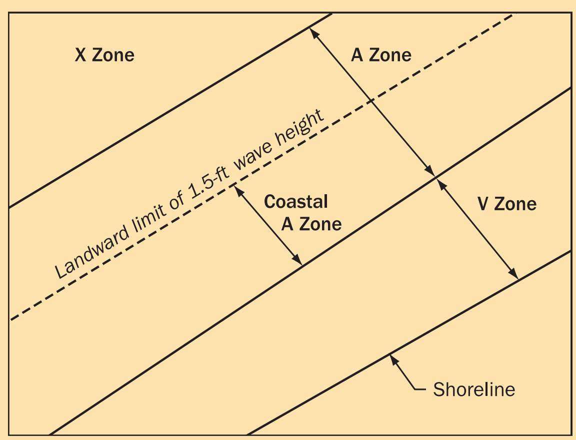
Figure 1. Failure of wood-frame walls used to support a coastal building, which was subjected to shallow flooding, small waves, and floating debris (Fort Walton Beach, FL, Hurricane Opal).

The Hurricane Ike Mitigation Assessment Team (MAT) observed small wave damage consistent with Coastal A-zone conditions throughout the area affected by Ike, including portions of west Galveston Island (Figure 4), communities situated along portions of Galveston Bay (Figure 5), Orange County (Figure 6), and portions of coastal Louisiana (Figure 7).

Coastal A Zone, Defined

Coastal A Zone: area landward of a V zone, or landward of an open coast without mapped V zones. In a Coastal A zone, the principal source of flooding will be astronomical tides, storm surges, seiches or tsunamis, not riverine flooding. During base flood conditions, the potential for wave heights between 1.5 and 3.0' will exist. At least 2 to 4' of stillwater depth is necessary to support these wave heights.

Coastal A-zone design and construction practices described herein are not mandated by the NFIP, but are recommended for communities that wish to adopt higher floodplain management standards. Community Rating System (CRS) credits are available for doing so. Note that some Coastal A-zone practices may be required by the International Building Code®, through its reference to ASCE 24, *Standard for Flood Resistant Design and Construction*.



Plan view showing a Coastal A zone landward of a V zone (source: ASCE 24-05).

zone." Base flood conditions in the Coastal A zone will be similar to, but less severe than, those in the V zone; base flood conditions in the A zone will be similar to those in riverine or lake floodplains.

- The Coastal A zone is not shown on the Flood Insurance Rate Maps (FIRMs) presently adopted by communities. Communities, designers, and owners will have to determine whether a site lies within a Coastal A zone, either by wave height estimation or by consultation with FEMA regarding the LiMWA (see text box).

> Flood insurance studies produced after Hurricane Katrina may include an advisory line indicating the limit of the 1.5' wave height during the base flood. This line is known as the Limit of Moderate Wave Action (LiMWA), and the area between this line and the VE zone boundary is the Coastal A zone.

- **In general, V-zone design and construction standards are recommended in Coastal A zones subject to erosion, high velocity flow, and/or wave heights greater than 1.5'.**

Figure 2. Failure of wood-frame wall, brick veneer, and windows as a result of 4' of stillwater flooding and small waves (Bay St. Louis, MS, Hurricane Katrina).

Figure 3. Failure of A-zone type foundation in coastal area, not subject to V-zone conditions (Topsail Island, NC, Hurricane Fran).

Figure 4. Coastal A-zone flood conditions are sufficient to cause failure of solid breakaway walls and garage doors (west Galveston Island, TX, Hurricane Ike).

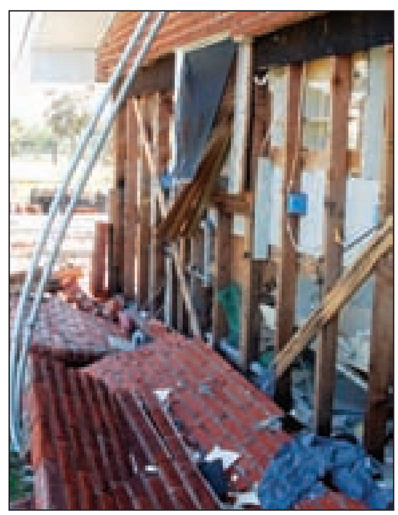


Figure 5. Damage to brick veneer walls due to shallow flooding, floating debris, and small waves. The damaged home was on a sheltered bay shoreline (Baytown, TX, Hurricane Ike).

V

V Zone

A Zones in Coastal Areas

Coastal A	Areas With Potential for Damaging Waves and Erosion During Base Flood	A	Areas With Shallow Flooding Only, Where Potential for Damaging Waves and Erosion Is Low

Figure 6. Damage attributed to small waves and approximately 5' of stillwater depth (Bridge City, TX, Hurricane Ike).

Figure 7. Damage believed to have resulted from Coastal A-zone conditions (Johnson Bayou, LA, Hurricane Ike).

Coastal A-Zone Construction Guidance

Because of the presence of damaging waves, V-zone design, construction, and certif cation practices are recommended for Coastal A zones.

Coastal A-zone construction should include:

- Use of open foundations (pile or pier) designed to resist all base flood conditions, including small waves, high velocity flow, erosion and scour, and floodborne debris (see Table 1).
- Elevation of the bottom of the lowest horizontal structural member supporting the lowest floor above the base flood wave crest elevation (Figure 8). Since waves and debris will be impacting on the floor joists and other foundation elements during the base flood, do not follow current NFIP minimum requirements that allow the lowest floor's walking surface to be set at the wave crest elevation in Zone A. **The 2009 International Residential Code® (IRC®) will require 1' of freeboard in V zones and Coastal A zones.**

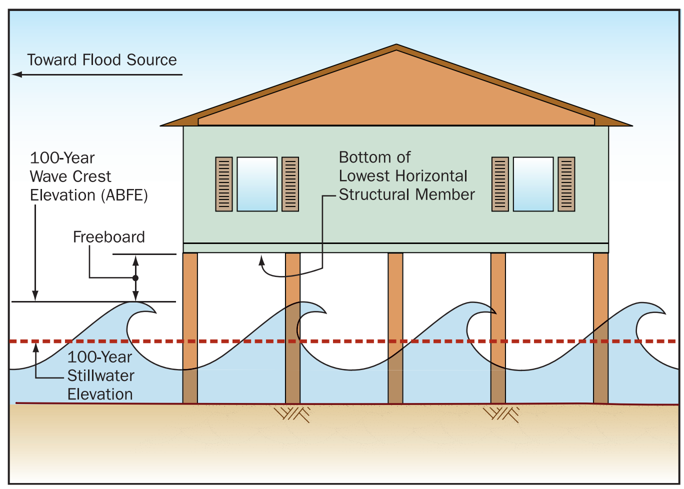


Figure 8. Recommended post-Katrina building standards in Coastal A zones.

- Use of flood-resistant materials above the level of the walking surface of the lowest floor (in the event that future flooding exceeds the lowest floor level and any freeboard incorporated into the building design).
- Specification of connections between the foundation and the elevated building that are capable of withstanding simultaneous wind and flood forces. Post-hurricane investigations typically find many foundation-to-building connections that are def cient.
- Use of space below the lowest horizontal structural member for parking, access, or storage only. Adding suff cient freeboard to allow parking beneath the building will not only reduce future flood damages, but will also lower flood insurance premiums.

- Use of screen, lattice, louvers, or solid breakaway walls if space below the elevated floor is enclosed (see Hurricane Ike Recovery Advisory, *Enclosures and Breakaway Walls*). Note: unless flood regulations are changed, solid breakaway walls in Coastal A zones must be equipped with flood openings.

Additional guidance for design and construction in Coastal A zones can be found in FEMA 499, *Home Builder's Guide to Coastal Construction* (http://www.fema.gov/library/viewRecord.do?id=1570). The publication is a series of 31 fact sheets that provide recommended design and construction practices for foundations, connections, building envelope, etc. Fact Sheet 2 summarizes recommended practices for Coastal A zones, and references other fact sheets that provide more details.

Table 1. Foundation Recommendations for Coastal A Zones (Users should read across from a foundation type to see under what soil and base flood conditions that foundation is acceptable. A foundation must be capable of resisting all base flood conditions likely to exist at the site, or it should not be used. For example, a properly constructed pier on a shallow footing will generally withstand 1.5 to 3.0' wave heights, but should not be used where soils are erodible, and where high velocity flow is possible.)

Foundation Type	Base Flood Condition Present	
	Wave Heights Between 1.5 and 3.0 Feet*	Velocity Flow, Erodible Soils
Fill	no	no
Slab on grade	no	no
Crawlspace, shallow footing	no	no
Foundation walls, shallow footing	no	no
Stem wall**	no	no
Pier, shallow footing	yes	no
Pier, deep footing***	yes	yes
Post, shallow embedment	no	no
Pile/Column, deep embedment***	yes	yes

* Wave heights greater than 3.0' mapped as V zone: fill, slab, crawlspace, wall foundations not permitted.

** Typical stem wall foundations are vulnerable to damage from small waves or undermining and are, therefore, not recommended for use in Coastal A zones.

*** Deep means suff ciently deep to withstand erosion and scour, including that induced by the presence of the foundation itself.

Identifying Coastal A Zones

Coastal A zones are not shown on present day FIRMs or mentioned in a community's Flood Insurance Study (FIS) Report. Those maps and studies show Zones VE, AE, and X (or older designations V1-30, A1-30, B, and C). Therefore, until Coastal A-zone designations or wave height contours are incorporated into FISs, the community official, designer, or owner will have to determine whether or not a site will be subject to Coastal A-zone conditions during the base flood.

In order for a Coastal A zone to be designated, two conditions are required:

1) a water depth suff cient to support waves between 1.5 and 3.0' high, and

2) the actual presence of wave heights between 1.5 and 3.0'.

Condition 1 requires stillwater depths (vertical distance between the 100-year stillwater elevation and the ground elevation) of at least 2 to 4' at the site.

Condition 2 requires wave heights at the shoreline greater than 1.5 to 3.0' (under the 100-year flood conditions), suff cient water depth between the shoreline and the site and few, if any obstructions (buildings, dense tree stands, etc.) that may block or dampen the waves, between the shoreline and the site.

Figure 9 illustrates the procedure that was used following Hurricane Katrina to estimate Advisory Base Flood Elevations (ABFEs) and corresponding Coastal A zones, knowing only the ground elevation and the 1-percent annual chance stillwater level.

Communities, designers, and owners can obtain the information necessary to make a post-Ike Coastal A-zone determination by observing the site and its surroundings, knowing site ground elevations, and using 1-percent annual chance stillwater elevations (from the FIS report or as determined by a government agency). Figure 10 shows how site and surrounding conditions would influence a Coastal-A zone determination.

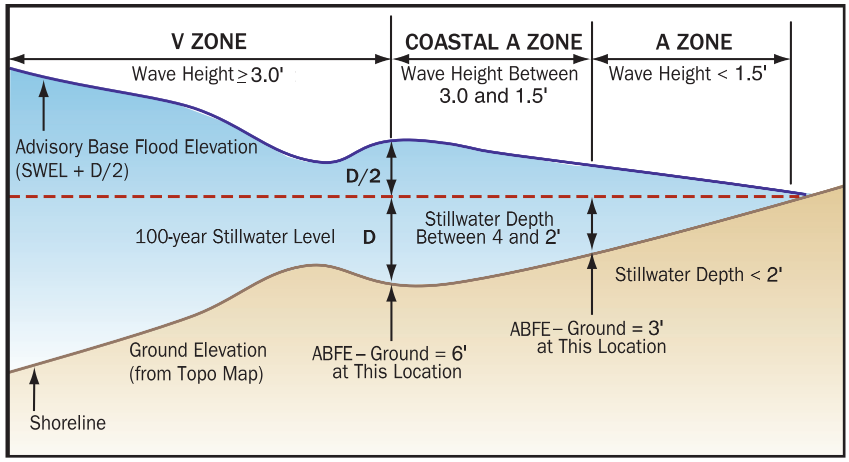


Figure 9. Post-Katrina Coastal A-zone methodology cross-section showing 1 percent annual chance stillwater elevation, stillwater depth and ABFE, and inland limits of an V zone and a Coastal A zone.

Figure 10. The site on the left is mapped Zone AE, and lies directly along the Gulf of Mexico shoreline. Limited obstructions to waves indicate the site could be classified as a Coastal A zone. The site on the right is over ½ mile from the Gulf shoreline, is mapped as Zone AE, and has a base flood stillwater level sufficient to support >1.5' wave heights – but obstructions to waves (e.g., trees and other buildings between the site and the shoreline) and distance from the source of flooding would indicate the area is not a Coastal A zone.

References

ASCE. 2005. *Standard for Flood Resistant Design and Construction*, ASCE 24-05.

FEMA. 2005. *Home Builder's Guide to Coastal Construction*, FEMA 499.

FEMA. 2009. *Hurricane Ike Recovery Advisory, Enclosures and Breakaway Walls*.

ICC 2006. International Building Code. 2006.

ICC 2009. International Residential Code. 2009.

Designing for Flood Levels Above the BFE

FEMA
http://www.fema.gov

HURRICANE IKE RECOVERY ADVISORY

Purpose: To recommend design and construction practices that reduce the likelihood of flood damage in the event that flood levels exceed the Base Flood Elevation (BFE).

Key Issues

- BFEs are established at a flood level, including wave effects, that has a 1-percent chance of being equaled or exceeded in any given year, also known as the 100-year flood or base flood. Floods more severe and less frequent than the 1-percent flood can occur in any year.
- Flood levels during some recent storms have exceeded BFEs depicted on the Flood Insurance Rate Maps (FIRMs), sometimes by several feet. In many communities, flooding extended inland, well beyond the 100-year floodplain (Special Flood Hazard Area (SFHA)) shown on the FIRM (see Figure 1).
- Flood damage increases rapidly once the elevation of the flood extends above the lowest floor of a building, especially in areas subject to coastal waves. In a V zone, a coastal flood with a wave crest 3 to 4' above the bottom of the floor beam (approximately 1 to 2 feet above the walking surface of the floor) will be sufficient to substantially damage or destroy most light-framed residential and commercial construction (see Figure 2).
- There are design and construction practices that can eliminate or minimize damage to buildings when flood levels exceed the BFE. The most common approach is to add freeboard to the design (i.e., to elevate the building higher than required by the FIRM).
- There are other benefits of designing for flood levels above the BFE: reduced building damage and maintenance: longer building life; reduced flood insurance premiums; reduced displacement and dislocation of building occupants after floods (and need for temporary shelter and assistance); reduced job loss; and increased retention of tax base.
- The cost of adding freeboard at the time of home construction is modest, and reduced flood insurance premiums will recover the freeboard cost in a few years time.

Figure 1. Bridge City, TX, homes were flooded during Ike, even though they were constructed outside the SFHA and in Zone B. The flood level was approximately 4' above the closest BFE.

Figure 2. Bolivar Peninsula, TX, V-zone house constructed with the lowest floor (bottom of floor beam) at the BFE (dashed line). The estimated wave crest level during Ike (solid line) was 3 to 4' above the BFE at this location.

How High Above the BFE Should a Building be Elevated?

Ultimately, the building elevation will depend on several factors, all of which must be considered before a final determination is made:

- **The accuracy of the BFE shown on the FIRM:** If the BFE is suspect, it is probably best to elevate several feet above the BFE; if the BFE is deemed accurate, it may only be necessary to elevate a couple of feet above the BFE.
- **Availability of Advisory Base Flood Elevations (ABFEs):** ABFEs have been produced for coastal areas following Hurricanes Ivan, Katrina, and Rita. These elevations are intended to be interim recommendations until new FISs can be completed.
- **Availability of Preliminary Digital Flood Insurance Rate Maps (DFIRMS):** As new Flood Insurance Studies (FISs) are completed for Louisiana and Texas communities, preliminary DFIRMs will be produced and available for use, even before they are officially adopted by those communities.
- **Future conditions:** Since the FIRM reflects conditions at the time of the FIS, some owners or jurisdictions may wish to consider future conditions (such as sea level rise, subsidence, wetland loss, shoreline erosion, increased storm frequency/intensity, and levee settlement/failure) when they decide how high to elevate.
- **State or local requirements:** The State or local jurisdiction may require a minimum freeboard through its floodplain management requirements or building code.
- **Building code requirements:** The International Building Code® (IBC®) requires buildings be designed and constructed in accordance with American Society of Civil Engineers (ASCE) 24 (*Standard for Flood Resistant Design and Construction*). ASCE 24 requires between 0 and 2' of freeboard, depending on the building importance and the edition of ASCE 24 referenced.[1] The 2009 IRC will require 1 foot of freeboard in V and Coastal A zones.
- **Critical and essential facilities:** Given the importance of these facilities, some of which must remain operational during a hurricane, they should be elevated higher than commercial and residential buildings.
- **Building owner tolerance for damage, displacement, and downtime:** Some building owners may wish to avoid building damage and disruption, and may choose to elevate far above the BFE.

The Hurricane Ike MAT report recommends that critical and essential facilities be elevated to the 500-year flood elevation or to the requirements of ASCE 24-05, whichever is higher. This recommendation may also be appropriate for residential and commercial structures, as well.

The 500-year wave crest elevation can be approximated as 1.5 times the 500-year stillwater depth (500-year stillwater elevation minus the ground elevation) added to the ground elevation. This procedure is similar to the procedure used to calculate ABFEs, but with a different stillwater level.

If the 500-year stillwater elevation (feet North American Vertical Datum of 1988 [NAVD] or feet National Geodetic Vertical Datum of 1929 [NGVD]) is not available, a rule of thumb can be used to approximate it as 1.25 times the 100-year stillwater elevation (feet NAVD or feet NGVD).

MAT Elevation Recommendation

The Hurricane Ike MAT recommends new and reconstructed residential and commercial buildings be elevated above the effective BFEs with freeboard equal to that specified in ASCE 24-05, plus 3 feet. Once new DFIRMs are available and adopted, the MAT recommends new and reconstructed residential and commercial buildings be elevated to or above the freeboard elevation specified by ASCE 24-05. Critical and essential facilities should be elevated higher than residential and commercial buildings.

Flood Insurance Rate Maps and Flood Risk

Hurricanes Ivan (2004), Katrina (2005), Rita (2005), and Ike (2008) have demonstrated that constructing a building to the minimum National Flood Insurance Program (NFIP) requirements – or constructing a building outside the SFHA shown on the FIRMs – is no guarantee that the building will not be damaged by flooding. This is due to two factors: 1) flooding more severe than the base flood occurs, and 2) some FIRMs, particularly older FIRMs, may no longer depict the true base flood level and SFHA boundary.

Even if the FIRM predicted flood levels perfectly, buildings constructed to the elevations shown on the FIRM will offer protection only against the 1-percent annual chance flood level (BFE). Some coastal storms will result in

[1] The 1998 edition of ASCE 24 is referenced by the 2003 edition of the IBC, and requires between 0 and 1' of freeboard. The 2005 edition of ASCE 24 is referenced by the 2006 edition of the IBC, and requires between 0 and 2' of freeboard.

flood levels that exceed the BFE, and buildings constructed to the minimum elevation could sustain flood damage. The black dashed line in Figure 3 shows the probability that the level of the flood will exceed the 100-year flood level during time periods between 1 year and 100 years; there is an 18-percent chance that the 100-year flood level will be exceeded in 20 years, a 39-percent chance it will be exceeded in 50 years, and a 51-percent chance it will be exceeded in 70 years. As the time period increases, the likelihood that the 100-year flood will be exceeded also increases.

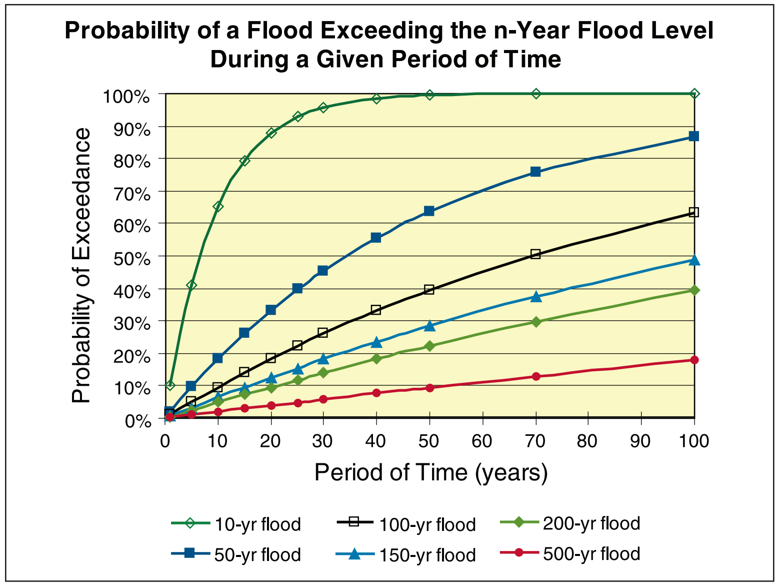


Figure 3. Probability that a flood will exceed the n-year flood level over a given period of time. (Note: this analysis assumes no shoreline erosion, and no increase in sea level or storm frequency/severity over time.)

Figure 3 also shows the probabilities that floods of other severities will be exceeded. For example, taking a 30-year time period where there is a 26-percent chance that the 100-year flood level will be exceeded, there is an 18-percent chance that the 150-year flood will be exceeded, a 14-percent chance that the 200-year flood will be exceeded, and a 6-percent chance that a flood more severe than the 500-year flood will occur.

FIRMs depict the limits of flooding, flood elevations, and flood hazard zones during the base flood. As seen in Figure 3, buildings elevated only to the BFEs shown on the FIRMs have a significant chance of being flooded over a period of decades. Users should also be aware that the flood limits, flood elevations, and flood hazard zones shown on the FIRM reflect ground elevations, development, and flood conditions at the time of the FIS.[2]

Consequences of Flood Levels Exceeding the BFE

Buildings are designed to ***resist*** most environmental hazards (e.g., wind, seismic, snow, etc.), but are generally designed to ***avoid*** flooding by elevating the building above the anticipated flood elevation. The difference in design approach is a result of the sudden onset of damage when a flood exceeds the lowest floor elevation of a building. Unlike wind – where exposure to a wind speed slightly above the design speed does not generally lead to severe building damage – occurrence of a flood level even a few inches above the lowest floor elevation generally leads to significant flood damage, therefore, the recommendation to add freeboard.

This is especially true in cases where waves accompany coastal flooding. Figure 4 illustrates the expected flood damage (expressed as a percent of a building's pre-damage market value) versus flood depth above the bottom of the lowest horizontal structural member supporting the lowest floor (e.g., bottom of the floor beam), for a V-zone building and for a riverine A-zone building.[3]

FIRMs do not account for the following:

- Shoreline erosion, wetland loss, subsidence, and relative sea level rise
- Upland development or topographic changes
- Degradation or settlement of levees and floodwalls
- Changes in storm climatology (frequency and severity)
- The effects of multiple storm events

Thus, what was once an accurate depiction of the 100-year floodplain and flood elevations may no longer be so.

One striking difference between the two curves is that a V-zone flood depth (wave crest elevation) 3 to 4' above the bottom of the floor beam (or approximately 1 to 2' above the top of the floor) is sufficient to cause substantial (>50 percent) damage to a building. In contrast, A zone riverine flooding (without waves and high velocity) can submerge a structure without causing substantial damage. This difference in building damage is a direct result of the energy contained in coastal waves striking buildings – something obvious to those who saw the wave damage that Hurricane Ike caused in Texas and Louisiana (see Figure 5).

[2] Sections 7.8.1.3 and 7.9 of FEMA's *Coastal Construction Manual* (FEMA 55, 2000 edition) provide guidance on evaluating a FIRM to determine whether it still provides an accurate depiction of base flood conditions, or whether it is obsolete.

[3] Since the normal floor reference for A-zone buildings is the top of the lowest floor, the A-zone curve was shifted for comparison with the V-zone curve.

In cases where buildings are situated behind levees, a levee failure can result in rapid flooding of the area. Buildings near a levee breach may be exposed to high velocity flows, and damages to those buildings will likely be characterized by the V-zone damage curve in Figure 4. Damages to buildings farther away from the breach will be a result of inundation by floodwaters, and will likely resemble the A-zone curve in Figure 4.

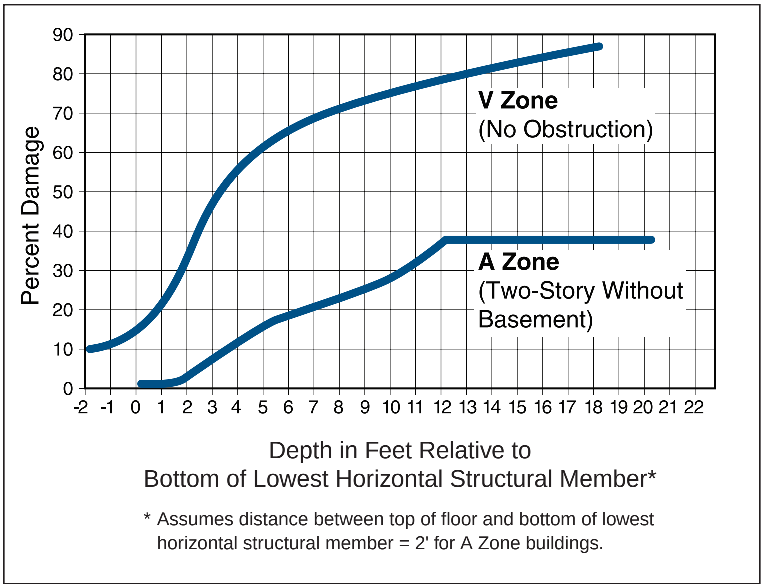


Figure 4. Flood depth versus building damage curves for V zones and riverine A zones (Source:* FEMA 55, *Coastal Construction Manual).

Figure 5. Hurricane Ike damage to buildings. The upper left and upper right photos are of buildings that were close to the Gulf of Mexico shoreline and subjected to storm surge and large waves above the lowest floor. The lower left photo is of a building close to Galveston Bay shoreline and subjected to storm surge and small waves. The lower right photo is of a Cameron Parish, Louisiana, school that was approximately 1.3 miles from the Gulf shoreline, but subjected to storm surge and small waves.

General Recommendations

The goal of this Advisory is to provide methods to minimize damage to buildings in the event that coastal flood levels rise above the BFE. Achieving this goal will require adherence to one or more of the following general recommendations:

- **In all areas where flooding is a concern**, inside and outside the SFHA, **elevate the lowest floor so that the bottom of the lowest horizontal structural member is at or above the Design Flood Elevation (DFE).** Do not place the top of the lowest floor at the DFE, since this guarantees flood damage to wood floor systems, wood floors, floor coverings, and lower walls during the design flood, and may lead to mold/contamination damage (see Figure 6).
- **In flood Zones V and A**, use a DFE that results in **freeboard** (elevate the lowest floor above the BFE) (see Figure 7).
- In flood Zones V and A, **calculate design loads and conditions** (hydrostatic loads, hydrodynamic loads, wave loads, floating debris loads, and erosion and scour) under the assumption that the flood level will exceed the BFE.
- In an A zone subject to moderate waves (1.5 to 2.9 ft high) and/or erosion (i.e., a Coastal A zone), use a pile or column foundation (see Figure 7). See the Hurricane Ike Recovery Advisory at http://www.fema.gov/library/viewRecord.do?id=3539 for details on Coastal A zones.
- Outside the SFHA (in **flood Zones B, C, and X**), **adopt flood-resistant design and construction practices** if historical evidence or a review of the available flood data shows the building could be damaged by a flood more severe than the base flood (see Figure 8).
- **Design and construct buildings using the latest model building code, ASCE 7-05**, *Minimum Design Loads for Buildings and Other Structures* and **ASCE 24-05**, *Standard for Flood Resistant Design and Construction*.
- **Follow the recommendations in FEMA 499**, *Home Builder's Guide to Coastal Construction Technical Fact Sheets* Series (available at: http://www.fema.gov/rebuild/mat/mat_fema499.shtm).
- **Use the pre-engineered foundations shown in FEMA 550**, *Recommended Residential Construction for the Gulf Coast: Building on Strong and Safe Foundations* (available at: http:\\www.fema.gov\library\viewRecord.do?id=1853).
- Use **strong connections between the foundation and the elevated building** to prevent the building from floating or washing off the foundation, in the event that flood levels do rise above the lowest floor.

Figure 6. Other concerns when flood levels rise above the lowest floor are mold and biological/chemical contamination. These may render an otherwise repairable building unrepairable, or will at least make the cleanup, restoration, and repairs much more expensive and time-consuming.

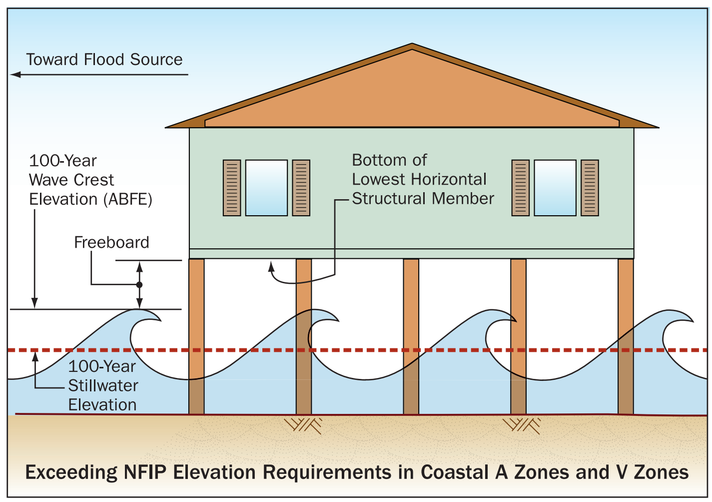


Figure 7. Recommended construction in Coastal A zones and V zones.

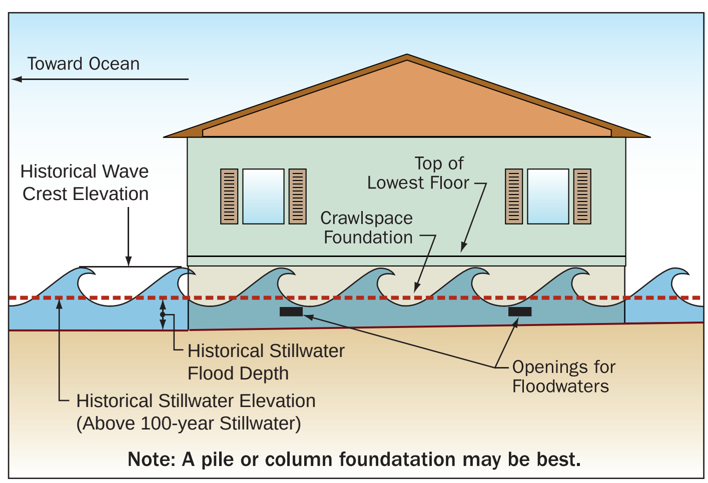


Figure 8. Recommended construction in Zones B, C, and X.

- Use **flood damage-resistant building materials and methods** above the lowest floor. For example, consider using drainable, dryable interior wall assemblies (see Figure 9). This allows interior walls to be opened up and dried after a flood above the lowest floor, minimizing damage to the structure. For cavity and mass wall assemblies, the methods and materials in Figures 10 and 11 are recommended.

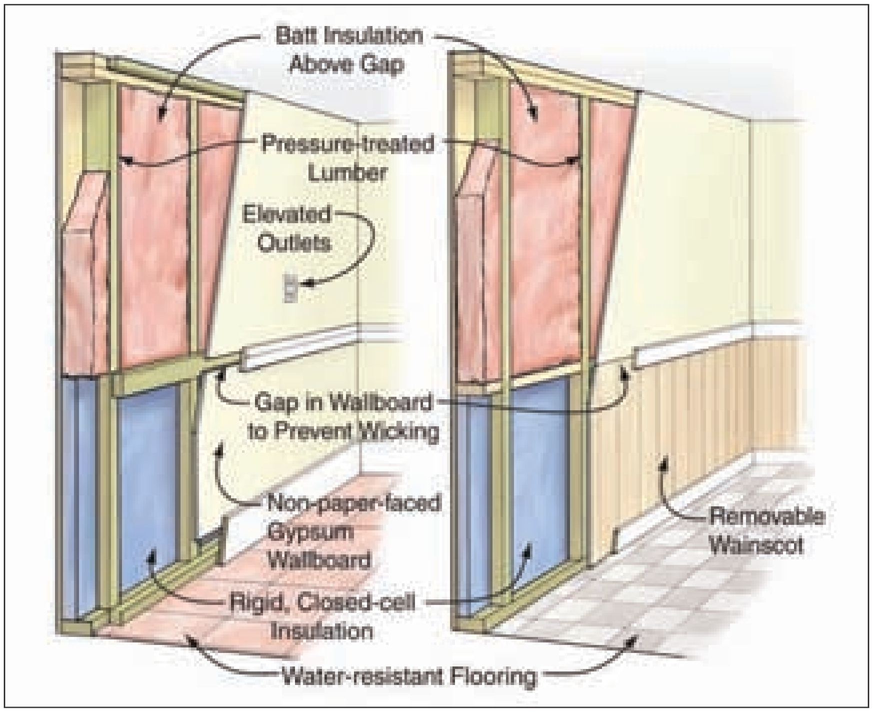


Figure 9. Recommended wet floodproofing techniques for interior wall construction. The following flood damage-resistant materials and methods will prevent wicking and limit flood damage: 1) construct walls with horizontal gaps in wallboard; 2) use non-paper-faced gypsum wallboard below gap, painted with latex paint; 3) use rigid, closed-cell insulation in lower portion of walls; 4) use water-resistant flooring with waterproof adhesive; and 5) use pressure treated wood framing (Source: LSU AgCenter and Coastal Contractor Magazine).

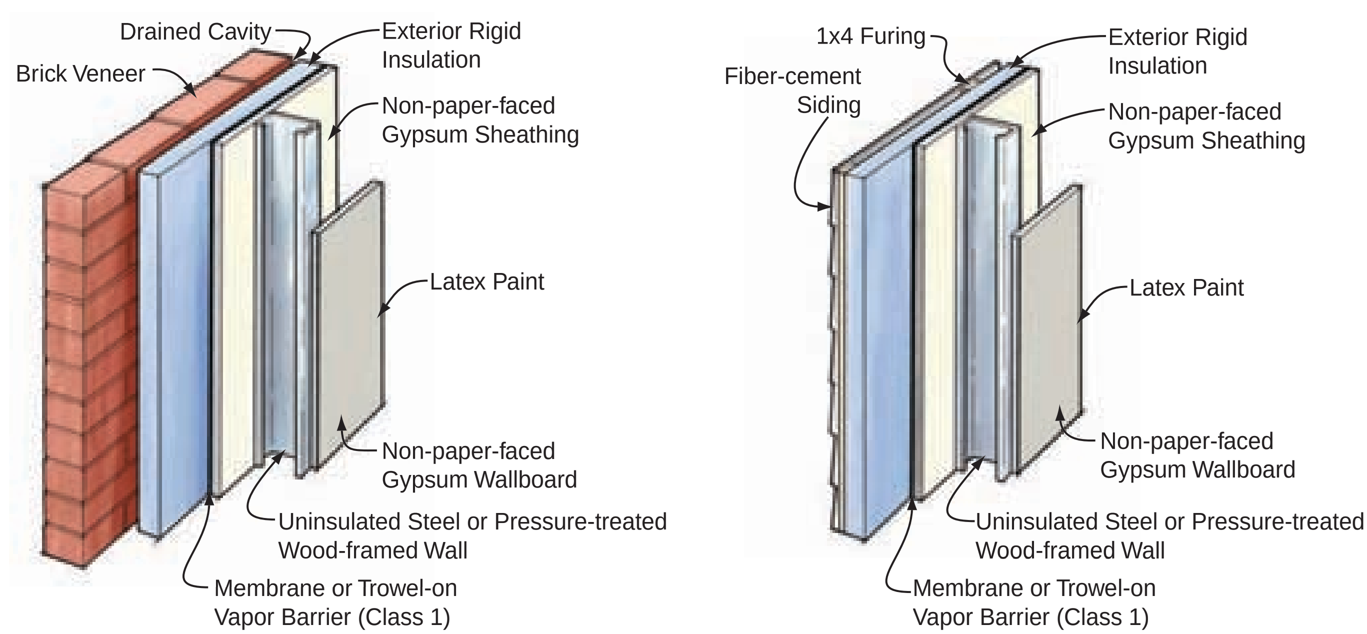


Figure 10. Recommended flood-resistant exterior cavity wall construction. The following materials and methods will limit flood damage to exterior cavity walls: 1) use brick veneer or fiber-cement siding, with non-paper-faced gypsum sheathing (vinyl siding is also flood-resistant but is less resistant to wind damage); 2) provide cavity for drainage; 3) use rigid, closed-cell insulation; 4) use steel or pressure-treated wood studs and framing; and 5) use non-paper-faced gypsum wallboard painted with latex paint (Source: Coastal Contractor Magazine and Building Science Corporation).

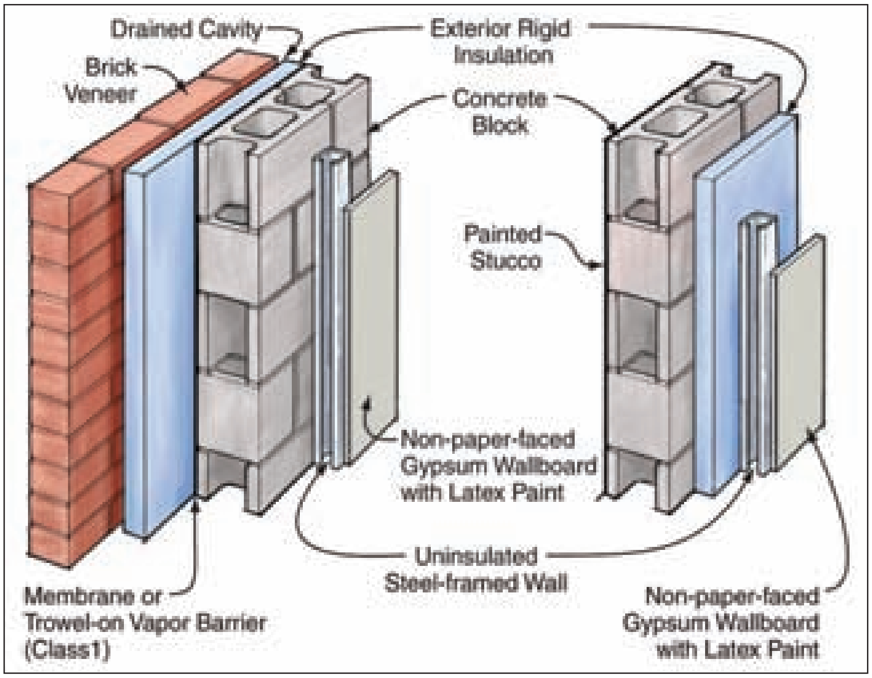


Figure 11. Recommended flood-resistant exterior mass wall construction. The following materials and methods will limit flood damage to exterior mass walls: 1) use concrete masonry with stucco or brick veneer (provide drainage cavity if brick veneer is used); 2) use rigid, closed-cell insulation; 3) use steel framing; and 4) use non-paper-faced gypsum wallboard painted with latex paint (Source: Coastal Contractor Magazine and Building Science Corporation).

- **New and replacement manufactured homes should be installed in accordance with the provisions of the 2009 edition of the National Fire Protection Association (NFPA) 225**, *Model Manufactured Home Installation Standard* (http://www.nfpa.org/aboutthecodes/AboutTheCodes.asp?DocNum=225&cookie_test=1). The standard provides flood, wind, and seismic-resistant installation procedures. It also calls for elevating A-zone manufactured homes with the bottom of the main chassis frame beam at or above the BFE, not with the top of the floor at the BFE.

Other Considerations

As previously stated, in addition to reduced building damage, there are other reasons to design for flood levels above the BFE:

- Reduced building maintenance and longer building life
- Reduced flood insurance premiums
- Reduced displacement and dislocation of building occupants after floods (and need for temporary shelter and assistance)
- Reduced job loss
- Increased retention of tax base

Until flooded, many homeowners and communities don't think about these benefits. However, one of the most persuasive (to homeowners) arguments for elevating homes above the BFE is the reduction in annual flood insurance premiums. In most cases, flood premiums can be cut in half by elevating a home 2 feet above the BFE, saving several hundred dollars per year in A zones, and $2,000 or more per year in V zones. In V zones, savings increase with added freeboard.

A comprehensive study of freeboard (American Institutes for Research, 2006) demonstrated that adding freeboard at the time of house construction is cost-effective. Reduced flood damage yields a benefit/cost ratio greater than 1 over a wide range of scenarios, and flood insurance premium reductions make adding freeboard even more beneficial to the homeowner. **Reduced flood insurance premiums will pay for the cost of incorporating freeboard in a Zone V house in 1 to 3 years; for a Zone A house, the payback period is approximately 6 years**.

Flood Insurance Premium Reductions Can Be Significant

Example 1: V-zone building, supported on piles or piers, no below-BFE enclosure or obstruction. $250,000 building coverage, $100,000 contents coverage.		**Example 2:** A-zone building, slab or crawlspace foundation (no basement). $200,000 building coverage, $75,000 contents coverage.	
Floor Elevation Above BFE	**Reduction in Annual Flood Premium***	**Floor Elevation Above BFE**	**Reduction in Annual Flood Premium***
1 foot	25%	1 foot	39%
2 feet	50%	2 feet	48%
3 feet	62%	3 feet	48%
4 feet	67%	4 feet	48%

* Compared to flood premium with lowest floor at BFE

References

American Institutes for Research. 2006. *Evaluation of the National Flood Insurance Program's Building Standards.* (available at: http://www.fema.gov/library/viewRecord.do?id=2592)

ASCE. 2005. *Minimum Design Loads for Buildings and Other Structures*. ASCE 7-05.

ASCE. 2005. *Standard for Flood Resistant Design and Construction*. ASCE 24-05.

Building Science Corporation. 2006. (relevant articles and publications available at: http://www.buildingscience.com).

Coastal Contractor Magazine. July 2006. *Low Country Rx: Wet Floodproofing. Drainable, dryable assemblies made with water-tolerant materials help speed recovery from deeper than-expected floods*, by Ted Cushman. (available at: http://www.coastalcontractor.net/cgi-bin/issue.pl?issue=9)

FEMA. 2000. *Coastal Construction Manua*l. FEMA 55. (ordering information at: http://www.fema.gov/pdf/plan/prevent/nhp/nhp_fema55.pdf)

FEMA. 2005. *Home Builder's Guide to Coastal Construction Fact Sheets* Series. FEMA 499. (available at: http://www.fema.gov/rebuild/mat/mat_fema499.shtm)

FEMA. 2006. *Recommended Residential Construction for the Gulf Coast, Building on Strong and Safe Foundations*. FEMA 550. (available at: http://www.fema.gov/library/viewRecord.do?id=1853)

FEMA. 2009. *Mitigation Assessment Team Report, Hurricane Ike in Texas and Louisiana: Building Performance Observations, Recommendations, and Technical Guidance.* FEMA P-757. (available at: http://www.fema.gov/library/viewRecord.do?id=3577)

LSU AgCenter. 1999. *Wet Floodproofing. Reducing Damage from Floods*. Publication 2771. (available at: http://www.lsuagcenter.com/NR/rdonlyres/B2B6CDEC-2BS8-472E-BBD9-0BDEB0B29C4A/26120/pub2771Wet6.pdf)

NFPA. 2009. *Model Manufactured Home Installation Standard*. NFPA 225. (available at: http://www.nfpa.org/aboutthecodes/AboutTheCodes.asp?DocNum=225&cookie_test=1)

Enclosures and Breakaway Walls

FEMA
http://www.fema.gov

HURRICANE IKE RECOVERY ADVISORY

Purpose: To discuss requirements and recommendations for enclosures and breakaway walls below the Base Flood Elevation (BFE).

Key Issues

- Spaces below elevated buildings can be used only for building access, parking, and storage.
- Areas enclosed by solid walls below the BFE ("enclosures") are subject to strict regulation under the National Flood Insurance Program (NFIP). Note that some local jurisdictions enforce stricter regulations for enclosures.
- Enclosures in V-zone buildings must be breakaway (non-breakaway enclosures are prohibited). Breakaway enclosures in V zones must be built with flood-resistant materials, meet specific design requirements, and be certified by a registered design professional.
- Enclosures (breakaway and non-breakaway) in A-zone buildings must be built with flood-resistant materials and equipped with flood openings that allow water levels inside and outside to equalize.
- Breakaway enclosure walls should be considered expendable, and the building owner could incur significant costs when the walls are replaced. Breakaway wall replacement is not covered by the flood insurance policy.
- For V zones, breakaway wall enclosures below an elevated building will result in higher flood insurance premiums; however, surrounding below-BFE space with insect screening, open lattice, slats, or shutters (louvers) can result in much lower flood insurance premiums (Figure 1). Use of these materials will allow floodwaters to pass into and out of the enclosed space and minimize damage to the enclosure "walls." Although not required by the NFIP, installation of flood openings in breakaway walls may also reduce damage to the walls.

WARNING

Designers and owners should realize that: (1) enclosures and items within them are likely to be destroyed even during minor flood events; (2) enclosures, and most items within them, are not covered by flood insurance and can result in significant costs to the building owner; and (3) even the presence of properly constructed breakaway wall enclosures will increase flood insurance premiums for the entire building (the premium rate will increase as the enclosed area increases). Including enclosures in a building design can have significant cost implications.

The Hurricane Ike Mitigation Assessment Team (MAT) observed some breakaway walls in excess of 11' high. While FEMA promotes elevating homes above the BFE (i.e., adding freeboard), one of the unintended consequences appears to be the increasing size of floodborne debris elements due to taller breakaway walls.

Figure 1. Wood louvers installed beneath an elevated house in a V zone are a good alternative to solid breakaway walls.

Space Below the BFE – What Can It Be Used For?

NFIP regulations state that the area below an elevated building can be used only for parking, building access, and storage. These areas must not be finished or used for recreational or habitable purposes. No mechanical, electrical, or plumbing equipment is to be installed below the BFE.

What is an Enclosure?

An "**enclosure**" is formed when any space below the BFE is enclosed on all sides by walls or partitions. Enclosures can be divided into two types, breakaway and non-breakaway.

- **Breakaway** enclosures are designed to fail under base flood conditions without jeopardizing the elevated building (Figure 2) – **any below-BFE enclosure in a V zone must be breakaway**. Breakaway enclosures are permitted in A zones, but must be equipped with flood openings.
- **Non-breakaway** enclosures can be constructed in an A zone. They may be used to provide structural support to the elevated building. All A-zone enclosures must be equipped with flood openings to allow the automatic entry and exit of floodwaters. **This Recovery Advisory recommends their use only in A-zone areas subject to shallow, slow-moving floodwaters without breaking waves**.

Breakaway Walls

Breakaway walls must be designed to break free under the larger of: 1) the design wind load, 2) the design seismic load, or 3) 10 pounds per square foot (psf), acting perpendicular to the plane of the wall (see Figure 3 for an example of a compliant breakaway wall). If the loading at which the breakaway wall is intended to collapse exceeds 20 psf, **the breakaway wall design must be certified**. When certification is required, a registered engineer or architect must certify that the walls will collapse under a water load associated with the base flood and that the elevated portion of the building and its foundation will not be subject to collapse, displacement, or lateral movement under simultaneous wind and water loads. **Breakaway walls must break away cleanly and must not damage the elevated building when they do so** (Figure 4). **Utilities should not be attached to or pass through breakaway walls.** See FEMA (2008a) Technical Bulletin 9, Design and *Construction Guidance for Breakaway Walls* for more information.

Figure 2. Breakaway walls beneath this building failed as intended under the flood forces of Hurricane Ike.

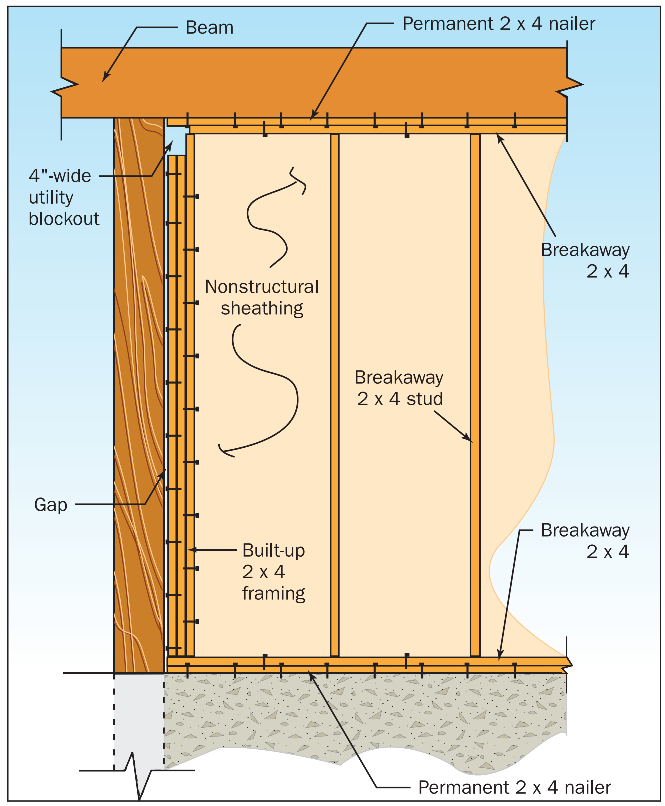


Figure 3. NFIP-compliant breakaway wall construction.

Figure 4. Building siding extended down and over the breakaway wall. Lack of a clean separation allowed damage to spread upward as the breakaway wall failed.

Obstruction Considerations

A V-zone building, elevated on an open foundation without an enclosure or other obstructions below the BFE, is said to be free of obstructions, and enjoys favorable flood insurance premiums (see FEMA (2008b) Technical Bulletin 5, *Free-of-Obstruction Requirements* for more information).

The following building scenarios are also classified by the NFIP as free of obstructions:

- Below BFE space is surrounded by insect screening and/or by wooden or plastic lattice, slats, or shutters (louvers), if at least 40 percent of the lattice and louver area is open. Lattice can be no thicker than ½"; slats or louvers can be no thicker than 1".
- Below BFE space is surrounded by a combination of one solid breakaway wall (or garage door), and all other sides of the enclosure are insect screening, or wooden or plastic lattice, slats, or louvers.

The following building scenarios are classified by the NFIP as with obstructions:

- Below BFE space is fully enclosed by solid breakaway walls.
- Below BFE space is enclosed by a combination of two or more solid breakaway walls, with the remaining sides of insect screening, or wooden or plastic lattice, slats, or louvers.

Flood Openings

Foundation walls and other enclosure walls of A-zone buildings (including Coastal A-zone buildings) must be equipped with openings that allow the **automatic entry and exit of floodwaters** (Figure 5).

Figure 5. Flood opening in a below-BFE enclosure wall.

A-zone opening requirements are as follows:

- Flood openings must be provided in **at least two of the walls** forming the enclosure.
- **The bottom of each flood opening must be no more than 1' above the higher of the interior or exterior adjacent grade.**
- **Louvers, screens, or covers** may be installed over flood openings as long as they do not interfere with the operation of the openings during a flood.
- Flood openings may be **sized** according to either a prescriptive method (1 square inch of flood opening per square foot of enclosed area) or an engineering method (which must be certified by a registered engineer or architect).

Details concerning flood openings can be found in FEMA (2008c) Technical Bulletin 1, *Openings in Foundation Walls and Walls of Enclosures*.

Other Considerations

Enclosures are strictly regulated because, if not constructed properly, they can transfer flood forces to the main structure (possibly leading to structural collapse). There are other considerations as well:

- Owners may be tempted to convert enclosed areas below the BFE into habitable space, leading to life-safety concerns and uninsured losses. Construction without enclosures should be encouraged. Contractors **should not stub out utilities in enclosures** (utility stub-outs make it easier for owners to finish and occupy the space).
- Siding used on the elevated portions of a building should not extend down over breakaway walls. Instead, a clean separation should be provided so that any siding installed on breakaway walls is structurally independent of siding elsewhere on the building. Without such a separation, the failure of breakaway walls can result in damage to siding elsewhere on the building (see Figure 4).
- Solid breakaway wall enclosures in V zones will result in **significantly higher flood insurance premiums** (especially where the enclosed area is 300 square feet or greater). Insect screening or lattice, slats, or louvers are recommended instead.

- If enclosures are constructed in **Coastal A zones** (see the Hurricane Ike Recovery Advisory, *Design and Construction in Coastal A Zones*), **open foundations with breakaway enclosures are recommended** in lieu of foundation walls or crawlspaces. If solid breakaway walls are used, they must be equipped with flood openings that allow floodwaters to enter and exit the enclosure. Use of breakaway enclosures in Coastal A zones (or any A zone) will not lead to higher flood insurance premiums.

This Recovery Advisory recommends the use of insect screening, or open wood or plastic lattice, slats, or louvers, instead of solid breakaway walls beneath elevated residential buildings.

- Garage doors installed in below-BFE enclosures of V-zone buildings – even reinforced and high-wind-resistant doors – must meet the performance requirement discussed in the *Breakaway Walls* section of this Recovery Advisory. Specifically, the doors must be designed to break free under the larger of the design wind load, the design seismic load, or 10 psf, acting perpendicular to the plane of the door. If the loading at which the door is intended to collapse is greater than 20 psf, **the door must be designed and certified to collapse under base flood conditions**. See the *Breakaway Walls* section for information about certification requirements.

This Recovery Advisory recommends that flood openings be considered for solid breakaway walls in V zones, even though they are not required by the NFIP. The presence of flood openings may relieve flood forces against the solid breakaway walls and reduce damage to the walls.

References

FEMA. 2008a. *Design and Construction Requirements for Breakaway Walls*. Technical Bulletin 9, available at: http://www.fema.gov/library/viewRecord.do?id=1722.

FEMA. 2008b. *Free-of-Obstruction Requirements*. Technical Bulletin 5, available at: http://www.fema.gov/library/viewRecord.do?id=1718.

FEMA. 2008c. *Openings in Foundation Walls and Walls of Enclosures*. Technical Bulletin 1, available at: http://www.fema.gov/library/viewRecord.do?id=1579.

FEMA. 2009. Hurricane Ike Recovery Advisory, *Design and Construction in Coastal A Zones*.

Erosion, Scour, and Foundation Design

FEMA
http://www.fema.gov

HURRICANE IKE RECOVERY ADVISORY

Purpose: To discuss how any lowering of the ground surface can affect the ability of a building foundation to resist design loads, and to provide additional guidance for coastal foundation design.

Key Issues

Erosion refers to a general lowering of the ground surface over a wide area.

Scour refers to a localized loss of soil, often around a foundation element.

- Coastal buildings are often subject to flood loads and conditions that do not affect inland buildings. These include waves, high velocity storm surge flow, floodborne debris, and **erosion** and **scour**. This Recovery Advisory will focus on erosion and scour. See FEMA 499, *Home Builder's Guide to Coastal Construction* (2005), Fact Sheets 11 through 15 at: http://www.fema.gov/library/viewRecord.do?id=1570, and FEMA 55, *Coastal Construction Manual* (2000) at: http://www.fema.gov/library/viewRecord.do?id=1671 for discussion of other foundation issues.
- Foundations must transfer all loads imposed on the building into the ground. If the foundation is not strong enough or deep enough to do this, the building will be destroyed. If the foundation embedment into the ground is not sufficient to account for erosion and scour that may occur over the life of the building, the building is vulnerable to collapse under design flood and wind conditions.
- Predicting the incidence, location, and magnitude of coastal erosion and scour is difficult, and present-day building codes and standards do not prescribe clear-cut solutions for designers. Therefore, designers should be conservative with their foundation designs. This means foundations may need to be stronger, deeper, and higher than what has historically been used. Lessons learned from Hurricane Ike and other recent coastal storm events should be incorporated into foundation designs.

Erosion and Scour Basics

Erosion is defined by the International Building Code® (ICC, 2006) as the "wearing away of the ground surface as a result of the movement of wind, water or ice." Section 7.5 of FEMA's *Coastal Construction Manual* describes erosion as "the wearing or washing away of coastal lands." Since the exact configuration of the soil loss is important for foundation design purposes, a more specific definition is used in this Recovery Advisory (see text box and Figure 1).

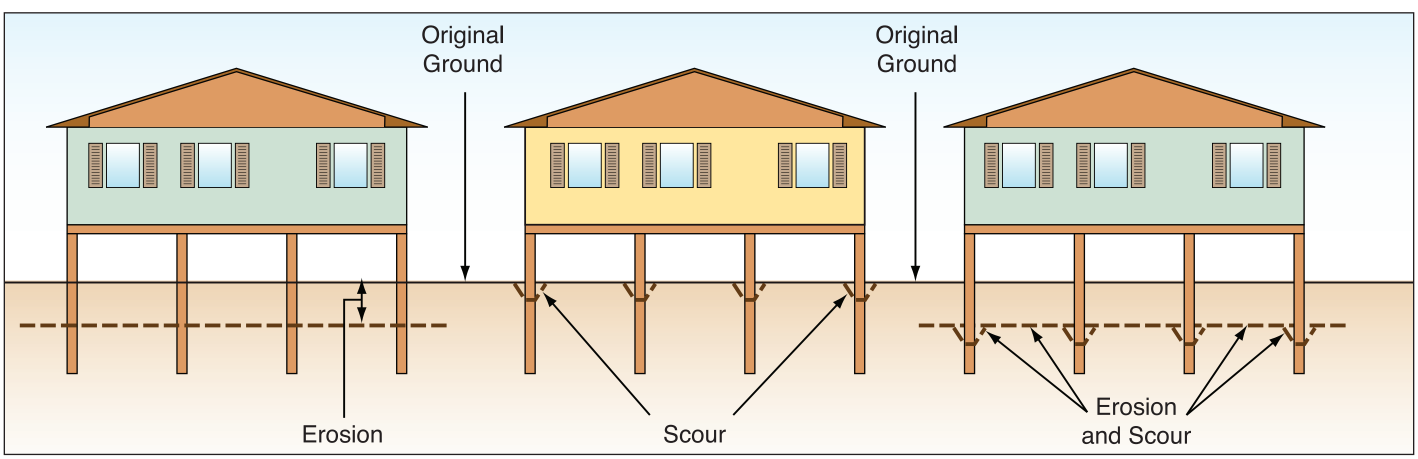


Figure 1. Distinguishing between coastal erosion and scour. A building may be subject to either or both, depending on the building location, soil characteristics, and flood conditions.

Erosion can occur across a wide range of timeframes – it can be gradual, occurring over a long period of time (many years); more rapid, occurring over a relatively short period of time (weeks or months); or episodic, occurring during a single coastal storm event over a short period of time (hours or days). Figure 2 shows the result of erosion occurring over a long timeframe – buildings that were formerly on upland property, but now stand on the active beach. Figure 3 shows episodic erosion that occurred during Hurricane Ike. In both cases, the recession of the shoreline resulted in a horizontal translation of the beach profile and a lowering of the ground elevation under and near the affected buildings. The closer a building is to the shoreline, the more likely erosion will occur and the greater the erosion depth will be.

Scour occurs when floodwater passes around obstructions in the water column. As the water flows around an object, it must change direction and accelerate. Soil can be loosened and suspended by this process or by waves striking the object, and be carried away. Pilings, pile caps, columns, walls, footings, slabs, and other objects found under a coastal building can lead to localized scour. Scour effects increase with increasing flow velocity and turbulence, and with increasing soil erodibility.

Scour effects are generally **localized**, ranging from small, shallow conical depressions in the sand around individual piles (Figure 4) to larger and deeper depressions around individual piles (Figure 5), to a building-sized shallow depression around a group of piles (Figure 6), to a large and deep depression around a building foundation (Figure 7). Scour depressions like that shown in Figure 7 were observed frequently following Hurricane Ike, and many of these reportedly were 6 to 10' deep and required hundreds of cubic yards of soil to fill. The presence of large, non-frangible concrete slabs and deep grade beams under the buildings may be a contributing factor to the large local scour depressions observed.

In some cases, buildings may settle due to inadequate pile embedment, coupled with some combination of erosion, scour, and soil liquefaction that leads to loss of bearing. This type of failure was observed by the Huricane Ike FEMA Mitigation Assessment Team (MAT) at Surfside Beach, TX (Figure 8) and Holly Beach, LA.

Figure 2. Long-term erosion has caused the shoreline to retreat and has left homes standing on the beach (Surfside Beach, TX). July 2007 Texas General Land Office photo.

Figure 3. Storm-induced erosion beneath an elevated coastal building (Galveston Island, TX, Hurricane Ike).

Figure 4. Local scour around foundation piles (Pensacola Beach, FL, Hurricane Ivan).

Figure 5. Local scour around foundation piles (Holly Beach, LA, Hurricane Ike).

Figure 6. Local scour around a 3rd row house's pile foundation (Bolivar Peninsula, TX, Hurricane Ike).

Figure 7. Extreme local scour around a Gulf-front pile foundation (Bolivar Peninsula, TX, Hurricane Ike).

Figure 8. Differential settlement of buildings thought to be a result of inadequate foundation embedment coupled with erosion, scour, and/or soil liquefaction (Surfside Beach, TX, Hurricane Ike).

Figure 9. Linear scour and erosion patterns aligning with canals and roads (Bolivar Peninsula, TX, Hurricane Ike).

There is one other erosion and scour scenario to consider in foundation design – the loss of soil around or under a building as a result of storm surge flow being channeled or directed across a building site. This process usually takes place where storm surge flow is constrained between large buildings or gaps in shore protection, or when return flow to the sea follows paths of least resistance, such as along canals and roads (Figure 9).

Erosion and Scour – Impacts on Foundations

Erosion and scour have several adverse impacts on coastal foundations:

- Erosion and scour reduce the embedment of the foundation into the soil, causing shallow foundations to collapse and making buildings on deep foundations more susceptible to settlement, lateral movement, or overturning from lateral loads.
- Erosion and scour increase the unbraced length of pile foundations, increase the bending moment to which they are subjected, and can overstress piles.
- Erosion over a large area between a foundation and a flood source exposes the foundation to increased lateral flood loads (i.e., greater stillwater depths, possible higher wave heights, and higher flow velocities).
- Local scour around individual piles or a building foundation will not generally expose foundations to greater flood loads, but linear scour across a building site may do so.

Resisting *higher bending moments* brought about by erosion and scour may necessitate a larger pile cross-section or decreased pile spacing (i.e., more piles) or, in some cases, use of a different pile material (e.g., concrete or steel instead of wood). Resisting increased lateral flood loads brought about by erosion (and possibly by linear scour) would necessitate a similar approach. However, designers must remember that increasing the number of piles or increasing the pile diameter will, in turn, also increase lateral flood loads on the foundation.

Resisting *increased unbraced lengths* brought about by erosion and scour will require additional embedment of the foundation into the ground.

To illustrate these points, calculations were made to examine the effects of erosion and scour on foundation design for a simple case – a 32' x 32', two-story house (10' story height), situated away from the shoreline and elevated 8' above grade on 25 square timber piles (spaced 8' apart), on medium dense sand. The house was subjected to a design wind event with a 130-mph (3-second gust) wind speed and a 4' stillwater depth above the uneroded grade, with storm surge and broken waves passing under the elevated building. Lateral wind and flood loads were calculated in accordance with ASCE/SEI 7-05 *Minimum Design Loads for Buildings and Other Structures* (model codes and related prescriptive standards, such as the International Building Code (IBC), the International Residential Code® (IRC®), and ICC-600 *Standard for Residential Construction in High Wind Areas*, are based on ASCE 7 loads). For this illustration, the piles were analyzed under lateral wind and flood loads only; dead, live and wind uplift loads were neglected. If these neglected loads are included in the analysis, deeper pile embedment and possibly larger piles may be needed.

Three different timber pile sizes (8" square, 10" square, and 12" square) were evaluated using pre-storm embedment depths of 10', 15', and 20', and five different erosion and scour conditions (Erosion = 0' or 1'; Scour ranges from 2.0 times the pile diameter to 4.0 times the pile diameter). The results of the analysis are shown in Table 1. A shaded cell indicates the combination of pile size, pre-storm embedment, and erosion/scour does not provide the bending resistance and/or embedment required to resist lateral loads. The reason(s) for a foundation failure is indicated in each shaded cell, using “P” for failure due to bending and overstress within the pile and “E” for an embedment failure from the pile/soil interaction. An unshaded cell with “OK” indicates bending and foundation embedment criteria are both satisfied by the particular pile size/pile embedment/erosion-scour combination.

Table 1. Example foundation adequacy calculations for a two-story house supported on square timber piles and situated away from the shoreline, storm surge and broken waves passing under the building, 130-mph wind zone, soil = medium dense sand. Shaded cells indicate the foundation fails to meet bending (P) and/or embedment (E) requirements.

Pile Embedment Before Erosion and Scour	Erosion and Scour Conditions	Pile Diameter, a		
		8 inch	10 inch	12 inch
10 feet	Erosion = 0, Scour = 0	P, E	E	OK
	Erosion = 1 foot, Scour = 2.0 a	P, E	E	E
	Erosion = 1 foot, Scour = 2.5 a	P, E	E	E
	Erosion = 1 foot, Scour = 3.0 a	P, E	E	E
	Erosion = 1 foot, Scour = 4.0 a	P, E	P, E	E
15 feet	Erosion = 0, Scour = 0	P	OK	OK
	Erosion = 1 foot, Scour = 2.0 a	P	OK	OK
	Erosion = 1 foot, Scour = 2.5 a	P	OK	OK
	Erosion = 1 foot, Scour = 3.0 a	P	OK	OK
	Erosion = 1 foot, Scour = 4.0 a	P, E	P, E	E
20 feet	Erosion = 0, Scour = 0	P	OK	OK
	Erosion = 1 foot, Scour = 2.0 a	P	OK	OK
	Erosion = 1 foot, Scour = 2.5 a	P	OK	OK
	Erosion = 1 foot, Scour = 3.0 a	P	OK	OK
	Erosion = 1 foot, Scour = 4.0 a	P	P	OK

Review of the table shows several key points:

- Increasing pile embedment will not offset foundation inadequacy (bending failure) resulting from too small a pile cross-section or too weak a pile material.
- Increasing pile cross-section (or material strength) will not compensate for inadequate pile embedment
- Given the building and foundation configuration used in the example, the 8" square pile is not strong enough to resist the lateral loads resulting from the 130-mph design wind speed under any of the erosion and scour conditions evaluated, even if there is no erosion or scour. Homes supported by 8" square timber piles, with embedment depths of 10' or less, will likely fail in large numbers when subjected to design or near-design loads and conditions. Homes supported by deeper 8" piles may still be lost during a design event due to pile (bending) failures

WARNING

The results in Table 1 should not be used in lieu of building- and site-specific engineering analyses and foundation design. The table is for illustrative purposes only and is based upon certain assumptions and simplifications, and for the combinations of building characteristics, soil conditions, and wind and flood conditions described above. Registered design professionals should be consulted for foundations designs.

- The 10" square pile is strong enough to resist bending under all but the most severe erosion and scour conditions analyzed.
- The 12" pile is the only pile size evaluated that satisfies bending requirements under all erosion and scour conditions analyzed. The 12" pile works with 10' of embedment under the no erosion and scour condition. However, introducing as little as 1' of erosion, and scour equal to twice the pile diameter, was enough to render the foundation too shallow.
- 15' of pile embedment is adequate for both 10" and 12" piles subject to 1' of erosion and scour up to three times the pile diameter. However, when the scour is increased to four times the pile diameter (frequently observed following Hurricane Ike), 15' of embedment is inadequate for both piles. In general terms, approximately 11' of embedment is required in this example house to resist the loads and conditions after erosion and scour are imposed.
- The 12" pile with 20' of embedment was the only foundation that worked under all erosion and scour conditions analyzed. This pile design may be justified for the sample house analyzed when expected erosion and scour conditions are unknown or uncertain.

NFIP and Building Code Requirements

One of the requirements of **Section 60.3(a)(3)** of the NFIP regulations that applies to all flood hazard zones (V, VE, V1-30, A, AE, A1-30, AO, AH, etc.) within the Special Flood Hazard Area (SFHA) is:

> "If a proposed building site is in a flood-prone area, all new construction and substantial improvements shall be designed (or modified) and adequately anchored to prevent flotation, collapse, or lateral movement of the structure resulting from hydrodynamic and hydrostatic loads, including the effects of buoyancy."

A requirement in **Section 60.3(e)(4)** states that all new construction and substantial improvements in V zones must be elevated on pilings and columns so that:

> "(i) the bottom of the lowest horizontal structural member of the lowest floor (excluding the pilings or columns) is elevated to or above the base flood level; and
>
> (ii) the pile or column foundation and structure attached thereto is anchored to resist flotation, collapse and lateral movement due to the effects of wind and water loads acting simultaneously on all building components.
>
> Water loading values used shall be those associated with the base flood. Wind loading values used shall be those required by applicable State or local building standards. A registered professional engineer or architect shall develop or review the structural design, specifications and plans for the construction, and shall certify that the design and methods of construction to be used are in accordance with accepted standards of practice for meeting the provisions of paragraphs (e)(4)(i) and (ii) of this section."

The International Residential Code (2006) has similar requirements:

> "**R324.1.1 [Flood Resistant Construction] Structural systems**. All structural systems of all buildings and structures shall be designed, connected and anchored to resist flotation, collapse or permanent lateral movement due to structural loads and stresses from flooding equal to the design flood elevation.
>
> **R324.3.3 [Coastal high-hazard areas] Foundations**. All buildings and structures erected in coastal high-hazard areas shall be supported on pilings or columns and shall be adequately anchored to such pilings or columns. Pilings shall have adequate soil penetration to resist the combined wave and wind loads (lateral and uplift). Water loading values used shall be those associated with the design flood. Wind loading values used shall be those required by this code. Pile embedment shall include consideration of decreased resistance capacity caused by scour of soil strata surrounding the piling. Pile systems design and installation shall be certified in accordance with Section R324.3.6. Mat, raft or other foundations that support columns shall not be permitted where soils investigations that are required in accordance with Section R401.4 indicate that soil material under the mat, raft or other foundation is subject to scour or erosion from wave-velocity flow conditions.
>
> Buildings and structures, and all parts thereof, shall be constructed to support safely all loads, including dead loads, live loads, roof loads, flood loads, snow loads, wind loads and seismic loads as prescribed in this code. The construction of buildings and structures shall result in a system that provides a complete load path capable of transferring all loads from their point of origin through the load-resisting elements of the foundation."

Thus, designers are responsible for ensuring that a foundation for a building in any flood hazard area must be adequate to support a building under applicable design loads and load combinations. Designers must consider the effects of erosion and scour when foundations are designed. Designers must certify the foundations.

There may also be other (State or local) foundation design and certification requirements.

Erosion and Scour Design Guidance

Given that the design requirements listed above are performance requirements, designers must translate those into practice. This can be difficult with respect to estimating erosion and scour conditions at a particular site, since definitive guidance for estimating coastal erosion and scour is not present in building codes and standards.

FEMA's *Coastal Construction Manual* (FEMA, 2000) provides some information and guidance, but even this should be considered preliminary and subject to improvement as we learn more from post-storm investigations. The pertinent CCM sections and guidance are summarized below:

CCM Section 7.5: this section summarizes the causes of erosion, its impacts on coastal lands and buildings, and how it is measured. Section 7.5.2.5 discusses local scour. One key point is a procedure outlined in the note on page 7-28 and illustrated in *CCM* Figure 7-66 – three steps that a designer should use to estimate future ground elevations and flood conditions at a site:

- Step 1: determine the most landward shoreline location expected during the life of the building
- Step 2: define the lowest expected ground elevation during the life of the building
- Step 3: define the highest expected BFE during the life of the building

> Designers in Texas and Louisiana can obtain erosion data and other related information from various state agencies (see References).

CCM Section 7.8.1.4 discusses FEMA's current procedures for estimating storm-induced erosion.

CCM Section 7.9.2 discusses how designers can update an obsolete flood hazard description for a site by accounting for long-term (Step 1 above) and storm-induced erosion (Step 2 above). *CCM* Figure 7-67 (Figure 10) provides an example, illustrating the use of published long-term erosion information and simple storm erosion calculations to estimate future ground elevations at a building site.

CCM Section 11.6.11 discusses local scour and presents a simple method for calculating erosion around a single pile. The method predicts the depth of a scour depression below the eroded ground elevation is equal to 2.0 times the pile diameter, unless non-erodible soil lies beneath the ground surface (Figure 11).

Designers should use the CCM scour depth relationship (Smax = 2.0 a) with caution. Observations after Hurricane Ike showed scour exceeded twice the pile diameter at many locations. This could have been due to deeper scour depths around entire pile foundations (Figures 6 and 7), or to the presence of concrete slabs and deep grade beams that channeled flow between the bottom of the slab and the soil, or to other factors. Given the uncertainty over the exact cause of local scour during Hurricane Ike, foundation designs for reconstruction along the Gulf shoreline should be very conservative, and an assumed scour depth of 6 to 8' would not be unreasonable. Designers should investigate local soils and Hurricane Ike-induced scour at nearby locations before selecting a scour depth. Post-hurricane aerial photographs, such as those obtained after Hurricane Ike by NOAA and USGS (see References) will provide a good source of data for designers.

The *CCM* mentions linear scour channels occurring between large buildings or in-line with roads, canals, and drainage features (see *CCM* Section 8.3.2), but does not provide design guidance for estimating linear scour depths. As was the case with local scour, designers should utilize post-hurricane data when they estimate linear scour likelihood and depth.

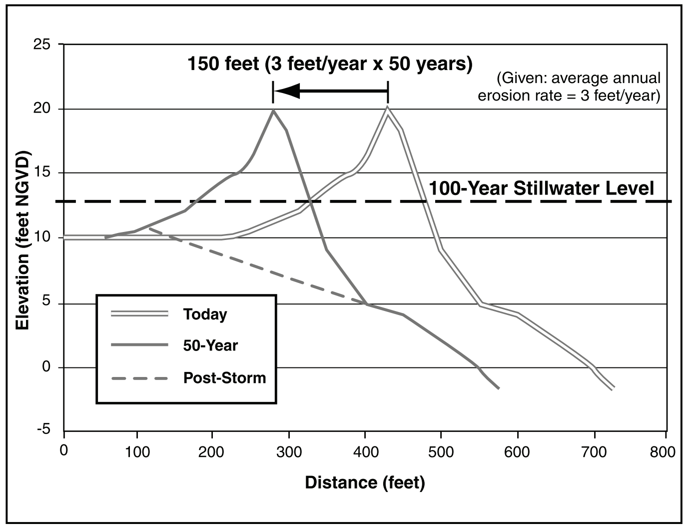


Figure 10. CCM Figure 7-67 illustrating a simple procedure to account for long-term erosion and storm erosion.

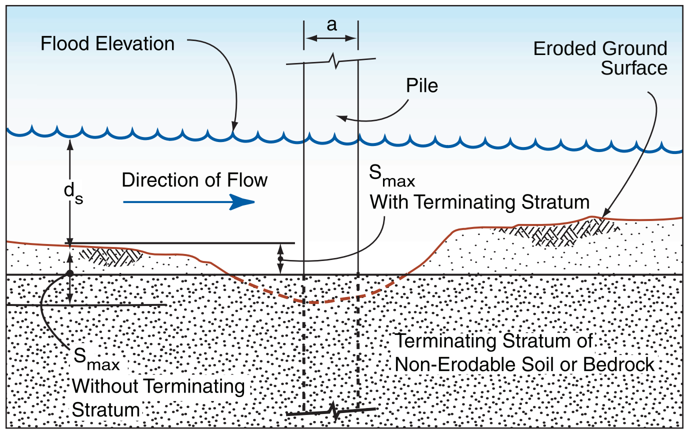


Figure 11. CCM Figure 11-12 illustrating scour estimate around a single pile – Hurricane Ike showed this method may underestimate local scour.

Existing Homes: Are the Pile Foundations Adequate?

The owner of an existing home may wonder whether the pile foundation is adequate to withstand erosion and scour during a design event. The builder or building official may have permit records, building plans, or foundation design information for the house, or may be able to provide information about typical design requirements, construction practices, and probable pile embedment depths for houses of the same age. A licensed engineer can perform an inspection of the foundation, provide information about non-destructive testing methods to determine pile embedment depth, review available foundation data, and analyze the foundation.

References

ASCE. 2005. *Minimum Design Loads for Buildings and Other Structures*. ASCE/SEI 7-05.

FEMA. 2000. *Coastal Construction Manual*, 3rd ed. FEMA 55.

FEMA. 2005. *Home Builder's Guide to Coastal Construction*. FEMA 499. See http://www.fema.gov/library/viewRecord.do?id=1570

ICC 2006. International Building Code.

ICC 2006. International Residential Code with 2007 Supplement.

ICC 2008. *Standard for Residential Construction in High Wind Areas*. ICC 600.

Louisiana Department of Natural Resources. 2008. Coastal Restoration and Management data and reports. See http://dnr.louisiana.gov/crm/

NOAA. 2008. Post-Ike aerial photographs. See http://ngs.woc.noaa.gov/ike/index.html

Texas Bureau of Economic Geology. 2008. Coastal Studies Program data and reports. See http://www.beg.utexas.edu/coastal/coastal01.htm

USGS. 2008. Post-Ike aerial photographs and data. See http://coastal.er.usgs.gov/hurricanes/ike/

Minimizing Water Intrusion Through Roof Vents in High-Wind Regions

FEMA
http://www.fema.gov

HURRICANE IKE RECOVERY ADVISORY

Purpose: To recommend practices for minimizing water intrusion through roof vent systems that can lead to interior damage and mold growth in high-wind regions (i.e., greater than 90-miles per hour [mph] gust design wind speed).

Key Issues

- Hurricane winds can drive large amounts of water through attic ventilation openings. The accumulating water soaks insulation, which can lead to mold growth and, in some cases, to the collapse of ceilings.
- Attic ventilation can be provided by a number of devices, most of which have been observed to allow water intrusion under certain conditions and some of which have been observed to blow off. These devices include:
  - Soffit vents
  - Ridge vents
  - Gable end vents
  - Off-ridge vents
  - Gable rake vents
  - Turbines
- Adequate ventilation of attics is generally required to promote the health of wood structural members and sheathing in the attic.
- Attic ventilation can reduce the temperatures of roof coverings, which will typically prolong the life of the roof covering. However, roof color can have more of an impact on roof covering temperature than the amount of ventilation that is or is not provided.
- An unventilated attic can be an effective way to prevent water intrusion and this type of attic is gaining popularity for energy efficiency reasons, provided the air conditioning system is sized appropriately. However, an unventilated attic is best accomplished when it is specifically designed into the house and all of the appropriate details are handled properly. On an existing house, any attempt to change to an unventilated attic configuration needs to be done very carefully with the advice of knowledgeable experts. There are a number of changes that have to be made to produce a successful transition from a ventilated to an unventilated attic. One side effect of going to an unventilated attic may be to void the warranty for the roof covering.
- The following information is intended to help minimize water intrusion through new and existing attic ventilation systems, not to change from a ventilated to an unventilated system. With the exception of the plugging of gable rake vents, all other shuttering of openings or plugging of vents should be done on a temporary basis and removed once the storm threat is over so that the attic is once again properly ventilated.

The Unventilated Attic

The most conservative approach to preventing wind-driven rain from entering the attic is to eliminate attic ventilation, but unventilated attics are controversial. Although allowed by the International Residential Code® (IRC®), provided the Code's criteria are met, unventilated attics may not comply with local building codes.

However, when unventilated attics are allowed by the building code or code compliance is not an issue, and when climatic and interior humidity conditions (e.g., no indoor swimming pools) are conducive to an unventilated design, an unventilated attic is a reliable way to prevent wind-driven rain from entering the attic.

Air barrier: Refer to the *Siding Installation in High-Wind Regions*, Hurricane Ike Recovery Advisory for recommendations regarding attic air barriers.

Mitigation Guidance

Soffit Vents

Key Issues

- First and foremost, it is important to keep the soffit material in place. While some water can be blown into the attic through almost any type of soffit vent, the amount of water intrusion increases dramatically when the soffit material is missing (Figure 1).
- Plywood or wood soffits are generally adequately anchored to wood framing attached to the roof structure and/or the walls. However, it has been common practice for vinyl and aluminum soffit panels to be installed in tracks that are frequently very poorly connected to the walls and fascia at the edge of the roof overhang. When these poorly anchored soffits are blown off, water intrusion increases significantly. Properly installed vinyl and aluminum soffit panels are fastened to the building structure or to nailing strips placed at intervals specified by the manufacturer.

Figure 1. Missing soffit material.

Proper Installation

The details of proper installation of vinyl and aluminum soffits depend on the type of eave to which they are attached. The key elements are illustrated in Figure 2.

A. Roof truss or rafter framing should extend across the bottom of the eaves, or be added to create a structural support for the soffit. As an alternative, soffits can be attached directly to the undersides of the angled rafters.

B. Nailing strips should be provided, if necessary, to allow attachment of the soffit at the ends. Intermediate nailing strips may be needed, depending on the maximum span permitted for the soffit. If this is not known, the span between attachment points should not exceed 12" in high-wind regions.

C. A J-channel (illustrated), F-channel, or other receiver as specified by the manufacturer should cover the ends of the soffit panels. Fasteners should be those specified by the manufacturer. Fasteners should be used through the nailing strip of each panel and at any other points (such as in the “valleys” of the soffit) if specified.

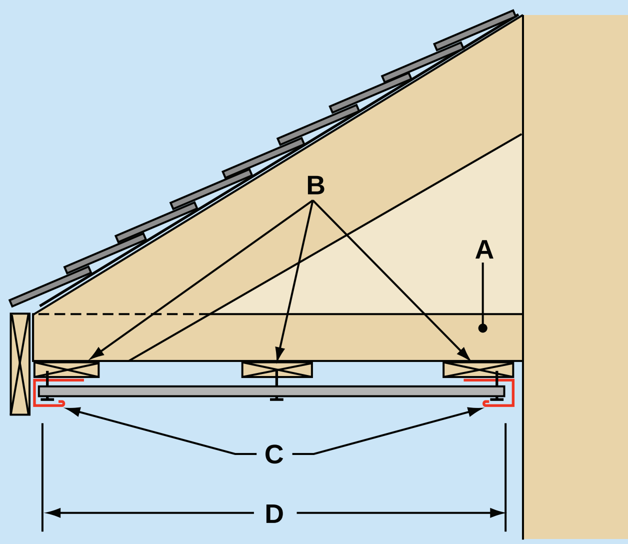


Figure 2. Key soffit installation points.

D. The overall span (eave depth) of the soffit should not exceed any limits specified by the manufacturer, and any required intermediate attachment points should be used.

Checking Soffit Material Installation

As noted above, the most critical soffit installations to check are those where vinyl or aluminum soffit panels are used. Soffits should be fastened to the eave structure; they should not be loose in the channels. Pushing up on the soffit material and the channels used to support the material can be revealing. If it moves

Soffits can receive positive and negative (suction) loads; therefore, soffits need to be designed and installed to resist loads that push up and pull down on the soffit.

readily or is easy to deform, it probably is not attached very well. Similarly, if the width of the overhang is greater than 12", there should be an intermediate support running along the middle of the soffit and the panels should be attached to this support in addition to the supports at the ends of the panels. If you are concerned about the installation but can't be sure, there are a couple of tools with a viewing screen connected to a small camera lens and light mounted at the end of a flexible tube that can be used to observe the connections. These devices allow inspection through a small hole that is drilled in an inconspicuous location that can be later filled with sealant. In order to ensure that you have a strong connection at the wall, there should be wood blocking running along the wall above the track where the soffit channel is attached and the channel should be fastened to that blocking. If you do not find wood blocking and either see no vertical nailing surface on the channel or see occasional tabs that have been cut and bent up to allow fastening to the wall, strengthening of the anchorage of the soffit material is clearly indicated.

Figure 3. Applying a bead of sealant. (Note: Black sealant was used so that it would be visible in the photograph. Normally a matching sealant color would be used.)

Figure 4. Applying dabs of sealant.

Figure 5. Screws through wall channel.

Remedial Measures

If the inspection indicates a poorly attached soffit, the best way to ensure that the soffit material is adequately anchored in place is to remove it and install adequate wood blocking to allow solid anchorage of the soffit material. In some cases, it may be possible to remove the soffit material and reinstall it. However, it is also likely that some or all of the material will need to be replaced, so make sure that it can be matched before it is removed. Short of removing and properly reinstalling the soffit material, testing has shown that the anchorage can be greatly improved by applying a bead of sealant (Figure 3) along the bottom edge of the wall channel to adhere it to the wall surface below followed by applying large dabs of sealant in indentations between the soffit panels and the wall channel at one end (Figure 4) and the fascia flashing at the other end. Surfaces receiving sealant should be cleaned in order to facilitate bonding. Extra resistance can be gained by installing screws that mechanically tie the soffit panels to both the fascia flashing and to the wall channel (Figure 5). Note that use of sealant is a remedial measure only and is not a substitute for proper installation and fastening of soffits in a new installation.

Wind-driven rain penetration: Currently there is no adequate standard test method to evaluate the potential for wind-driven rain to enter attics through soffit vent openings, such as those shown in Figure 6. To avoid water entry at soffit vents, options include eliminating soffit vents and providing an alternate method for air to enter the attic, or design for an unventilated attic. Another approach is to place filter fabric (like that used for heating, ventilation, or cooling

> Rain screen wall venting: In lieu of providing soffit vents, another method to provide attic air intake is through a pressure-equalized rain screen wall system as discussed in *Siding Installation in High-Wind Regions*, Hurricane Ike Recovery Advisory. This alternative approach eliminates soffit vents and their susceptibility to wind-driven rain entry.

[HVAC] system filters) above the vent openings; however, such an approach needs to be custom designed.

Fascia cover: Field investigations after Hurricane Ike showed many cases where the aluminum fascia cover (fascia cap) from the fascia board was blown off (Figure 7). The fascia cover normally covers the ends of vinyl and aluminum soffits. When the fascia cover is blown off, the ends of the soffit panels are exposed to wind and wind-driven rain.

The IRC currently has no guidelines for the installation of fascia covers. Aluminum fascia covers are typically tucked under the roof drip edge and face-nailed every few feet. More frequent nailing would help secure the fascia cover, but would also inhibit normal thermal movement, which can cause unattractive warping and dimpling of the cover. Vinyl fascia covers are available, which are attached to a continuous strip of utility trim placed underneath the drip edge. This provides a somewhat more secure, continuous attachment and allows for thermal movement. Aluminum fascia covers can also be field-notched and installed with utility trim.

Figure 6. Fiber cement soffit with ventilation slots (red arrow).

Figure 7. Loss of fascia cover exposes ends of vinyl soffit to direct entry of wind-driven rain.

Ridge Vents

Key Issues

- Ridge vents are frequently fastened down using ordinary roofing nails since these are normally handy. It is pretty common to find ridge vents dislodged or blown off during a hurricane (Figure 8). Even a partially dislodged ridge vent can begin to act like a scoop that collects wind-driven rain and directs it into the attic.
- Most roofing manufacturers now make ridge vents that have passed wind-driven water tests. They are identified as having passed Florida Building Code's Product Approvals or Testing Application Standard (TAS) 100(A). Typically, they include a baffle in front of the vent tubes that provide the passageway for hot attic gasses to escape. This baffle is intended to trip any flow of wind and water blowing up the surface of the roof and deflect it over the top of the roof ridge.

Figure 8. This metal ridge vent was attached with widely spaced roofing nails.

Slotting the Deck

When ridge venting is being added to a roof that previously did not have it, it is necessary to cut a slot through the decking. When doing so, it is important to set the depth of the saw blade so that it only slightly projects below the bottom of the decking. At the residence shown in Figure 8, the saw blade cut approximately 1½" into the trusses and cut a portion of the truss plate (red arrow).

Checking Ridge Vents and Their Installation

When they are used, ridge vents are the last part of the roof to be installed. Consequently, the connection is readily accessible and frequently visible without having to pry up the edge of the vent cover top. Check the type and condition of the fasteners. If the fasteners are nails, replacement of the fasteners is in order. If the vent has clear holes or slots without any baffle or trip next to the edge of the vent channels, the vent is probably not one that is resistant to water intrusion and you should consider replacing the ridge vent with one that has passed the wind-driven water intrusion tests.

Remedial Measures

Replace nails with gasketed stainless steel wood screws that are slightly larger than the existing nails and, if possible, try to add fasteners at locations where they will be embedded in the roof structure below and not just into the roof sheathing. Close spacing of fasteners is recommended (e.g., in the range of 3 to 6" on center, commensurate with the design wind loads). If the ridge vents are damaged or are one of the older types that are not resistant to water intrusion, they should be replaced with vents that have passed the wind-driven water intrusion tests.

Figure 9. Gable end vent.

Gable End Vents

Key Issues

- Virtually all gable end vents (Figure 9) will leak when the wall they are mounted on faces into the wind-driven rain. The pressures developed between the outside surface of the wall and the inside of the attic are sufficient to drive water uphill for a number of inches and, if there is much wind flow through the vent, water carried by the wind will be blown considerable distances into the attic.

Figure 10. Shuttered gable end vent.

Remedial Measures

If it is practical and possible to shutter gable end vents from the outside of the house, this is the preferable way to minimize water intrusion through gable end vents (Figure 10). Install permanent anchors in the wood structure around the gable vent and precut, pre-drill, and label plywood or other suitable shutter materials so that they are ready for installation by a qualified person just before a storm approaches. If installation of shutters from the outside is difficult because of the height or other considerations, but there is access through the attic, the gable vent opening can be shuttered from the inside. However, careful attention needs to be paid to sealing around the shutter and making sure that any water that accumulates in the cavity can drain to the outside of the house and not into the wall below.

Figure 11. Two off-ridge vents are shown in this photograph. The vent that is covered with roofing felt flipped up and allowed a substantial amount of water to enter the residence. Carpeting, kitchen cabinets, and a large amount of gypsum board had to be replaced because of the water intrusion.

Off-ridge Vents

Key Issues

- Poorly anchored off-ridge vents can flip up and become scoops that direct large amounts of wind-driven rain into the attic (Figure 11).

- Some vents are also prone to leaking when winds blow from certain directions. This will depend on the location of the vent on the roof surface and the geometry of the roof, as well as the geometry of the particular vent.

Checking Off-ridge Vent Installations

Off-ridge vents typically have a flange that lies against the top surface of the roof sheathing and is used to anchor the vent to the roof sheathing. Frequently, roofing nails are used to attach the flange to the roof sheathing. The off-ridge vents should be checked to make sure that they are well anchored to the roof sheathing. If they seem loose, or there are not many fasteners holding them down, it could be a weak link in preventing water intrusion when a storm occurs. Since the flange and fasteners are hidden below the roof covering, it is not possible to simply add nails or screws to improve the anchorage as these will create holes through the roof covering.

Remedial Measures

If the off-ridge vent is attached to the roof sheathing with long, thin nails, it may be possible to improve the anchorage by cinching the nails (bending them over against the underside of the roof sheathing). However, if they are short and/or thick, trying to bend them over may cause more harm than good. Some homeowners have had covers made that can be installed from the inside of the attic over the hole where the off-ridge vent is installed. This will be easiest if the vent is larger than the hole and the cover can be attached to the sheathing in an area where the fasteners can't be driven through the roof covering. Otherwise, it will be important to ensure that the fasteners are short enough that they won't extend through the roof sheathing and damage the roof cover. If the edge of the hole in the roof deck is flush with the inside edge of the vent, it may be possible to install metal straps that are screwed into the walls of the vent and attached with short screws to the bottom surface of the roof sheathing. Again, it is critical to use screws that are short enough that they won't extend through the roof sheathing and damage the roof covering. The strapping should be connected to the walls of the vent with short stainless steel sheet metal screws.

Gable Rake Vents

Key Issues

- Gable rake vents are formed when porous soffit panels or screen vents are installed on the bottom surface of the roof overhang at the gable end and there is a clear path for wind to blow into the attic. This usually happens when the gable overhang is supported by what are called outriggers. Outriggers are typically used when gable overhangs exceed 12". In these cases, the last roof truss or rafter (the gable end truss or rafter) is smaller than the trusses or rafters at the next location inside the attic. Outriggers (2x4s) are installed over top of the last gable truss or rafter, one end is anchored to the second truss or rafter back from the gable end, and the other end sticks out past the gable end wall to support the roof sheathing on the overhang.

Finding Out if You Have Gable Rake Vents and Whether You Still Need Them

The easiest way to tell if your roof has gable rake vents is to look in the attic on a cool sunny day and see if light is visible in gaps just below the sheathing at the gable end. The presence of the outriggers (2x4s running perpendicular to the gable truss and disappearing into the gable overhang) should also be visible. If you also have a gable end vent or a ridge vent, then you probably don't need the gable rake vent in order to provide adequate venting for your attic.

Remedial Measures

The best solution if you don't actually need the venting provided by the gable rake vents is to simply plug them up with metal flashing (Figure 12) or pieces of wood that are cut and anchored so that they are well attached and completely seal as many of the openings as possible and particularly those near the gable peak. Sealant can be used to seal around the edges of the metal or wood plugs.

Figure 12. Metal plugs (red arrows) in gable rake vents.

Turbines

Key Issues

- The rotating top portion of many turbines is not designed to withstand high-wind conditions and they are frequently installed with just a friction fit to the short standpipe that provides the venting of the attic. It is possible to find high-wind rated turbines on store shelves in hurricane-prone regions but, in hurricane winds, the turbines will be rotating at tremendous speeds and can be easily damaged by windborne debris.
- The flange on the standpipe that provides the connection of the pipe to the roof sheathing may also be poorly anchored to the roof sheathing.

Checking Turbines and Their Installation

Check any turbines to make sure that the stand pipes are not loose and that the turbine head is anchored to the stand pipe by sheet metal screws and not simply by a friction fit (Figure 13).

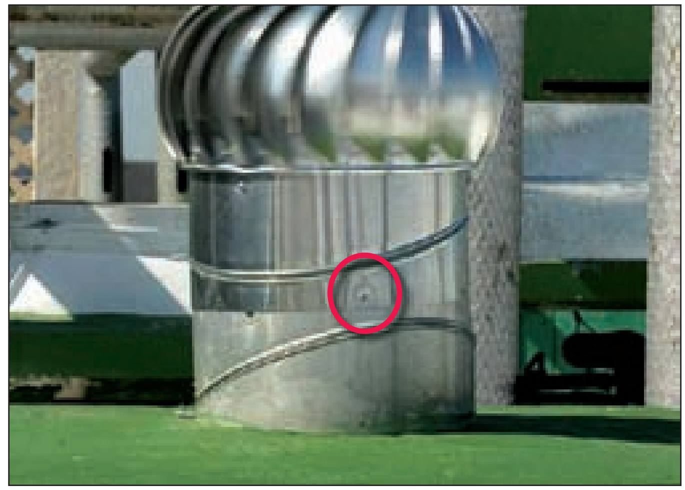


Figure 13. This turbine head is attached to the standpipe with dimple punches. Sheet metal screws should be added to strengthen the connection.

Remedial Measures

Loose standpipes should be securely anchored to the roof sheathing. If the standpipe is attached to the roof sheathing with long, thin nails, it may be possible to improve the anchorage by cinching the nails (bending them over against the underside of the roof sheathing). However, if they are short and/or thick, trying to bend them over may cause more harm than good. Some homeowners have had covers made that can be installed from the inside of the attic over the hole where the standpipe is installed. This will be easiest if the standpipe is larger than the hole and the cover can be attached to the sheathing in an area where the fasteners can't be driven through the roof cover. Otherwise, it will be important to ensure that the fasteners are short enough that they won't extend through the roof sheathing and damage the roof cover. If the edge of the hole in the roof deck is flush with the inside edge of the standpipe, it may be possible to install metal straps that are screwed into the walls of the standpipe and attached with short screws to the bottom surface of the roof sheathing. Again, it is critical to use screws that are short enough that they won't extend through the roof sheathing and damage the roof cover. The strapping should be connected to the walls of the standpipe with short stainless steel sheet metal screws. Beyond any remedial measures taken to anchor the standpipe to the roof sheathing or to plug the hole from the attic side, it is also important to try and seal the standpipe from the outside so that water doesn't build up in the pipe and leak into the roof sheathing around the hole. The best approach is to have a qualified person remove the top active portion of the turbine vent before the storm and plug the hole at the top of the standpipe. A wooden plug can be used that covers the entire hole and has blocks that rest against the walls of the standpipe where screws can be installed to anchor the plug to the standpipe. Some homeowners have had the entire turbine wrapped in plastic to keep water out during a storm (Figure 14). This can work as long as the turbine or wrapping doesn't get dislodged. The smaller area provided by removing the turbine top and plugging the hole is considered preferable.

Figure 14. Plastic wrapped turbine.

Metal Roof Systems in High-Wind Regions

FEMA
http://www.fema.gov

HURRICANE IKE RECOVERY ADVISORY

Purpose: To recommend practices for designing and installing metal roof systems that will enhance wind resistance in high-wind regions (i.e., greater than 90-miles per hour [mph] gust design wind speed). This Advisory is applicable to residential and commercial/industrial buildings and critical facilities.

Metal Roofing Options

A variety of metal panel systems (including composite foam panels) are available for low-slope (i.e., 3:12 or less) and steep-slope (i.e., greater than 3:12) roofs. Metal shingles are also available for steep-slope roofs. Common metal roofing options are:

Standing-Seam Hydrostatic (i.e., water-barrier) Systems: These panel systems are designed to resist water infiltration under hydrostatic pressure. They have standing seams, which raise the joint between panels above the water line. The seam is sealed with sealant tape or sealant in case it becomes inundated with water backed up by an ice dam or driven by high wind.

Most hydrostatic systems are structural systems (i.e., the roof panel has sufficient strength to span between purlins or nailers). A hydrostatic architectural panel (which cannot span between supports) may be specified, however, if continuous or closely spaced decking is provided.

An advantage of exposed fastener panels (versus panels with concealed clips) is that, after installation, it is easy to verify that the correct number of fasteners was installed. If fastening was not sufficient, adding exposed fasteners is easy and economical.

For attachment of corrugated metal panels, see FEMA 55, *Coastal Construction Manual*, Appendix K, available online at: http://www.fema.gov/library/viewRecord.do?id=1671.

Hydrokinetic (i.e., water-shedding) panels:
These panel systems are not designed to resist water infiltration under hydrostatic pressure and therefore require a relatively steep slope (typically greater than 3:12) and the use of an underlayment to provide secondary protection against water that infiltrates past the panels. Most hydrokinetic panels are architectural systems, thus requiring continuous or closely spaced decking to provide support for gravity loads.

This Recovery Advisory addresses wind and wind-driven rain issues. For general information on other aspects of metal roof system design and construction (including seam types, metal types, and finishes), see:

Architectural Sheet Metal Manual (Sheet Metal and Air Conditioning Contractors National Association, 2003: http://www.smacna.org/bookstore

***Copper and Common Sense*:** http://www.reverecopper.com/candcs.html

Copper Development Association: http://www.copper.org/publications/pub_list/architecture.html

Metal Construction Association: http://www.metalconstruction.org/pubs

Metal Roofing Systems Design Manual (Metal Building Manufacturers Association, 2000, http://www.mbma.com/display.cfm?p=44&pp6&i=47

National Institute of Building Sciences, Whole Building Design Guide: http://www.wbdg.org/design/env_roofing.php

***The NRCA Roofing Manual*:** Metal Panel and SPF Roof Systems (National Roofing Contractors Association, 2008, http://www.nrca.net/rp/technical/manual/default.aspx

Some hydrokinetic panels have standing ribs and concealed clips (Figure 1), while others (such as 5V-crimp panels, R-panels [box-rib] and corrugated panels) are through-fastened (i.e., attached with exposed fasteners). Panels are available that simulate the appearance of tile.

Metal Shingles: Metal shingles are hydrokinetic products and therefore also require a relatively steep-slope and the use of an underlayment. Metal shingles are available that simulate the appearance of wood shakes and tiles.

Key Issues

Damage investigations have revealed that some metal roofing systems have sufficient strength to resist extremely high winds (Figure 2), while other systems have blown off during winds that were well below design wind speeds given in ASCE 7. When metal roofing (or hip, ridge, or rake flashings) blow off during hurricanes, water may enter the building at displaced roofing; blown-off roofing can damage buildings and injure people. Guidance for achieving successful wind performance is presented below:

1. Always follow manufacturer's installation instructions and local building code requirements.

2. Calculate loads on the roof assembly in accordance with ASCE 7 or the local building code, whichever procedure results in the highest loads.

3. Specify/purchase a metal roof system that has sufficient uplift resist resistance to meet the design uplift loads.

- For standing seam and through-fastened metal panel systems, the International Building Code® (IBC®) requires test methods UL 580 or ASTM E 1592. For standing seam systems, it is recommended that design professionals specify E 1592 testing, because it gives a better representation of the system's uplift performance capability.

  For safety factor determination, refer to Chapter F in standard NAS-01, published by the American Iron and Steel Institute (available online at: http://www.professionalroofing.net/article.aspx?id=266).

- For through-fastened steel panel systems, the IBC allows uplift resistance to be evaluated by testing or by calculations in accordance with standard NAS-01.

- For architectural panels with concealed clips, test method UL 580 is commonly used. However, it is recommended that design professionals specify E 1592 because it gives a better representation of the system's uplift performance capability. When testing architectural panel systems via E 1592, the deck joints need to be unsealed in order to allow air flow to the underside of the metal panels. Therefore, underlayment should be eliminated from the test specimen, and a

Figure 1. This architectural panel system has concealed clips. The panels unlatched from the clips. The first row of clips (just above the red line) was several inches from the end of the panels. The first row of clips should have been closer to the eave.

Figure 2. This structural standing seam roof system survived Hurricane Andrew (Florida, 1992), but some hip flashings were blown off. The estimated wind speed was 170 mph (peak gust, Exposure C at 33 feet).

For observations of metal roofing performance during Hurricanes Charley (2004, Florida), Ivan (2004, Alabama and Florida), and Katrina (Alabama, Louisiana, and Mississippi, 2005), respectively; see Chapter 5 in FEMA MAT reports 488, 489, and 549, available on-line at:

FEMA 488: http://www.fema.gov/library/viewRecord.do?id=1444

FEMA 489: http://www.fema.gov/library/viewRecord.do?id=1569

FEMA 549: http://www.fema.gov/library/viewRecord.do?id=1857

1/8” minimum gap between deck panel side and end joints should be specified.

For safety factor determination, refer to Chapter F in standard NAS-01.

- For copper roofing testing, see “NRCA analyzes and tests metal,” Professional Roofing, May 2003 (available online at: http://www.professionalroofing.net/article.aspx?id=266).
- For metal shingles, it is recommended that uplift resistance be based on test method UL 580 or 1897.
- Specify the design uplift loads for field, perimeter, and corners of the roof. Also specify the dimension of the width of the perimeter. (Note: For small roof areas, the corner load can be used throughout the entire roof area.)

4. Suitably design the roof system components (see the construction guidance below).

5. Obtain the services of a professional roofing contractor to install the roof system.

Construction Guidance

- Consult the local building code and manufacturer’s literature for specific installation requirements. Requirements may vary locally.
- Underlayment: If a robust underlayment system is installed, it can serve as a secondary water barrier if the metal roof panels or shingles are blown off (Figures 1 and 3). For enhanced underlayment recommendations, see Technical Fact Sheet No. 19 in FEMA 499, *Home Builder’s Guide to Coastal Construction Technical Fact Sheet Series* (available online at: http://www.fema.gov/library/viewRecord.do?id=1570). Fact Sheet 19 pertains to underlayment options for asphalt shingle roofs. For metal panels and tiles, where Fact Sheet 19 recommends a Type I (#15) felt, use a Type II (#30) felt because the heavier felt provides greater resistance to puncture by the panels during application. Also, if a self-adhering modified bitumen underlayment is used, specify/purchase a product that is intended for use underneath metal (such products are more resistant to bitumen flow under high temperature).
- Where the basic (design) wind speed is 110 mph or greater, it is recommended that two clips be used along the eaves, ridges, and hips. Place the first eave clip within 2 to 3" of the eave, and place the second clip approximately 3 to 4" from the first clip. Figures 1 and 4 illustrate ramifications of clips being too far from the eave.
- For copper panel roofs in areas with a basic wind speed greater than 90 mph, it is recommended that Type 316 stainless steel clips and stainless steel screws be used in lieu of the much more malleable copper clips.

Figure 3. These architectural panel system have snap-lock seams. One side of the seam is attached with a concealed fastener. Although a large number of panels blew away, the underlayment did not.

Figure 4. These eave clips were too far from the panel ends. The clip at the left was 13" from the edge of the deck. The other clip was 17" from the edge. It would have been prudent to install double clips along the eave.

Figure 5. The panels blew off the upper roof and landed on the lower roof of this house. The upper asphalt shingle roof shown had been re-covered with 5V-Crimp panels that were screwed to nailers. The failure was caused by inadequate attachment of the nailers (which had widely-spaced nails) to the sheathing. Note that the hip flashing on the lower roof blew off.

Figure 6. Blow-off of nailers caused these panels to progressively fail. The nailers were installed directly over the trusses. In an assembly such as this where there is no decking, there is no opportunity to incorporate an underlayment. With loss of the panels, rainwater was free to enter the building.

Figure 7. 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.

- When clip or panel fasteners are attached to nailers (Figures 5, 6, and 7), detail the connection of the nailer to the nailer support (including the detail of where nailers are spliced over a support).
- When clip or panel fasteners are loaded in withdrawal (tension), screws are recommended in lieu of nails.
- For roofs located within 3,000' of the ocean line, stainless steel clips and fasteners are recommended.
- For concealed clips over a solid substrate, it is recommended that chalk lines be specified so that the clips are correctly spaced.
- Hip, ridge, and rake flashings: Because exposed fasteners are more reliable than cleat attachment, it is recommended that hip, ridge, and rake flashings be attached with exposed fasteners. Two rows of fasteners are recommended on either side of the hip/ridge line. Close spacing of fasteners is recommended (e.g., spacing in the range of 3 to 6" on center, commensurate with the design wind loads), as shown in Figure 8 in order to avoid flashing blow-off as shown in Figure 9.

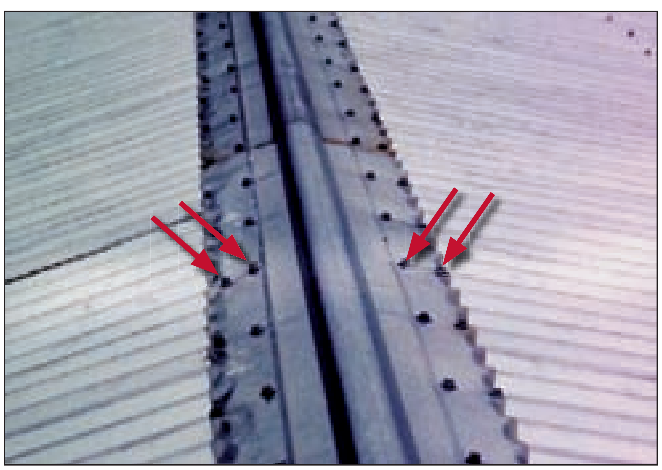


Figure 8. The ridge flashing on these corrugated metal panels had two rows of fasteners on each side of the ridge line.

Figure 9. The ridge flashing fasteners were placed too far apart. A significant amount of water leakage can occur when ridge flashings are blown away.

Critical Facilities

For metal roofs on critical facilities in hurricane-prone regions (as defined in ASCE 7), see the recommendations in FEMA 543, Section 3.4.3.4 (available online at http://www.fema.gov/library/viewRecord.do?id=2441). (For facilities located outside of hurricane-prone regions, see Section 3.3.3.4.) For load calculation recommendations, see Section 3.3.1.2.

For metal roofs on hospitals in hurricane-prone regions, see the recommendations in FEMA 577, Section 4.3.3.8 (available online at http://www.fema.gov/library/viewRecord.do?id=2739). (For hospitals located outside of hurricane-prone regions, see Section 4.3.3.7.) For load calculation recommendations, see Section 4.3.1.2.

Sustainable Design

Cool Roofs: Use metal roofs with a solar reflectance Index (SRI) equal to or greater than 78 for low-slope and 29 for steep-sloped roofs. The higher solar reflectance will reduce the heat-island effect (thermal gradient differences between developed and undeveloped areas), minimizing the impact buildings have on microclimate and human and wildlife habitat. Heat islands can affect communities by increasing summertime peak energy demand, air conditioning costs, greenhouse gas emissions and air pollution, heat-related illness and mortality, and water quality (http://www.EPA.gov/heatisland).

Recycled Content: Use metal roof systems with recycled content. Many roofing products have recycled scrap content generated both from consumer and industrial users. Recycled content is defined in the International Organization of Standards (ISO) document, ISO 14021 (http://www.iso.org/iso/catalogue_detail?csnumber=23146). Using recycled products reduces impacts from extraction and processing of new materials.

For further information pertaining to sustainable design aspects of metal roofing, see: http://www.metalconstruction.org/design.

Siding Installation in High-Wind Regions

FEMA
http://www.fema.gov

HURRICANE IKE RECOVERY ADVISORY

Purpose: To provide basic design and installation tips for various types of siding that will enhance wind resistance in high-wind regions (i.e., greater than 90-mph gust design wind speed).

Key Issues

> **Moisture barrier** (also known as a water-resistive barrier): In the context of residential walls, the moisture barrier is either housewrap or building paper (felt). The moisture barrier occurs between the wall sheathing and the siding. It is a dual-purpose layer that sheds water that gets through the siding and limits air flow through the wall. When properly sealed, housewrap is considered an air barrier. Although building paper provides some resistance to air flow, it is not considered an air barrier. Moisture barriers shed water, but they allow water vapor to pass through them.

> For further guidance on principles, materials, and procedures for the design and construction of walls to make them resistant to water intrusion, see American Society for Testing and Materials (ASTM) E 2266, *Standard Guide for Design and Construction of Low-Rise Frame Building Wall Systems to Resist Water Intrusion.*

- Siding is frequently blown off walls of residential and non-residential buildings during hurricanes. Also, wind-driven rain is frequently blown into wall cavities (even when the siding itself is not blown off). Guidance for achieving successful wind performance is presented below.
- To avoid wind-driven rain penetration into wall cavities, an effective moisture barrier (housewrap or building paper) is needed. For further information on moisture barriers, see Technical Fact Sheet No. 9 in FEMA 499, *Home Builder's Guide to Coastal Construction*, Technical Fact Sheet Series (available online at: http://www.fema.gov/library/viewRecord.do?id=1570). For further information on housewrap, see Technical Fact Sheet No. 23.
- Always follow manufacturer's installation instructions and local building code requirements.
- Use products that are suitable for a coastal environment. Many manufacturers do not rate their products in a way that makes it easy to determine whether the product will be adequate for the coastal environment. Use only siding products where the supplier can provide specific information on product performance in coastal or high-wind environments.
- For buildings located within 3,000' of the ocean line, stainless steel fasteners are recommended.
- Avoid using dissimilar metals together.
- The installation details for starting the first (lowest) course of lap siding can be critical. Loss of siding often begins at the lowest course and proceeds up the wall (Figures 4 and 12). This is particularly important for elevated buildings, where the wind blows under the building as well as against the sides.
- When applying new siding over existing siding, use shims or install a solid backing to create a uniform, flat surface on which to apply the siding, and avoid creating gaps or projections that could catch the wind.
- Coastal buildings require more maintenance than inland buildings. This maintenance requirement needs to be considered in both the selection and installation of siding.

Vinyl Siding

Vinyl siding can be used successfully in a coastal environment if properly designed and installed.

- Windload resistance:

- Vinyl siding is required by the International Building Code® (IBC®) and the International Residential Code® (IRC®) to comply with ASTM D 3679, *Standard Specification for Rigid Poly(Vinyl Chloride) (PVC) Siding*, which requires the siding to withstand wind pressures equivalent to 110 mph on a building up to 30' in height in Exposure B. Most vinyl siding has also been tested for higher wind pressures, and can be used in locations with a higher basic wind speed, greater building height, more open exposure, or some combination of those. The design wind pressure or wind speed for which these products are rated is available from product literature, installation instructions, or listings of agencies such as the International Code Council® (ICC®) Evaluation Service.
- For design wind speeds greater than 110 mph, or building heights greater than 30', or Exposure C, choose a model of siding rated for those conditions or higher. The manufacturer's product literature or installation instructions should specify the fastener type, size and spacing, and any other installation details needed to achieve this rating.

Definition of Wind Exposure Zones

Exposure B: Urban, suburban, wooded areas.

Exposure C: Open terrain, flat open country, grasslands, all water surfaces in hurricane-prone regions.

- Products that have been rated for high winds typically have an enhanced nailing hem and are sometimes made from thicker vinyl (Figure 1). Thick, rigid panels provide greater wind resistance, withstand dents, and lie flatter and straighter against the wall. Optimum panel thickness should be 0.040 to 0.048", depending on style and design. Thinner gauge vinyl works well for stable climates; thicker gauge vinyl is recommended for areas with high winds and high temperature changes.
- Position nails in the center of the nailing slot (Figure 2).
- To allow for thermal movement of the siding, do not drive the head of the nail tight against the nail hem (unless the hem has been specifically designed for this). Allow approximately 1/32" (which is about the thickness of a dime) clearance between the fastener head and the siding panel (Figure 3).

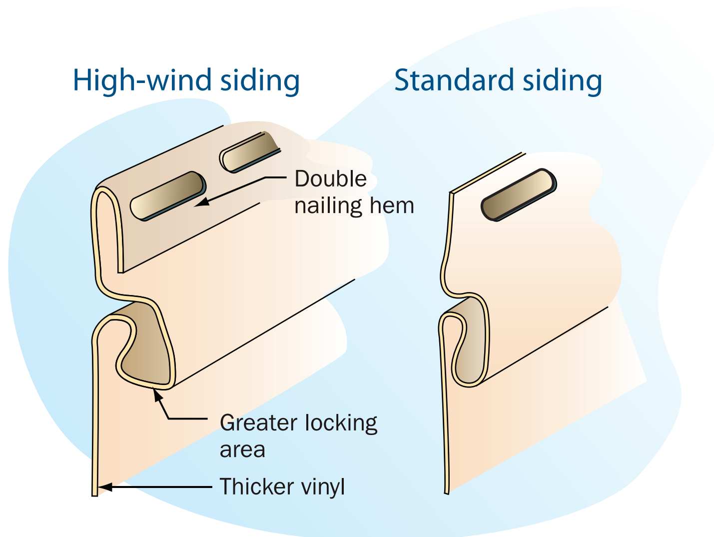


Figure 1. Features of typical high-wind siding and standard siding.

- Drive nails straight and level to prevent distortion and buckling in the panel.
- Do not caulk the panels where they meet the receiver of inside corners, outside corners, or J-trim. Do not caulk the overlap joints.
- Do not face-nail or staple through the siding.

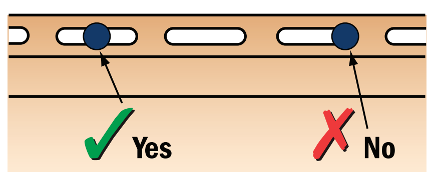


Figure 2. Proper and improper fastener locations.

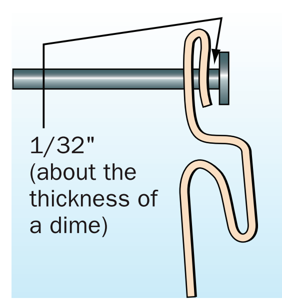


Figure 3. Allow 1/32" clearance between the fastener head and the siding panel.

- Use aluminum, galvanized steel, or other corrosion-resistant nails when installing vinyl siding. Aluminum trim pieces require aluminum or stainless steel fasteners.
- Nail heads should be 5/16" minimum in diameter. Shank should be 1/8" in diameter.
- Use the manufacturer-specified starter strip to lock in the first course; do not substitute other accessories such as a J-channel or utility trim (Figure 4) unless specified by the manufacturer. If the manufacturer specifies a particular strip for high-wind applications, use it. Make sure that the starter strip is designed to positively lock the panel, rather than just hooking over a bulge in the strip; field test the interlock before proceeding with the installation.

- Make sure that every course of siding is positively locked into the previous course (Figure 5). Push the panel up into the lock from the bottom before nailing rather than pulling from the top. Do not attempt to align siding courses with adjacent walls by installing some courses loosely.
- Make sure that adjacent panels overlap properly, about half the length of the notch at the end of the panel, or approximately 1". Make sure the overlap is not cupped or gapped, which is caused by pulling up or pushing down on the siding while nailing. Reinstall any panels that have this problem.
- Use utility trim under windows or anywhere the top nail hem needs to be cut from siding to fit around an obstacle. Be sure to punch snap-locks into the siding to lock into the utility trim. Do not overlap siding panels directly beneath a window (Figure 6).

Figure 4. Utility trim was substituted for the starter strip and the bottom lock was cut off the siding. Siding was able to pull loose under wind pressure.

- At gable end walls, it is recommended that vinyl siding be installed over wood sheathing rather than over plastic foam sheathing, as was done at the house shown in Figure 7.
- Install vinyl siding in accordance with manufacturer's installation instructions and local building code requirements.
- It is recommended that vinyl siding installers be certified under the VSI Certified Installer Program sponsored by the Vinyl Siding Institute. For more information, go to http://www.vinylsiding.org/aboutsiding/installation/certinstaller.

Figure 5. The siding panel was not properly locked into the panel below.

Figure 6. Proper detailing around windows and other obstacles is important. Use utility trim, punch snap-locks into siding, and don't overlap directly beneath a window.

Figure 7. The vinyl siding at this gable was installed over plastic foam insulation. Without wood sheathing, the wind pressures on the vinyl are increased. Also, if the siding blows away, the foam insulation is very vulnerable to blow-off. With loss of the foam insulation, wind-driven rain can freely enter the attic, saturate the ceiling insulation, and cause collapse of the ceiling.

Wood Siding

- Use decay-resistant wood such as redwood, cedar, or cypress. See the Sustainable Design section regarding certified wood.
- To improve longevity of paint, back-prime wood siding before installation.
- Carefully follow manufacturer's detailing instructions to prevent excessive water intrusion behind the siding.
- For attachment recommendations, see *Natural Wood Siding: Selection, Installation and Finishing*, published by the Western Wood Products Association (http://www.wwpa.org).

  This publication recommends an air gap between the moisture barrier and the backside of the siding to promote drainage and ventilation. Such a wall configuration is referred to as a rain screen wall. See the text box on page 5.
- Follow the installation details shown in Figure 8. (Note: Although these details do not show a rain screen, inclusion of vertical furring strips to create a rain screen is recommended.)

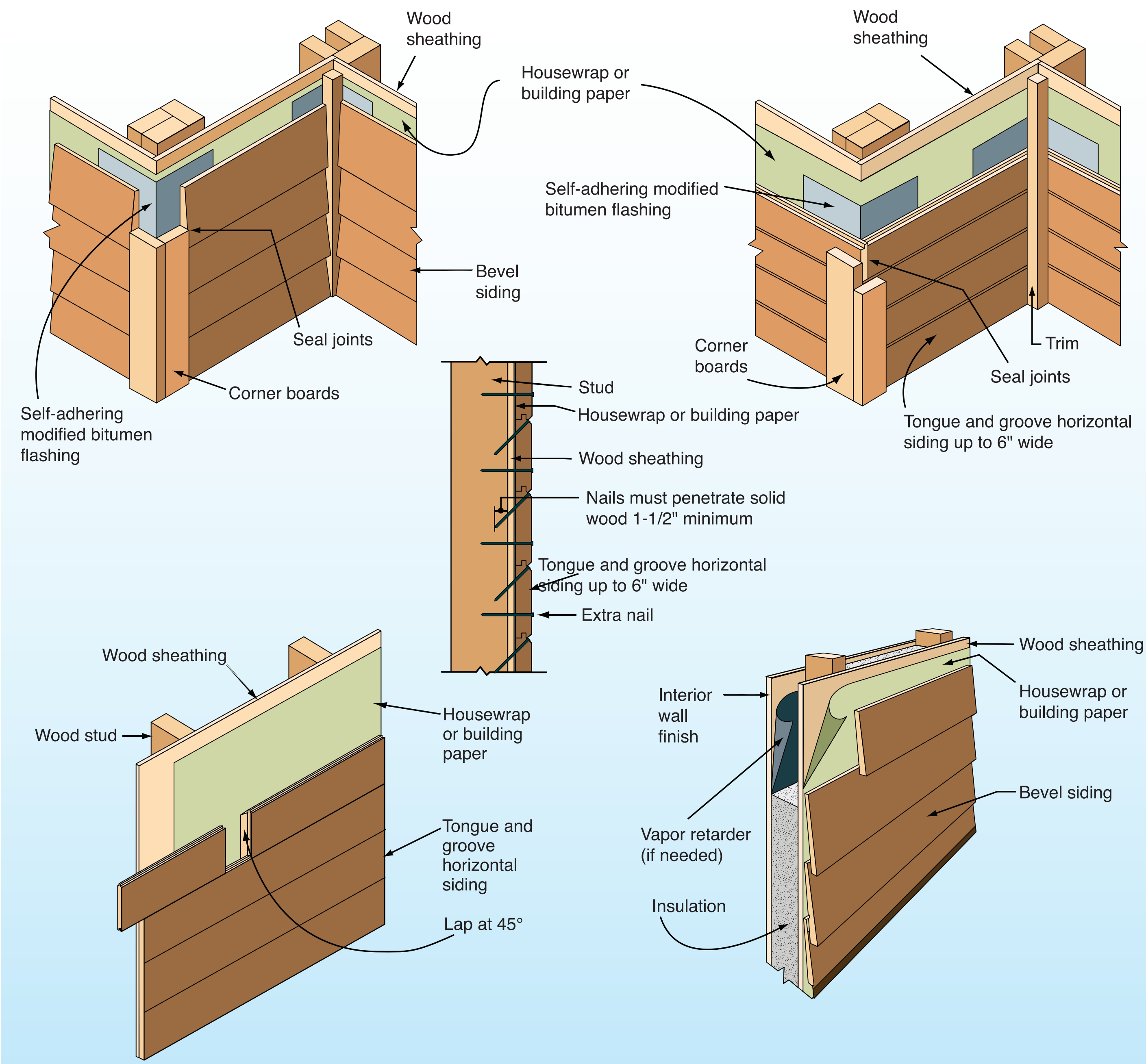


Figure 8. Wood siding installation details.

Pressure-equalized rain screen wall system

In areas that experience frequent wind-driven rain and areas susceptible to high winds, it is recommended that a rain screen design be considered when specifying wood or fiber cement siding. (Typical vinyl siding products inherently provide air cavities behind the siding that facilitate drainage. Therefore, incorporation of vertical furring strips is normally not applicable to this type of wall covering.) A rain screen design is accomplished by installing suitable vertical furring strips between the moisture barrier and siding material (see Figure 9). The cavity facilitates drainage of water from the space between the moisture barrier and backside of the siding and it facilitates drying of the siding and moisture barrier.

Furring strip attachment: For 1" x 2" furring strips, tack strips in place and use siding nails that are ¾" longer than would be required if there were no strips (thereby maintaining the minimally required siding nail penetration into the studs). For thicker furring strips, an engineered attachment is recommended.

At the bottom of the wall, the cavity should be open to allow water drainage. However, the opening should be screened to avoid insect entry.

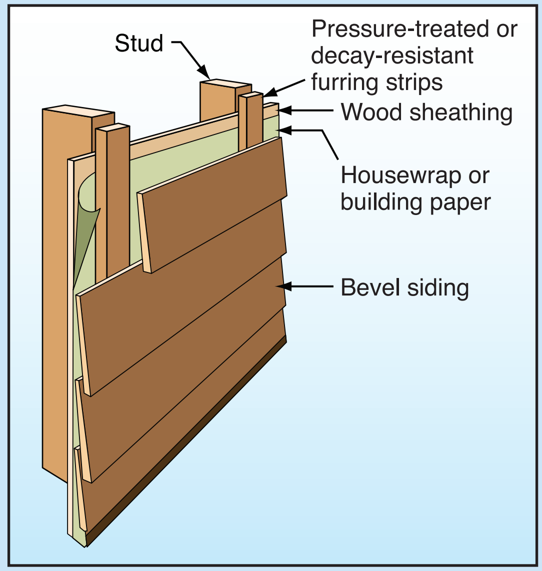


Figure 9. Pressure-equalized rain screen system.

At the wall/soffit juncture, the top of the cavity can open into the attic space to provide inlet air ventilation, thereby eliminating soffit vents and their susceptibility to wind-driven rain entry. If the rain screen cavity vent path is used in lieu of soffit vents, the depth of the cavity needs to be engineered to ensure that it provides sufficient air flow to ventilate the attic.

Fiber Cement Siding

Installation procedures are similar to those for wood siding, but require specialized cutting blades and safety precautions because of the dust produced during cutting with power tools. Manufacturer's installation recommendations should be strictly adhered to, and particular attention paid to the painting and finishing recommendations for a high-quality installation.

- Always seal field-cut ends according to the manufacturer's instructions. Properly gap the intersection between siding edges and other building components and fill the gap with sealant.
- Always consult and follow the manufacturer's installation requirements for the needed wind speed rating or design pressure (refer to the manufacturer's building code compliance evaluation report). Observe the manufacturer's fastener specifications, including fastener type and size, spacing, and penetration requirements. Do not over drive or under drive.
- At gable end walls, it is recommended that fiber cement siding be installed over wood sheathing rather than over plastic foam sheathing.
- Keep blind nails between ¾ and 1" from the top edge of the panel (Figure 10). Be sure to drive nails at least 3/8" from butt ends, or use manufacturer-specified joiners.
- Face nailing (Figure 11) instead of blind nailing is recommended where the basic (design) wind speed is 100 miles per hour or greater. If the local building code or manufacturer specifies face nailing at a lower wind speed, install accordingly.
- Do not leave the underside of the first course exposed or extending beyond the underlying material (Figure 12). Consider the use of a trim board to close off the underside of the first course.

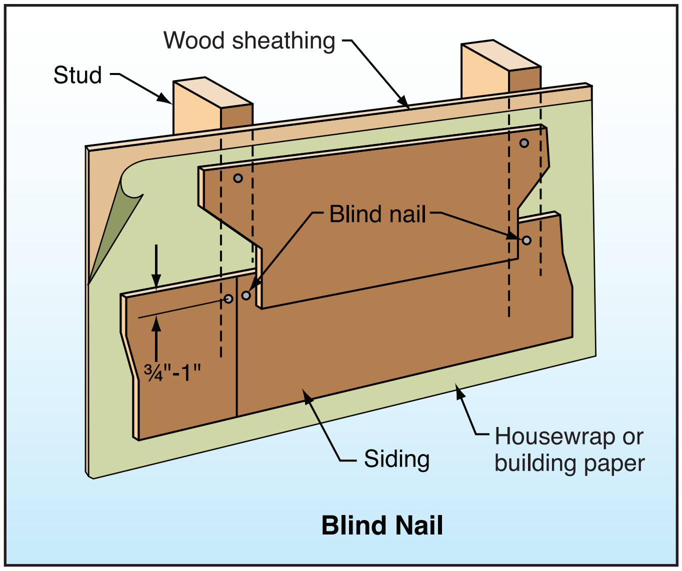


Figure 10. Blind nailing.

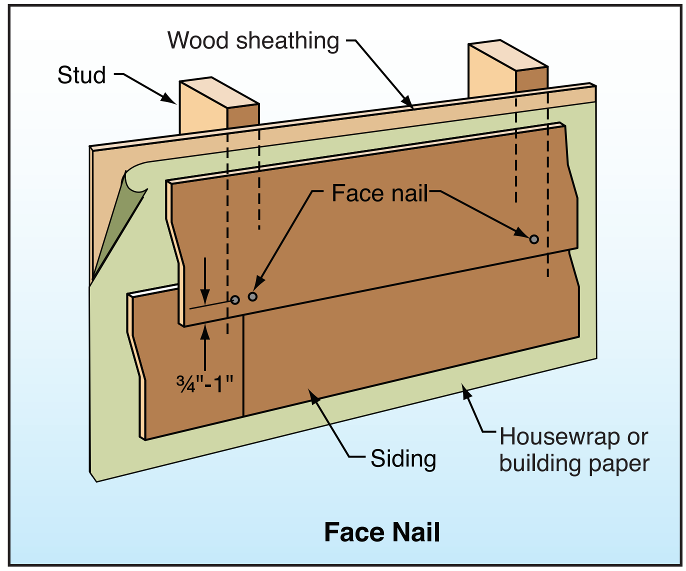


Figure 11. Face nailing.

Sustainable Design

Material selection for sustainable sources and durability

For wood products, select a Forest Stewardship Council (FSC) certified product. The FSC seeks to ensure that wood is harvested in a more responsible fashion, including protecting forest ecosystems, and avoids the use of chemicals and genetic engineering. While redwood, cedar, and cypress are decay-resistant and recommended for durability, they are generally cut from old growth timber. You can determine if the manufacturer is FSC certified by going to http://www.fsc-info.org.

For other siding products, consider long-term life spans for coastal environments, recycled content, and post-consumer use.

Figure 12. Blind nailed siding installed with exposed gap at bottom (red circle) is vulnerable to failure.

The following publications discuss sustainable aspects of vinyl siding:

A Dozen Things You Might Not Know That Make Vinyl Siding Green (available online at http://www.vinylsiding.org/aboutsiding/greenpaper/080919_VSI_Green_Paper_for_web.pdf).

Siding with the Environment (available online at http://www.vinylsiding.org/publications/final_Enviro_single_pg.pdf).

Energy Conservation and Air Barriers: Uncontrolled air leakage through the building envelope is often overlooked. The U.S. Department of Energy estimates that 40 percent of the cost of heating or cooling the average American home is lost to uncontrolled air leakage. In warmer climates, it is a lower percentage of loss. An air barrier system can reduce the heating, ventilation, and cooling (HVAC) system size, resulting in reduced energy use and demand.

Uncontrolled air leakage can also contribute to premature deterioration of building materials, mold and moisture problems, poor indoor air quality, and compromised occupant comfort. When uncontrolled air flows through the building envelope, water vapor moves with it. Controlling the movement of moisture by air infiltration requires controlling the air pathways and/or the driving force.

To effectively control air leakage through the building envelope, an effective air barrier is required. To be effective, it needs to be continuous; therefore, air barrier joints need to be sealed and the barrier needs to be sealed at penetrations through it. The Air Barrier Association of America recommends that materials used as a component of a building envelope air barrier be tested to have an air infiltration rate of less than 0.004 cfm/square foot, assemblies of materials that form the air barrier be tested to have an air infiltration rate of less than 0.04 cubic feet per minute (cfm)/square foot, and the whole building exterior enclosure have an air infiltration rate of less than 0.4 cfm/square foot.

Air barrier systems installed behind siding:

Housewrap is the most common air barrier material for residential walls. To be effective, it is critical that the joints between sheets of housewrap be sealed as recommended by the manufacturer, and penetrations (other than fasteners) should also be sealed. At transitions between the housewrap and door and window frame, use of self-adhering modified bitumen flashing tape is recommended.

An air barrier should be installed over a rigid material, or it will not function properly. It also needs to be restrained from pulling off of the wall under negative wind pressures. For walls, wood sheathing serves as a suitable substrate, and the siding (or furring strips in a rain screen wall system) provide sufficient restraint for the air barrier.

At the base of the wall, the wall air barrier should be sealed to the foundation wall. If the house is elevated on piles, the wall barrier should be sealed to an air barrier installed at the plane of the floor.

If the building has a ventilated attic, at the top of the wall, the wall air barrier should be sealed to an air barrier that is installed at the plane of the ceiling.

If the building has an unventilated attic or no attic, at the top of the wall, the wall air barrier should be sealed to an air barrier that is installed at the plane of the roof (the roof air barrier may be the roof membrane itself, or a separate air barrier element).

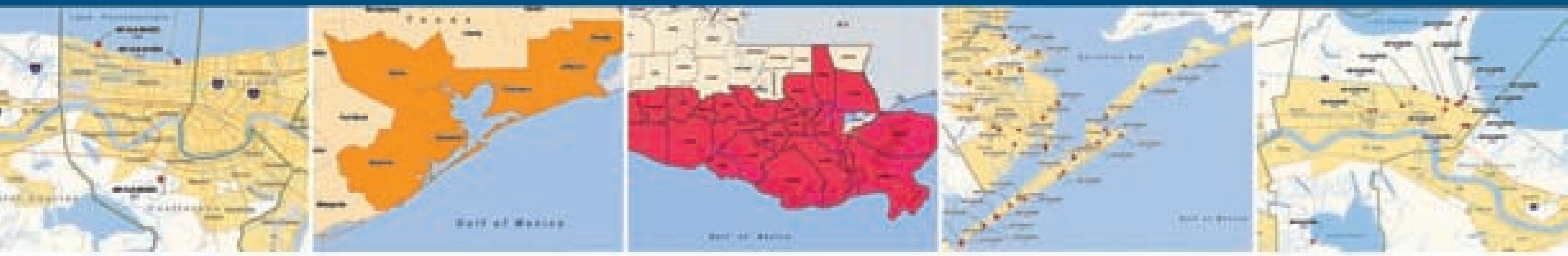
Siding maintenance:

For all siding products, it is very important to periodically inspect and maintain the product especially in a coastal environment. This includes recoating on a scheduled maintenance plan that is necessary according to the manufacturer's instructions and a periodic check of the sealant to ensure its durability. Check the sealant for its proper resiliency and that it is still in place. Sealant should be replaced before it reaches the end of its service life.

Air barrier: A component installed to provide a continuous barrier to the movement of air through the building envelope. Housewrap is a common air barrier material for residential walls. Although very resistant to airflow, housewrap is very vapor permeable and therefore is not suitable for use as a vapor retarder.

Vapor retarder: A component installed to resist diffusion of water vapor and provide a continuous barrier to movement of air through the building envelope. Polyethylene is a common vapor retarder material for residential walls. To determine whether or not a vapor retarder is needed, refer to the Moisture Control section of the *NRCA Roofing and Waterproofing Manual*, published by the National Roofing Contractors Association (NRCA) (http://www.nrca.net).

ASTM E 1677, *Standard Specification for an Air Retarder (AR) Material or System for Low-Rise Framed Building Walls*: This specification covers the minimum performance and acceptance criteria for an air barrier material or system for framed walls of low-rise buildings with the service life of the building wall in mind. The provisions contained in this specification are intended to allow the user to design the wall performance criteria and increase air barrier specifications to accommodate a particular climate location, function, or design of the intended building.



HURRICANE IKE IN TEXAS & LOUISIANA

E High Water Marks

The following HWM data is taken from FEMA's Texas Hurricane Ike Rapid Response Coastal High Water Mark Collection (October 2008).

High Water Marks in Texas

Summary of High Water Mark Survey Results					
HWM ID	Parish	Surveyed Elevation (feet) NAVD 88	Surveyed Latitude	Surveyed Longitude	Flood Type
353-ITX-02-027	Brazoria	6.6	29.3030	-95.2668	Coastal - Stillwater Only
353-ITX-02-028	Brazoria	6.9	29.2479	-95.2363	Coastal - Stillwater Only
353-ITX-02-029	Brazoria	8.8	29.1966	-95.2989	Coastal - Stillwater Only
353-ITX-02-030	Brazoria	5.1	29.1127	-95.3745	Coastal - Stillwater Only
353-ITX-02-031	Brazoria	5.3	28.9490	-95.5553	Coastal - Stillwater Only
353-ITX-02-032	Brazoria	5.5	28.8778	-95.4558	Coastal - Stillwater Only
353-ITX-02-033	Brazoria	7.2	28.8981	-95.3807	Coastal - Stillwater Only
353-ITX-02-034	Brazoria	6.6	28.9506	-95.3384	Coastal - Stillwater Only
353-ITX-02-035	Brazoria	7.3	28.9395	-95.2972	Coastal - Stillwater Only
353-ITX-02-036	Brazoria	7.7	28.9429	-95.2999	Coastal - Stillwater Only
353-ITX-02-037	Brazoria	10.7	28.9538	-95.2820	Coastal - Stillwater Only
353-ITX-02-038	Brazoria	7.7	28.9620	-95.2908	Coastal - Stillwater Only
353-ITX-04-011	Brazoria	8.3	28.9301	-95.3130	Coastal - Stillwater Only
353-ITX-04-012	Brazoria	8.7	28.9301	-95.3128	Coastal - Wave Height
353-ITX-04-013	Brazoria	7.8	28.9354	-95.3038	Coastal - Stillwater Only
353-ITX-04-014	Brazoria	8.0	28.9484	-95.2924	Coastal - Stillwater Only
353-ITX-04-015	Brazoria	9.2	28.9626	-95.2734	Coastal - Stillwater Only
353-ITX-04-016	Brazoria	6.7	29.0136	-95.3308	Coastal - Stillwater Only
353-ITX-04-017	Brazoria	6.3	29.0955	-95.2839	Coastal - Stillwater Only
353-ITX-04-018	Brazoria	6.4	29.2098	-95.2105	Coastal - Stillwater Only
353-ITX-04-019	Brazoria	9.4	29.2845	-95.1294	Coastal - Stillwater Only
353-ITX-03-001	Chambers	14.8	29.8755	-94.8295	Coastal - Stillwater Only
353-ITX-03-002	Chambers	12.9	29.8476	-94.8044	Coastal - Wave Runup
353-ITX-03-003	Chambers	12.5	29.6793	-94.9254	Coastal - Wave Height
353-ITX-03-004	Chambers	12.9	29.6599	-94.9165	Coastal - Wave Height
353-ITX-03-005	Chambers	17.2	29.6945	-94.8654	Coastal - Wave Runup
353-ITX-03-006	Chambers	15.4	29.7486	-94.8252	Coastal - Wave Height
353-ITX-03-007	Chambers	13.8	29.8379	-94.7588	Coastal - Wave Runup
353-ITX-03-008	Chambers	15.7	29.7729	-94.6856	Coastal - Wave Runup
353-ITX-03-009	Chambers	13.5	29.6584	-94.6895	Coastal - Stillwater Only
353-ITX-03-010	Chambers	16.6	29.7282	-94.6902	Coastal - Stillwater Only
353-ITX-03-011	Chambers	11.6	29.6816	-94.6412	Coastal - Stillwater Only
353-ITX-03-012	Chambers	15.4	29.6635	-94.6241	Coastal - Stillwater Only
353-ITX-03-013	Chambers	10.5	29.5380	-94.7614	Coastal - Stillwater Only
353-ITX-03-014	Chambers	12.4	29.5260	-94.7581	Coastal - Wave Height
353-ITX-03-015	Chambers	15.3	29.6320	-94.7023	Coastal - Stillwater Only
353-ITX-03-016	Chambers	14.5	29.6135	-94.5332	Coastal - Stillwater Only
353-ITX-03-019	Chambers	16.9	29.7149	-94.3755	Coastal - Stillwater Only
353-ITX-03-020	Chambers	17.5	29.7040	-94.4837	Coastal - Stillwater Only
353-ITX-02-001	Galveston	10.3	29.0957	-95.1097	Coastal - Stillwater Only
353-ITX-02-002	Galveston	7.9	29.1299	-95.0585	Coastal - Stillwater Only
353-ITX-02-003	Galveston	10.3	29.1476	-95.0300	Coastal - Wave Runup
353-ITX-02-004	Galveston	10.8	29.1894	-94.9777	Coastal - Stillwater Only

Summary of High Water Mark Survey Results					
HWM ID	Parish	Surveyed Elevation (feet) NAVD 88	Surveyed Latitude	Surveyed Longitude	Flood Type
353-ITX-02-005	Galveston	10.5	29.2445	-94.8743	Coastal - Stillwater Only
353-ITX-02-006	Galveston	14.2	29.4726	-94.5955	Coastal - Wave Height
353-ITX-02-007	Galveston	15.8	29.4615	-94.6302	Coastal - Wave Runup
353-ITX-02-008	Galveston	14.8	29.4273	-94.6911	Coastal - Wave Height
353-ITX-02-009	Galveston	10.6	29.3651	-94.7758	Coastal - Wave Height
353-ITX-02-010	Galveston	15.6	29.3243	-94.7414	Coastal - Wave Height
353-ITX-02-011	Galveston	12.0	29.3073	-94.7941	Coastal - Stillwater Only
353-ITX-02-012	Galveston	13.2	29.3370	-94.7774	Coastal - Wave Height
353-ITX-02-013	Galveston	12.4	29.2755	-94.8504	Coastal - Wave Runup
353-ITX-02-014	Galveston	11.9	29.2952	-94.9168	Coastal - Stillwater Only
353-ITX-02-015	Galveston	11.8	29.3003	-94.9152	Coastal - Stillwater Only
353-ITX-02-016	Galveston	12.8	29.3614	-94.9207	Coastal - Wave Runup
353-ITX-02-017	Galveston	15.5	29.3911	-94.8873	Coastal - Wave Runup
353-ITX-02-019	Galveston	11.4	29.4578	-95.0210	Coastal - Stillwater Only
353-ITX-02-020	Galveston	10.4	29.4572	-95.0475	Coastal - Stillwater Only
353-ITX-02-021	Galveston	10.9	29.4365	-95.0922	Coastal - Stillwater Only
353-ITX-02-022	Galveston	13.4	29.3810	-95.0891	Coastal - Stillwater Only
353-ITX-02-023	Galveston	10.3	29.3422	-95.0368	Coastal - Stillwater Only
353-ITX-02-024	Galveston	12.2	29.3043	-94.9876	Coastal - Stillwater Only
353-ITX-02-025	Galveston	10.9	29.3348	-94.9779	Coastal - Stillwater Only
353-ITX-03-017	Galveston	15.4	29.5697	-94.3962	Coastal - Wave Runup
353-ITX-03-018	Galveston	19.4	29.5574	-94.3916	Coastal - Wave Runup
353-ITX-04-001	Galveston	9.7	29.0912	-95.1115	Coastal - Wave Runup
353-ITX-04-002	Galveston	10.7	29.0931	-95.1107	Coastal - Wave Runup
353-ITX-04-003	Galveston	10.7	29.1326	-95.0602	Coastal - Wave Height
353-ITX-04-004	Galveston	9.4	29.1315	-95.0588	Coastal - Stillwater Only
353-ITX-04-005	Galveston	10.2	29.1497	-95.0303	Coastal - Wave Runup
353-ITX-04-006	Galveston	10.2	29.1494	-95.0279	Coastal - Wave Runup
353-ITX-04-007	Galveston	14.1	29.1737	-94.9977	Coastal - Wave Height
353-ITX-04-008	Galveston	10.7	29.1866	-94.9655	Coastal - Stillwater Only
353-ITX-04-009	Galveston	13.1	29.2365	-94.8830	Coastal - Wave Height
353-ITX-04-010	Galveston	11.0	29.3273	-94.7720	Coastal - Wave Height
353-ITX-04-020	Galveston	10.4	29.3355	-95.0224	Coastal - Stillwater Only
353-ITX-04-021	Galveston	10.6	29.3371	-95.0244	Coastal - Stillwater Only
353-ITX-04-028	Galveston	16.7	29.5356	-95.0115	Coastal - Wave Height
353-ITX-04-029	Galveston	15.4	29.5356	-95.0115	Coastal - Stillwater Only
353-ITX-04-030	Galveston	15.2	29.5117	-94.9788	Coastal - Stillwater Only
353-ITX-04-031	Galveston	12.4	29.5007	-94.9347	Coastal - Stillwater Only
353-ITX-04-032	Galveston	12.2	29.4644	-94.9743	Coastal - Wave Runup
353-ITX-04-022	Harris	12.8	29.6155	-94.9980	Coastal - Stillwater Only
353-ITX-04-023	Harris	12.5	29.6195	-95.0071	Coastal - Wave Height
353-ITX-04-024	Harris	12.9	29.5652	-95.0170	Coastal - Stillwater Only
353-ITX-04-025	Harris	10.6	29.5649	-95.0690	Coastal - Wave Height

Summary of High Water Mark Survey Results					
HWM ID	Parish	Surveyed Elevation (feet) NAVD 88	Surveyed Latitude	Surveyed Longitude	Flood Type
353-ITX-04-026	Harris	10.9	29.5386	-95.0851	Coastal - Stillwater Only
353-ITX-01-001	Jefferson	12.2	29.8666	-93.9343	Coastal - Wave Runup
353-ITX-01-002	Jefferson	11.9	29.9195	-93.8895	Coastal - Wave Runup
353-ITX-01-003	Jefferson	11.4	29.8654	-93.9314	Coastal - Wave Runup
353-ITX-01-004	Jefferson	11.7	29.8652	-93.9273	Coastal - Wave Runup
353-ITX-01-005	Jefferson	11.7	29.9486	-93.8769	Coastal - Wave Runup
353-ITX-01-006	Jefferson	11.8	29.9720	-93.8633	Coastal - Stillwater Only
353-ITX-01-007	Jefferson	12.2	29.9721	-93.8633	Coastal - Wave Height
353-ITX-01-016	Jefferson	11.1	30.0963	-94.0933	Coastal - Stillwater Only
353-ITX-01-017	Jefferson	11.2	30.0830	-94.0943	Coastal - Wave Runup
353-ITX-01-019	Jefferson	11.8	29.9964	-93.9498	Coastal - Stillwater Only
353-ITX-01-020	Jefferson	11.5	29.9689	-93.9134	Coastal - Stillwater Only
353-ITX-03-021	Jefferson	9.4	29.8785	-94.1604	Coastal - Stillwater Only
353-ITX-03-022	Jefferson	11.3	29.8494	-94.1350	Coastal - Stillwater Only
353-ITX-03-023	Jefferson	13.0	29.7309	-93.8971	Coastal - Stillwater Only
353-ITX-03-024	Jefferson	11.7	29.8872	-94.0432	Coastal - Wave Runup
353-ITX-03-025	Jefferson	13.6	29.7945	-94.2279	Coastal - Stillwater Only
353-ITX-03-026	Jefferson	9.2	29.9434	-94.1302	Coastal - Stillwater Only
353-ITX-03-027	Jefferson	9.6	29.9965	-94.1065	Coastal - Stillwater Only
353-ITX-03-028	Jefferson	11.6	30.0818	-94.0932	Coastal - Stillwater Only
353-ITX-03-029	Jefferson	8.8	30.0279	-94.1491	Coastal - Stillwater Only
353-ITX-03-030	Jefferson	12.8	29.8694	-93.9325	Coastal - Wave Runup
353-ITX-03-031	Jefferson	11.7	29.8224	-93.9637	Coastal - Wave Height
353-ITX-01-008	Orange	10.2	30.0181	-93.8486	Coastal - Stillwater Only
353-ITX-01-009	Orange	13.1	30.0154	-93.8370	Coastal - Stillwater Only
353-ITX-01-010	Orange	8.7	30.0915	-93.7268	Coastal - Stillwater Only
353-ITX-01-011	Orange	9.6	30.0773	-93.7448	Coastal - Stillwater Only
353-ITX-01-012	Orange	9.3	30.0741	-93.7236	Coastal - Stillwater Only
353-ITX-01-013	Orange	11.8	30.0748	-93.8493	Coastal - Stillwater Only
353-ITX-01-014	Orange	12.9	30.0507	-93.9184	Coastal - Stillwater Only
353-ITX-01-015	Orange	10.8	30.0972	-94.0671	Coastal - Stillwater Only
353-ITX-01-018	Orange	12.7	30.0535	-93.9735	Coastal - Stillwater Only
353-ITX-01-021	Orange	9.9	30.2270	-93.7379	Coastal - Stillwater Only
353-ITX-01-022	Orange	7.7	30.1564	-93.7077	Coastal - Stillwater Only
353-ITX-01-023	Orange	8.3	30.1774	-93.7074	Coastal - Stillwater Only
353-ITX-01-024	Orange	10.8	30.0475	-93.7716	Coastal - Stillwater Only
353-ITX-01-025	Orange	9.4	30.0660	-93.7456	Coastal - Stillwater Only
353-ITX-01-026	Orange	10.7	30.0452	-93.8139	Coastal - Stillwater Only
353-ITX-01-027	Orange	10.9	30.0957	-94.0893	Coastal - Stillwater Only
353-ITX-01-028	Orange	11.7	30.0964	-94.0573	Coastal - Stillwater Only

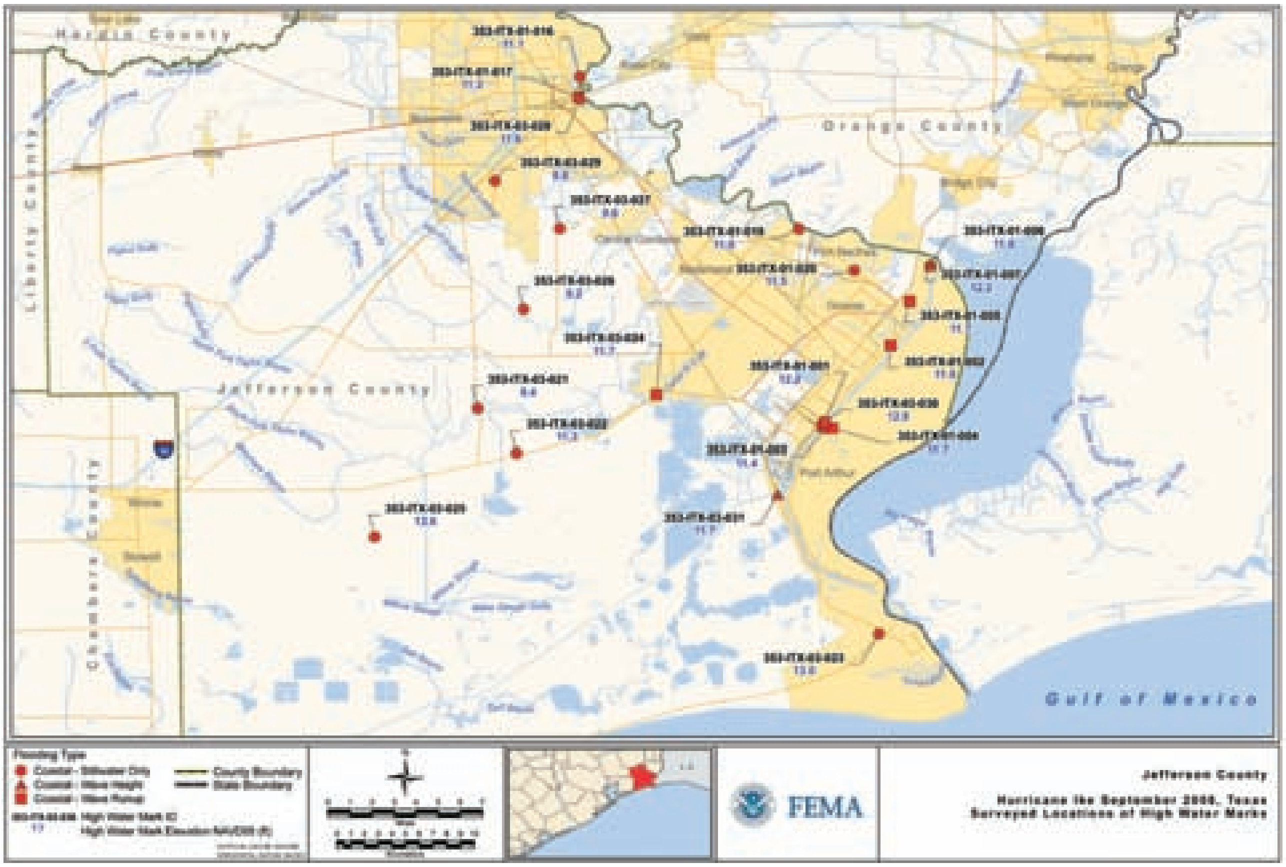

Walker
Polk
Tyler
San Jacinto
Grimes
Jasper
Newton
Montgomery
Hardin
Texas
Louisiana
Liberty
Orange
Waller
Jefferson
Harris
Chambers
Fort Bend
Galveston
Wharton
Brazoria
Matagorda
Gulf of Mexico
County with High Water Mark
FEMA

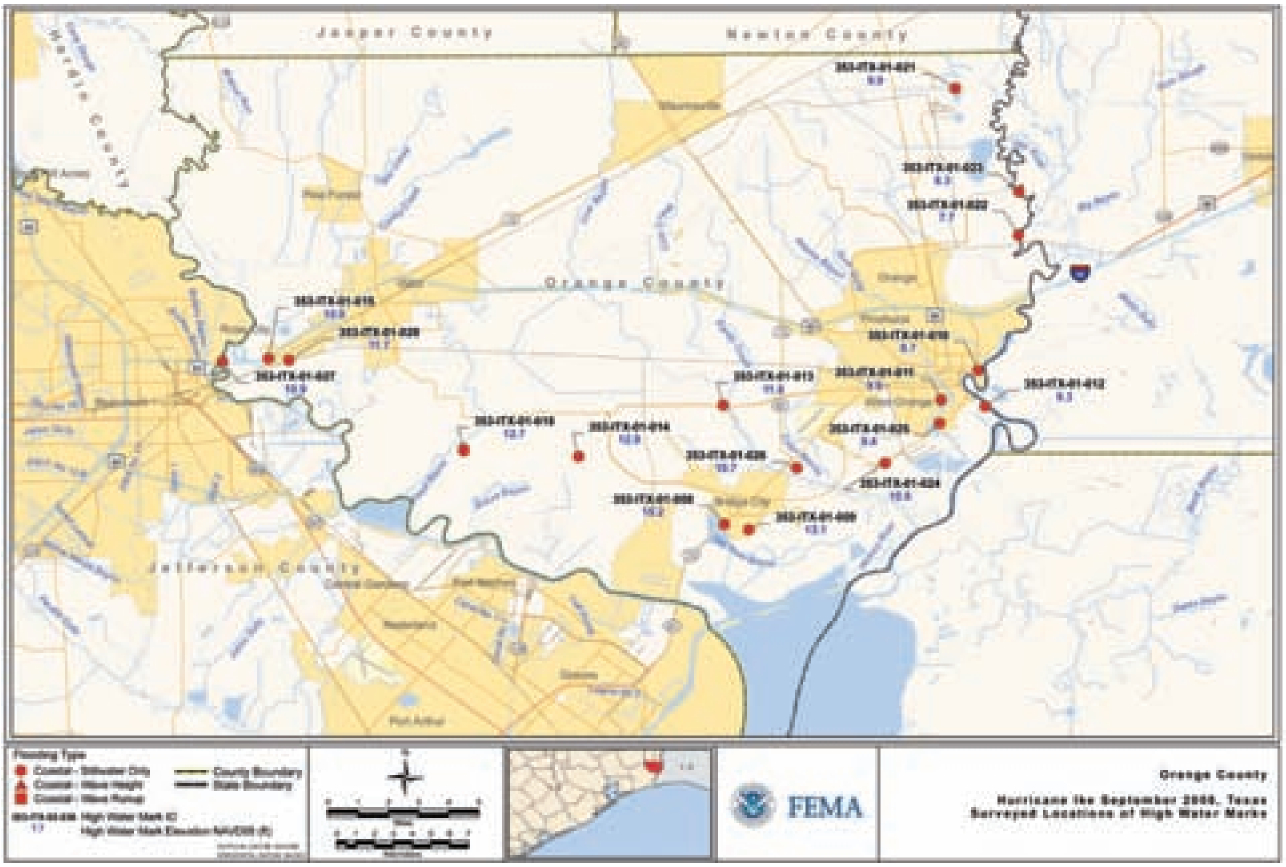

Galveston County
Brazoria County
Matagorda County
Gulf of Mexico
FEMA

Liberty County
Jefferson County
Harris County
Chambers County
Galveston Bay
Galveston County
Gulf of Mexico
FEMA
Chambers County
Hurricane Ike September 2008, Texas
Surveyed Locations of High Water Marks


Chambers County
Galveston Bay
Galveston County
Gulf of Mexico
FEMA
Galveston County
Hurricane Ike September 2008, Texas
Surveyed Locations of High Water Marks


Galveston Bay
Harris County
Galveston County
FEMA
Harris County
Hurricane Ike September 2008, Texas
Surveyed Locations of High Water Marks


Hardin County
Orange County
Liberty County
Jefferson County
Chambers County
Gulf of Mexico
Flooding Type
County Boundary
State Boundary
FEMA
Jefferson County
Hurricane Ike September 2008, Texas
Surveyed Locations of High Water Marks


Jasper County
Newton County
Orange County
Jefferson County
FEMA
Orange County
Hurricane Ike September 2008, Texas
Surveyed Locations of High Water Marks

High Water Marks in Louisiana

Summary of High Water Mark Survey Results					
HWM ID	Parish	Surveyed Elevation (feet) NAVD 88	Surveyed Latitude	Surveyed Longitude	Flood Type
401-ILA-02-009	Acadia	3.8	30.0817	-92.5062	Coastal - Stillwater Only
401-ILA-02-011	Acadia	3.5	30.1898	-92.5898	Coastal - Stillwater Only
401-ILA-01-006	Ascension	4.1	30.1906	-90.7862	Coastal - Stillwater Only
401-ILA-01-012	Ascension	3.8	30.1735	-90.7880	Coastal - Stillwater Only
401-ILA-03-005	Assumption	4.1	30.0006	-91.1932	Coastal - Stillwater Only
401-ILA-03-006	Assumption	3.1	29.9570	-91.2020	Coastal - Stillwater Only
401-ILA-03-007	Assumption	2.9	29.9008	-91.1861	Coastal - Stillwater Only
401-ILA-03-008	Assumption	2.9	29.8664	-91.1081	Coastal - Stillwater Only
401-ILA-03-012	Assumption	3.1	29.9366	-91.2213	Coastal - Stillwater Only
401-ILA-05-005	Calcasieu	8.7	30.1032	-93.3361	Coastal - Stillwater Only
401-ILA-05-006	Calcasieu	9.2	30.1140	-93.3417	Coastal - Stillwater Only
401-ILA-05-007	Calcasieu	5.6	30.0659	-93.3484	Coastal - Stillwater Only
401-ILA-05-013	Calcasieu	5.5	30.1910	-93.2680	Coastal - Stillwater Only
401-ILA-05-014	Calcasieu	9.2	30.1689	-93.2985	Coastal - Stillwater Only
401-ILA-05-015	Calcasieu	9.3	30.1043	-93.3063	Coastal - Stillwater Only
401-ILA-05-022	Calcasieu	4.5	30.1296	-92.9077	Coastal - Stillwater Only
401-ILA-05-027	Calcasieu	9.6	30.2366	-93.2300	Coastal - Stillwater Only
401-ILA-05-028	Calcasieu	8.4	30.2193	-93.2233	Coastal - Stillwater Only
401-ILA-05-029	Calcasieu	9.3	30.2110	-93.2356	Coastal - Stillwater Only
401-ILA-05-030	Calcasieu	9.2	30.2036	-93.2393	Coastal - Stillwater Only
401-ILA-05-008	Cameron	8.9	30.0049	-93.3433	Coastal - Stillwater Only
401-ILA-05-009	Cameron	8.9	29.9907	-93.4092	Coastal - Stillwater Only
401-ILA-05-010	Cameron	9.7	29.8904	-93.4020	Coastal - Stillwater Only
401-ILA-05-012	Cameron	12.6	29.7718	-93.4560	Coastal - Wave Height
401-ILA-05-016	Cameron	7.4	30.0108	-93.2274	Coastal - Stillwater Only
401-ILA-05-018	Cameron	3.8	29.9382	-93.0797	Coastal - Stillwater Only
401-ILA-05-019	Cameron	6.1	29.8943	-93.0796	Coastal - Stillwater Only
401-ILA-05-020	Cameron	8.7	29.8154	-93.1143	Coastal - Stillwater Only
401-ILA-05-026	Cameron	11.7	29.7648	-93.8810	Coastal - Stillwater Only
401-ILA-05-031	Cameron	7.0	30.0093	-93.1820	Coastal - Stillwater Only
401-ILA-05-032	Cameron	9.6	29.9886	-93.2663	Coastal - Stillwater Only
401-ILA-05-033	Cameron	9.0	29.8085	-93.1655	Coastal - Stillwater Only
401-ILA-05-034	Cameron	11.2	29.7871	-93.1314	Coastal - Wave Height
401-ILA-05-038	Cameron	8.0	29.7440	-92.8778	Coastal - Stillwater Only
401-ILA-05-040	Cameron	3.3	30.0318	-92.7513	Coastal - Stillwater Only
401-ILA-05-041	Cameron	3.0	30.0377	-92.6718	Coastal - Stillwater Only
401-ILA-05-042	Cameron	3.2	30.0224	-92.7688	Coastal - Stillwater Only
401-ILA-05-043	Cameron	2.3	30.0321	-92.7926	Coastal - Stillwater Only
401-ILA-05-044	Cameron	9.4	29.9837	-93.3750	Coastal - Stillwater Only
401-ILA-05-045	Cameron	8.7	29.9839	-93.4275	Coastal - Stillwater Only
401-ILA-02-002	Iberia	4.7	30.0617	-91.6086	Coastal - Stillwater Only
401-ILA-02-025	Iberia	5.2	30.0581	-91.6078	Coastal - Stillwater Only
401-ILA-02-026	Iberia	8.2	29.9519	-91.9849	Coastal - Stillwater Only
401-ILA-02-027	Iberia	6.4	29.9675	-91.9781	Coastal - Stillwater Only
401-ILA-02-028	Iberia	8.2	29.9472	-91.9840	Coastal - Stillwater Only
401-ILA-02-029	Iberia	8.5	29.9490	-91.9886	Coastal - Stillwater Only
401-ILA-02-030	Iberia	8.4	29.9146	-91.9045	Coastal - Stillwater Only
401-ILA-02-032	Iberia	7.2	29.9345	-91.8635	Coastal - Stillwater Only
401-ILA-02-034	Iberia	8.5	29.9497	-91.8359	Coastal - Stillwater Only
401-ILA-02-035	Iberia	8.1	29.9382	-91.8338	Coastal - Stillwater Only

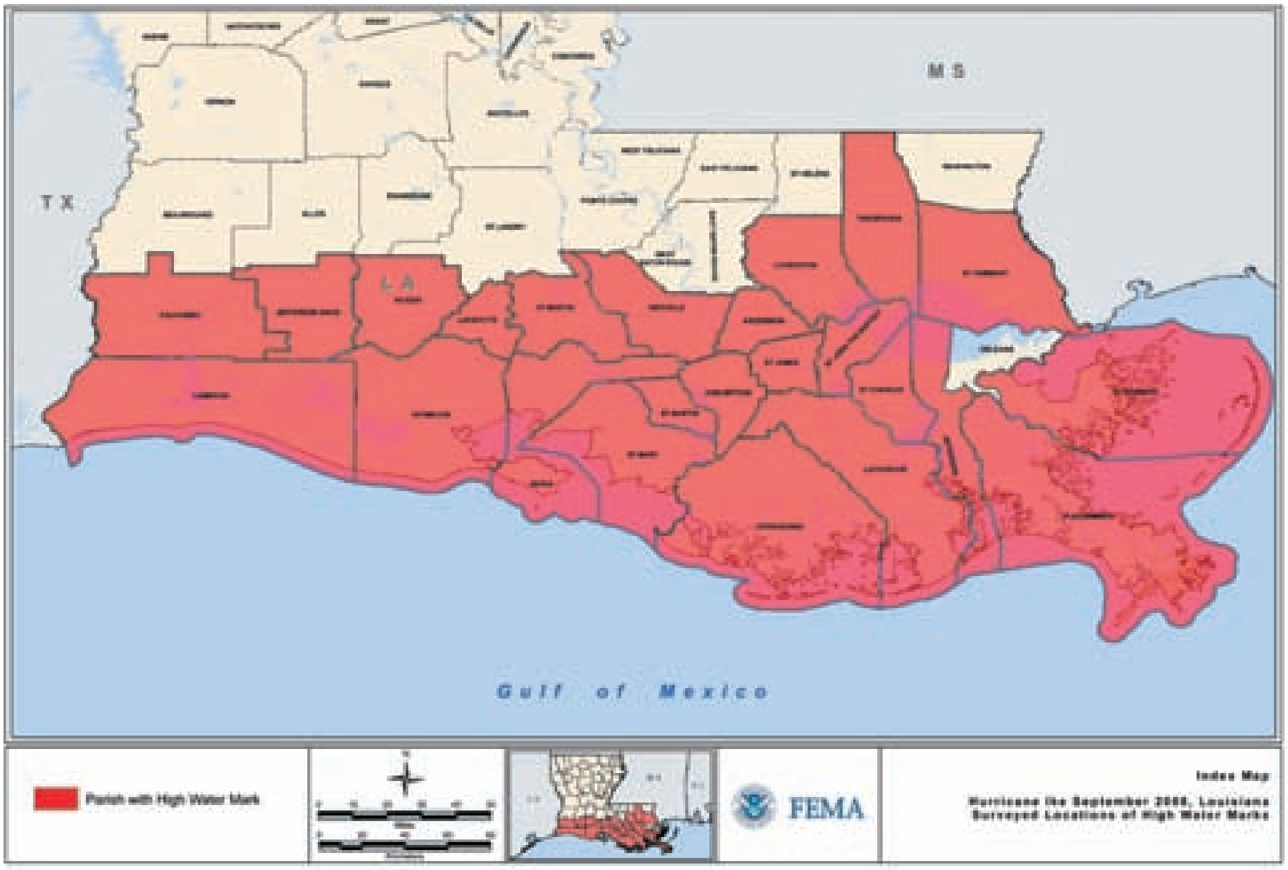
Summary of High Water Mark Survey Results					
HWM ID	Parish	Surveyed Elevation (feet) NAVD 88	Surveyed Latitude	Surveyed Longitude	Flood Type
401-ILA-02-038	Iberia	8.9	29.8265	-91.8081	Coastal - Stillwater Only
401-ILA-02-039	Iberia	5.1	29.9145	-91.6622	Coastal - Stillwater Only
401-ILA-02-040	Iberia	5.3	29.9789	-91.7539	Coastal - Stillwater Only
401-ILA-02-041	Iberia	5.5	30.0111	-91.7433	Coastal - Stillwater Only
401-ILA-02-042	Iberia	4.5	30.0192	-91.6808	Coastal - Stillwater Only
401-ILA-02-043	Iberia	7.1	30.0569	-91.7400	Riverine - Hurricane
401-ILA-02-044	Iberia	5.3	30.0060	-91.8170	Coastal - Stillwater Only
401-ILA-02-045	Iberia	5.0	30.0161	-91.7739	Coastal - Stillwater Only
401-ILA-01-007	Iberville	5.9	30.2193	-91.3177	Coastal - Stillwater Only
401-ILA-01-018	Iberville	3.2	30.1348	-91.0932	Coastal - Stillwater Only
401-ILA-01-019	Iberville	4.3	30.1034	-91.1984	Coastal - Stillwater Only
401-ILA-01-020	Iberville	9.8	30.3214	-91.0209	Coastal - Stillwater Only
401-ILA-01-021	Iberville	3.3	30.1264	-91.2761	Coastal - Stillwater Only
401-ILA-01-022	Iberville	5.1	30.1502	-91.3278	Coastal - Stillwater Only
401-ILA-04-020	Jefferson	5.2	29.6533	-90.1063	Coastal - Stillwater Only
401-ILA-04-022	Jefferson	4.7	29.8851	-90.1623	Coastal - Stillwater Only
401-ILA-04-023	Jefferson	4.8	30.0420	-90.2354	Coastal - Stillwater Only
401-ILA-04-025	Jefferson	5.3	30.0214	-90.1432	Coastal - Stillwater Only
401-ILA-06-001	Jefferson	4.9	29.2377	-89.9923	Coastal - Stillwater Only
401-ILA-06-002	Jefferson	4.9	29.2626	-89.9621	Coastal - Stillwater Only
401-ILA-06-004	Jefferson	4.7	29.2256	-90.0070	Coastal - Stillwater Only
401-ILA-06-005	Jefferson	5.1	29.2165	-90.0254	Coastal - Stillwater Only
401-ILA-06-006	Jefferson	6.1	29.2037	-90.0398	Coastal - Wave Height
401-ILA-02-010	Jefferson Davis	3.3	30.0727	-92.6594	Coastal - Stillwater Only
401-ILA-05-001	Jefferson Davis	4.0	30.0733	-92.6607	Coastal - Stillwater Only
401-ILA-05-002	Jefferson Davis	3.8	30.0752	-92.6771	Coastal - Stillwater Only
401-ILA-05-003	Jefferson Davis	3.3	30.0570	-92.7194	Coastal - Stillwater Only
401-ILA-05-004	Jefferson Davis	3.6	30.0694	-92.8842	Coastal - Stillwater Only
401-ILA-05-023	Jefferson Davis	3.5	30.1376	-92.8864	Coastal - Stillwater Only
401-ILA-02-004	Lafayette	8.0	30.2192	-91.9559	Coastal - Stillwater Only
401-ILA-06-008	Lafourche	7.6	29.1555	-90.1834	Coastal - Stillwater Only
401-ILA-06-009	Lafourche	8.3	29.1254	-90.1969	Coastal - Stillwater Only
401-ILA-06-010	Lafourche	8.0	29.1577	-90.1791	Coastal - Stillwater Only
401-ILA-06-011	Lafourche	7.0	29.2112	-90.2198	Coastal - Stillwater Only
401-ILA-06-013	Lafourche	6.7	29.2359	-90.2104	Coastal - Stillwater Only
401-ILA-06-014	Lafourche	5.8	29.2567	-90.2139	Coastal - Stillwater Only
401-ILA-06-016	Lafourche	6.2	29.3416	-90.2469	Coastal - Wave Height
401-ILA-06-017	Lafourche	4.4	29.5892	-90.3702	Coastal - Stillwater Only
401-ILA-06-018	Lafourche	4.4	29.5827	-90.3748	Coastal - Stillwater Only
401-ILA-06-019	Lafourche	4.3	29.5574	-90.3890	Coastal - Stillwater Only
401-ILA-06-020	Lafourche	3.9	29.5527	-90.5346	Coastal - Stillwater Only
401-ILA-01-004	Livingston	7.2	30.3268	-90.8233	Riverine - Hurricane
401-ILA-01-005	Livingston	4.4	30.2749	-90.7788	Coastal - Stillwater Only
401-ILA-07-024	Livingston	3.3	30.4335	-90.5472	Coastal - Stillwater Only
401-ILA-07-026	Livingston	4.0	30.3766	-90.5372	Coastal - Stillwater Only
401-ILA-07-028	Livingston	4.6	30.2618	-90.7128	Coastal - Stillwater Only
401-ILA-07-029	Livingston	4.0	30.2838	-90.7085	Coastal - Stillwater Only
401-ILA-07-030	Livingston	4.5	30.2732	-90.7105	Coastal - Stillwater Only
401-ILA-07-031	Livingston	4.4	30.2668	-90.7289	Coastal - Stillwater Only
401-ILA-07-032	Livingston	4.4	30.2754	-90.7387	Coastal - Stillwater Only
401-ILA-07-033	Livingston	3.7	30.2610	-90.7637	Coastal - Stillwater Only
401-ILA-07-034	Livingston	4.5	30.2639	-90.6419	Coastal - Stillwater Only

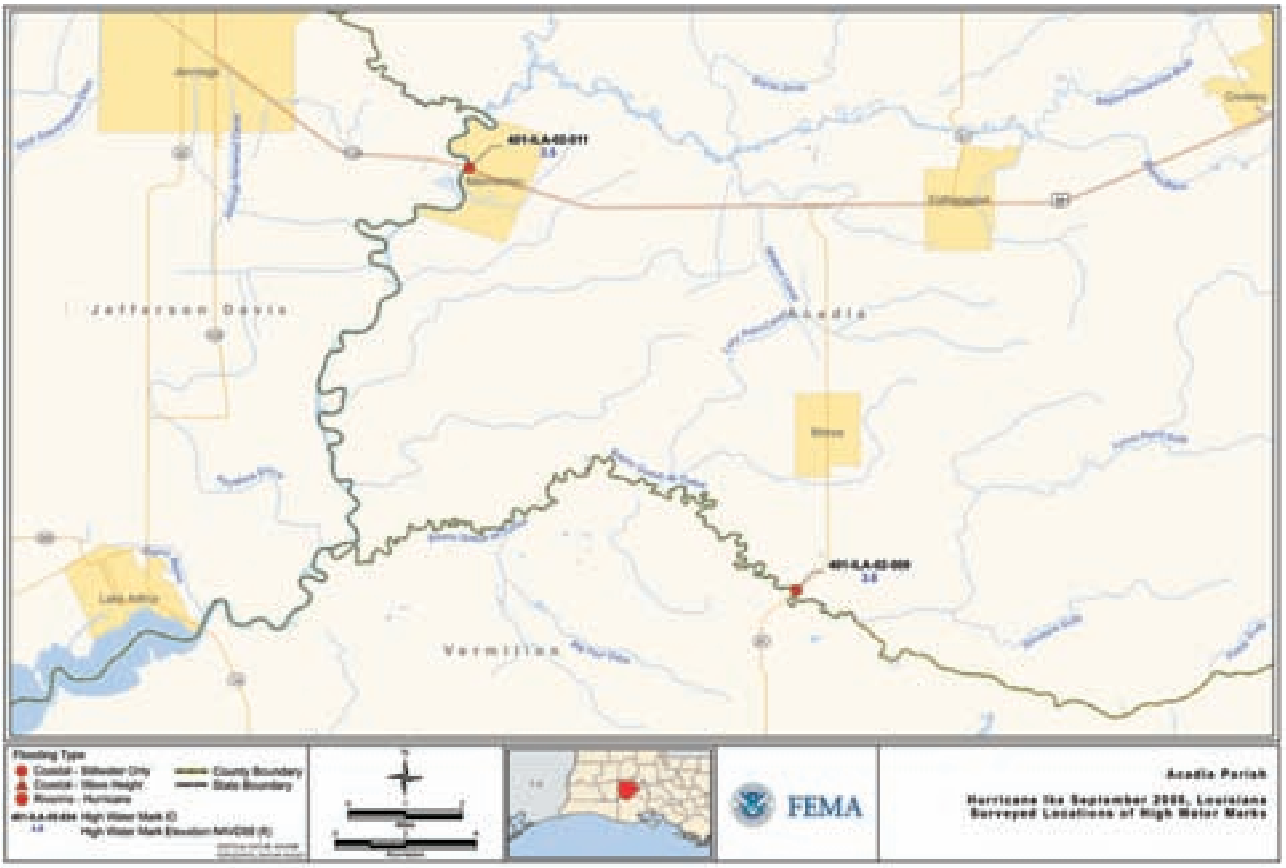
Summary of High Water Mark Survey Results					
HWM ID	Parish	Surveyed Elevation (feet) NAVD 88	Surveyed Latitude	Surveyed Longitude	Flood Type
401-ILA-04-001	Plaquemines	3.7	29.6355	-89.9527	Coastal - Stillwater Only
401-ILA-04-002	Plaquemines	7.5	29.3540	-89.5359	Coastal - Wave Height
401-ILA-04-003	Plaquemines	6.4	29.2212	-89.3943	Coastal - Wave Height
401-ILA-04-004	Plaquemines	4.1	29.6990	-89.9913	Coastal - Stillwater Only
401-ILA-04-005	Plaquemines	3.6	29.6481	-89.9629	Coastal - Stillwater Only
401-ILA-04-006	Plaquemines	4.3	29.6023	-89.8784	Coastal - Stillwater Only
401-ILA-04-008	Plaquemines	6.2	29.4169	-89.6167	Coastal - Stillwater Only
401-ILA-04-010	Plaquemines	10.9	29.5861	-89.7972	Coastal - Stillwater Only
401-ILA-04-011	Plaquemines	8.1	29.6359	-89.9056	Coastal - Stillwater Only
401-ILA-04-012	Plaquemines	8.4	29.7426	-89.9872	Coastal - Stillwater Only
401-ILA-04-013	Plaquemines	8.2	29.6484	-89.9357	Coastal - Stillwater Only
401-ILA-04-014	Plaquemines	9.0	29.8603	-89.9073	Coastal - Stillwater Only
401-ILA-04-019	Plaquemines	5.2	29.8363	-90.0456	Coastal - Stillwater Only
401-ILA-04-016	St. Bernard	9.4	29.8199	-89.6112	Coastal - Stillwater Only
401-ILA-04-017	St. Bernard	8.8	29.8408	-89.7561	Coastal - Stillwater Only
401-ILA-06-021	St. Charles	3.4	29.7891	-90.4204	Coastal - Stillwater Only
401-ILA-06-022	St. Charles	3.5	29.7824	-90.4048	Coastal - Stillwater Only
401-ILA-06-024	St. Charles	2.7	29.8737	-90.4489	Coastal - Stillwater Only
401-ILA-06-025	St. Charles	2.7	29.8625	-90.4545	Coastal - Stillwater Only
401-ILA-01-001	St. James	3.7	30.1018	-90.7349	Coastal - Stillwater Only
401-ILA-01-002	St. James	3.3	30.0691	-90.7499	Coastal - Stillwater Only
401-ILA-01-013	St. James	3.4	30.0566	-90.7116	Coastal - Stillwater Only
401-ILA-01-014	St. James	3.3	30.0561	-90.7110	Coastal - Stillwater Only
401-ILA-01-015	St. James	2.5	29.9224	-90.6720	Coastal - Stillwater Only
401-ILA-01-016	St. James	2.4	29.9539	-90.6920	Coastal - Stillwater Only
401-ILA-01-017	St. James	2.2	29.9114	-90.7288	Coastal - Stillwater Only
401-ILA-01-008	St. John The Baptist	2.6	29.9199	-90.6221	Coastal - Stillwater Only
401-ILA-06-026	St. John The Baptist	4.6	30.0936	-90.4379	Coastal - Stillwater Only
401-ILA-06-027	St. John The Baptist	4.9	30.0884	-90.4420	Coastal - Stillwater Only
401-ILA-06-028	St. John The Baptist	4.7	30.0859	-90.4469	Coastal - Stillwater Only
401-ILA-06-029	St. John The Baptist	4.7	30.0910	-90.4597	Coastal - Stillwater Only
401-ILA-06-030	St. John The Baptist	4.8	30.0940	-90.4692	Coastal - Stillwater Only
401-ILA-06-031	St. John The Baptist	4.7	30.1062	-90.4983	Coastal - Stillwater Only
401-ILA-06-033	St. John The Baptist	3.6	30.1899	-90.4385	Coastal - Stillwater Only
401-ILA-06-034	St. John The Baptist	7.3	30.1067	-90.4229	Coastal - Wave Height
401-ILA-06-035	St. John The Baptist	4.6	30.0958	-90.4370	Coastal - Stillwater Only
401-ILA-06-036	St. John The Baptist	4.5	30.0608	-90.4393	Coastal - Stillwater Only
401-ILA-06-037	St. John The Baptist	4.2	30.0606	-90.4344	Coastal - Stillwater Only
401-ILA-06-038	St. John The Baptist	4.1	30.0600	-90.4333	Coastal - Stillwater Only

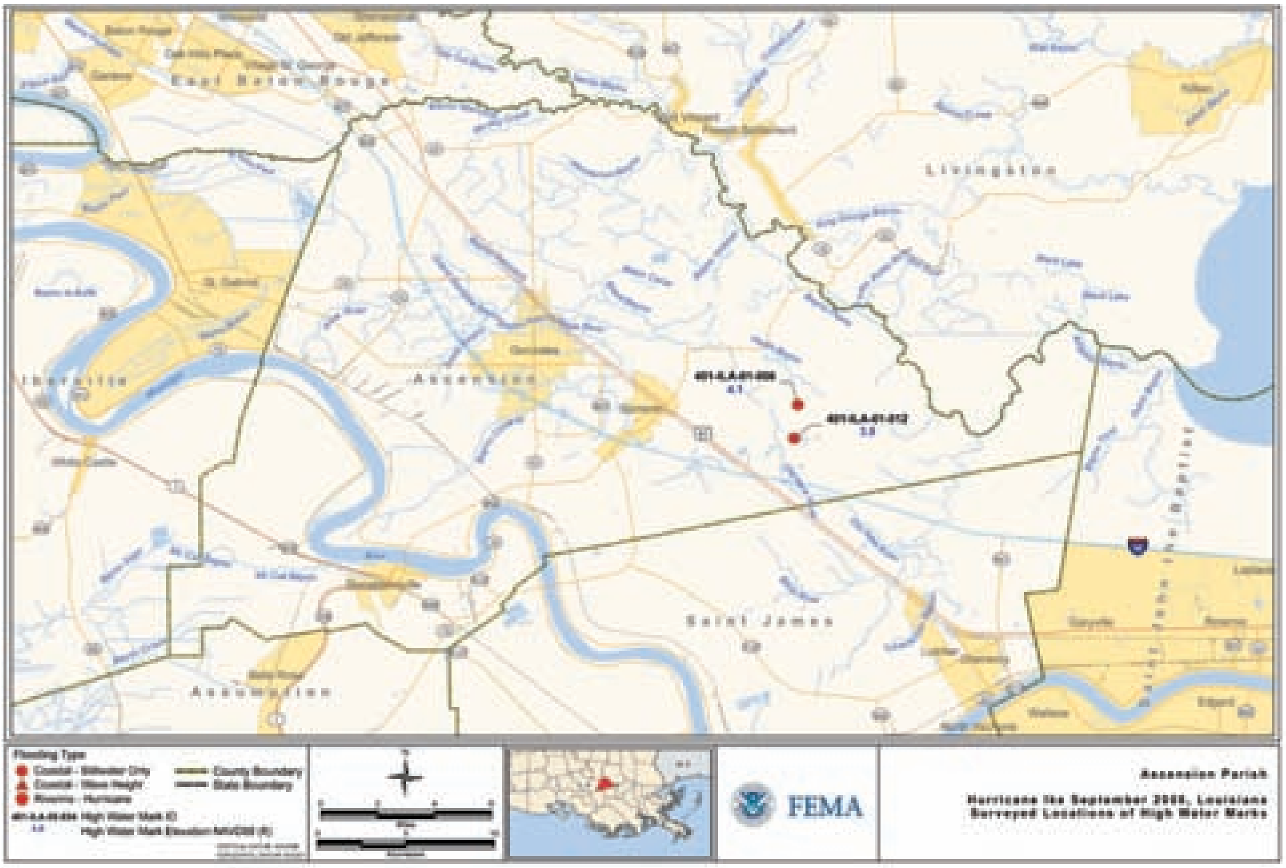
Summary of High Water Mark Survey Results					
HWM ID	Parish	Surveyed Elevation (feet) NAVD 88	Surveyed Latitude	Surveyed Longitude	Flood Type
401-ILA-06-040	St. John The Baptist	4.5	30.0802	-90.4611	Coastal - Stillwater Only
401-ILA-06-041	St. John The Baptist	4.3	30.0779	-90.5525	Coastal - Stillwater Only
401-ILA-06-042	St. John The Baptist	3.9	30.0785	-90.5459	Coastal - Stillwater Only
401-ILA-06-043	St. John The Baptist	4.0	30.0844	-90.5134	Coastal - Stillwater Only
401-ILA-02-014	St. Martin	8.4	30.3243	-91.7900	Coastal - Stillwater Only
401-ILA-02-017	St. Martin	7.4	30.3053	-91.7536	Coastal - Stillwater Only
401-ILA-02-018	St. Martin	7.2	30.2914	-91.7452	Coastal - Stillwater Only
401-ILA-02-021	St. Martin	5.3	30.2180	-91.6979	Coastal - Stillwater Only
401-ILA-02-022	St. Martin	5.5	30.1758	-91.6908	Coastal - Stillwater Only
401-ILA-03-001	St. Martin	3.0	29.8158	-91.1033	Coastal - Stillwater Only
401-ILA-03-003	St. Martin	9.3	29.8557	-91.1980	Coastal - Stillwater Only
401-ILA-03-004	St. Martin	3.1	29.9083	-91.2165	Coastal - Stillwater Only
401-ILA-03-009	St. Martin	2.6	29.7679	-91.1653	Coastal - Stillwater Only
401-ILA-03-010	St. Martin	8.0	29.7640	-91.1758	Coastal - Stillwater Only
401-ILA-03-011	St. Martin	9.7	29.9027	-91.2134	Coastal - Stillwater Only
401-ILA-02-036	St. Mary	9.3	29.7342	-91.8523	Coastal - Stillwater Only
401-ILA-02-037	St. Mary	10.6	29.7143	-91.8769	Coastal - Stillwater Only
401-ILA-03-056	St. Mary	7.3	29.6896	-91.0997	Coastal - Stillwater Only
401-ILA-03-057	St. Mary	6.7	29.6870	-91.1887	Coastal - Stillwater Only
401-ILA-03-058	St. Mary	4.2	29.6828	-91.1923	Coastal - Stillwater Only
401-ILA-03-059	St. Mary	6.9	29.6954	-91.2104	Coastal - Stillwater Only
401-ILA-03-060	St. Mary	6.8	29.6934	-91.2162	Coastal - Stillwater Only
401-ILA-03-061	St. Mary	7.4	29.6854	-91.2188	Coastal - Stillwater Only
401-ILA-03-062	St. Mary	6.7	29.9021	-91.5135	Coastal - Stillwater Only
401-ILA-03-063	St. Mary	4.7	29.8795	-91.4544	Coastal - Stillwater Only
401-ILA-03-064	St. Mary	9.7	29.7644	-91.3940	Coastal - Stillwater Only
401-ILA-03-065	St. Mary	4.8	29.7585	-91.4078	Coastal - Stillwater Only
401-ILA-03-066	St. Mary	5.1	29.7104	-91.3819	Coastal - Stillwater Only
401-ILA-03-067	St. Mary	6.4	29.7010	-91.3711	Coastal - Stillwater Only
401-ILA-03-068	St. Mary	5.1	29.7622	-91.4193	Coastal - Stillwater Only
401-ILA-08-029	St. Mary	10.2	29.7127	-91.8771	Coastal - Stillwater Only
401-ILA-08-030	St. Mary	8.7	29.7711	-91.7848	Coastal - Stillwater Only
401-ILA-08-032	St. Mary	6.0	29.7882	-91.5190	Coastal - Stillwater Only
401-ILA-08-034	St. Mary	6.9	29.7867	-91.5173	Coastal - Stillwater Only
401-ILA-08-037	St. Mary	6.3	29.8291	-91.5664	Coastal - Stillwater Only
401-ILA-08-038	St. Mary	4.4	29.8870	-91.5227	Coastal - Stillwater Only
401-ILA-08-039	St. Mary	4.0	29.8900	-91.5246	Coastal - Stillwater Only
401-ILA-08-040	St. Mary	5.5	29.8407	-91.4548	Coastal - Stillwater Only
401-ILA-08-042	St. Mary	4.7	29.8795	-91.5858	Coastal - Stillwater Only
401-ILA-08-044	St. Mary	8.1	29.5590	-91.5251	Coastal - Stillwater Only
401-ILA-08-045	St. Mary	6.2	29.6017	-91.5247	Coastal - Stillwater Only
401-ILA-08-048	St. Mary	5.1	29.7874	-91.4953	Coastal - Stillwater Only
401-ILA-08-049	St. Mary	6.7	29.7976	-91.4968	Coastal - Stillwater Only
401-ILA-08-050	St. Mary	5.3	29.7720	-91.4814	Coastal - Stillwater Only
401-ILA-07-001	St. Tammany	6.6	30.4083	-90.1420	Coastal - Stillwater Only
401-ILA-07-002	St. Tammany	6.3	30.3449	-90.0534	Coastal - Stillwater Only
401-ILA-07-004	St. Tammany	6.6	30.3657	-90.0959	Coastal - Stillwater Only
401-ILA-07-005	St. Tammany	6.7	30.3526	-90.0673	Coastal - Stillwater Only

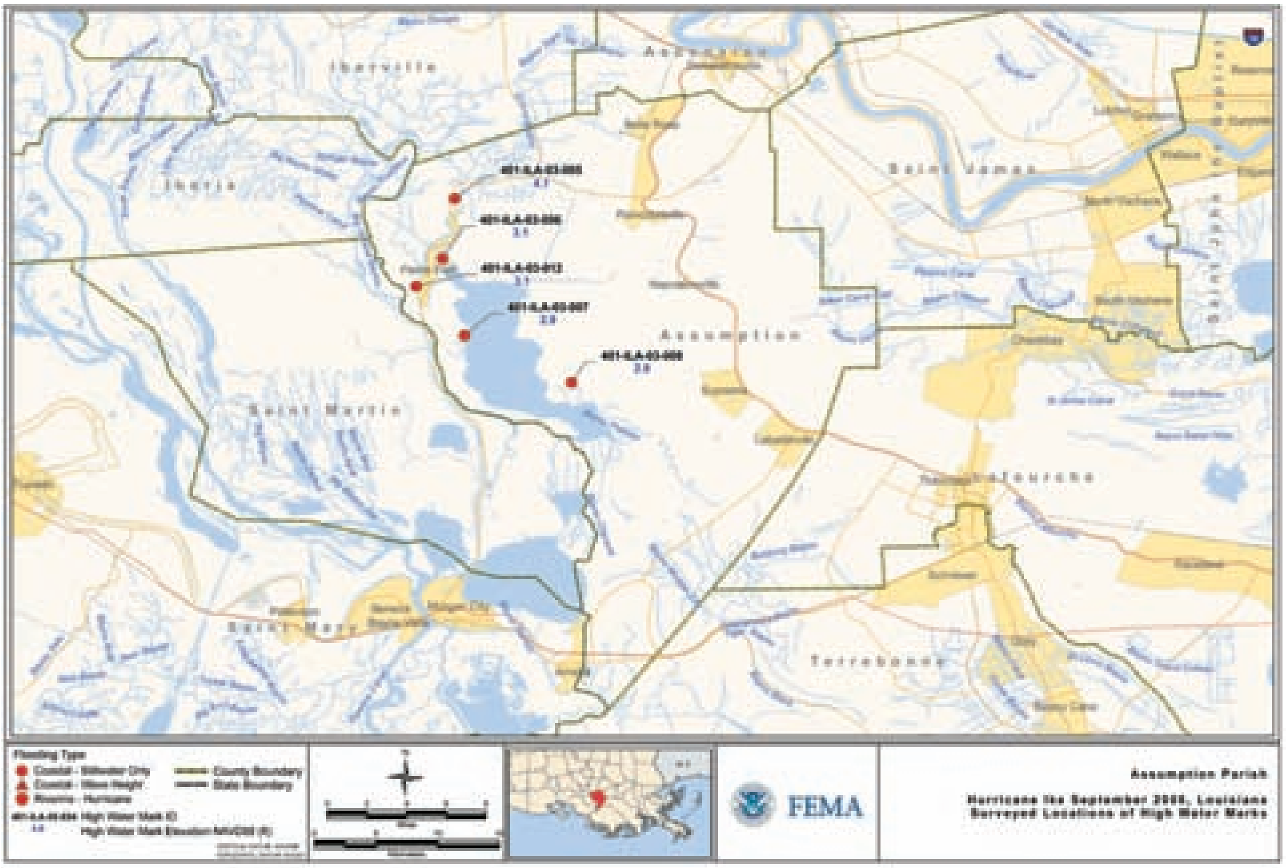
Summary of High Water Mark Survey Results					
HWM ID	Parish	Surveyed Elevation (feet) NAVD 88	Surveyed Latitude	Surveyed Longitude	Flood Type
401-ILA-07-006	St. Tammany	4.7	30.3291	-90.0044	Coastal - Stillwater Only
401-ILA-07-007	St. Tammany	5.5	30.2651	-89.9565	Coastal - Stillwater Only
401-ILA-07-008	St. Tammany	4.6	30.2912	-89.9279	Coastal - Stillwater Only
401-ILA-07-009	St. Tammany	4.9	30.2841	-89.9170	Coastal - Stillwater Only
401-ILA-07-012	St. Tammany	4.3	30.2795	-89.7844	Coastal - Stillwater Only
401-ILA-07-013	St. Tammany	5.2	30.2611	-89.8033	Coastal - Stillwater Only
401-ILA-07-014	St. Tammany	5.1	30.2346	-89.8553	Coastal - Stillwater Only
401-ILA-07-016	St. Tammany	4.8	30.1853	-89.7572	Coastal - Stillwater Only
401-ILA-07-017	St. Tammany	6.5	30.3943	-90.1203	Coastal - Stillwater Only
401-ILA-07-018	St. Tammany	6.6	30.4027	-90.1561	Coastal - Stillwater Only
401-ILA-07-019	St. Tammany	6.6	30.3977	-90.1562	Coastal - Stillwater Only
401-ILA-07-021	Tangipahoa	5.2	30.2897	-90.4014	Coastal - Stillwater Only
401-ILA-03-015	Terrebonne	5.3	29.5853	-90.6774	Coastal - Stillwater Only
401-ILA-03-016	Terrebonne	6.0	29.5545	-90.6592	Coastal - Stillwater Only
401-ILA-03-020	Terrebonne	6.0	29.5191	-90.6753	Coastal - Stillwater Only
401-ILA-03-022	Terrebonne	6.4	29.4822	-90.6983	Coastal - Stillwater Only
401-ILA-03-023	Terrebonne	7.1	29.4254	-90.7020	Coastal - Stillwater Only
401-ILA-03-024	Terrebonne	7.0	29.3946	-90.7120	Coastal - Stillwater Only
401-ILA-03-025	Terrebonne	6.9	29.3689	-90.7231	Coastal - Stillwater Only
401-ILA-03-026	Terrebonne	7.6	29.2532	-90.6600	Coastal - Stillwater Only
401-ILA-03-027	Terrebonne	7.7	29.2770	-90.6440	Coastal - Stillwater Only
401-ILA-03-028	Terrebonne	7.3	29.3047	-90.6480	Coastal - Stillwater Only
401-ILA-03-029	Terrebonne	6.9	29.3838	-90.6197	Coastal - Stillwater Only
401-ILA-03-030	Terrebonne	3.3	29.4737	-90.5575	Coastal - Stillwater Only
401-ILA-03-031	Terrebonne	3.9	29.4740	-90.5532	Coastal - Stillwater Only
401-ILA-03-032	Terrebonne	4.9	29.4804	-90.5517	Coastal - Stillwater Only
401-ILA-03-033	Terrebonne	8.0	29.3857	-90.5882	Coastal - Wave Height
401-ILA-03-034	Terrebonne	4.6	29.4992	-90.5512	Coastal - Stillwater Only
401-ILA-03-035	Terrebonne	7.8	29.3985	-90.4884	Coastal - Wave Height
401-ILA-03-037	Terrebonne	7.5	29.3986	-90.4888	Coastal - Stillwater Only
401-ILA-03-040	Terrebonne	7.1	29.4394	-90.4611	Coastal - Stillwater Only
401-ILA-03-041	Terrebonne	5.1	29.4905	-90.5198	Coastal - Stillwater Only
401-ILA-03-042	Terrebonne	5.5	29.5133	-90.5960	Coastal - Stillwater Only
401-ILA-03-043	Terrebonne	5.5	29.5161	-90.5978	Coastal - Stillwater Only
401-ILA-03-044	Terrebonne	4.7	29.5370	-90.7144	Coastal - Stillwater Only
401-ILA-03-045	Terrebonne	3.9	29.5447	-90.7234	Coastal - Stillwater Only
401-ILA-03-046	Terrebonne	3.9	29.6050	-90.7050	Coastal - Stillwater Only
401-ILA-03-048	Terrebonne	4.0	29.5692	-90.7252	Coastal - Stillwater Only
401-ILA-03-049	Terrebonne	5.9	29.4282	-90.7644	Coastal - Stillwater Only
401-ILA-03-050	Terrebonne	5.7	29.4169	-90.7760	Coastal - Stillwater Only
401-ILA-03-051	Terrebonne	6.9	29.3340	-90.8483	Coastal - Wave Height
401-ILA-03-052	Terrebonne	5.7	29.3360	-90.8424	Coastal - Stillwater Only
401-ILA-03-053	Terrebonne	3.8	29.6163	-90.9022	Coastal - Stillwater Only
401-ILA-03-054	Terrebonne	3.9	29.6245	-90.9111	Coastal - Stillwater Only
401-ILA-05-039	Vermilion	4.0	30.0435	-92.7060	Coastal - Stillwater Only
401-ILA-08-002	Vermilion	9.4	29.7939	-92.1449	Coastal - Stillwater Only
401-ILA-08-004	Vermilion	8.0	29.9350	-92.1494	Coastal - Stillwater Only
401-ILA-08-005	Vermilion	8.6	29.8847	-92.1245	Coastal - Stillwater Only
401-ILA-08-006	Vermilion	8.3	29.9835	-92.1360	Coastal - Stillwater Only
401-ILA-08-007	Vermilion	5.4	29.8428	-92.1810	Coastal - Stillwater Only
401-ILA-08-008	Vermilion	7.4	29.8464	-92.2756	Coastal - Stillwater Only
401-ILA-08-009	Vermilion	5.9	29.8316	-92.3061	Coastal - Stillwater Only

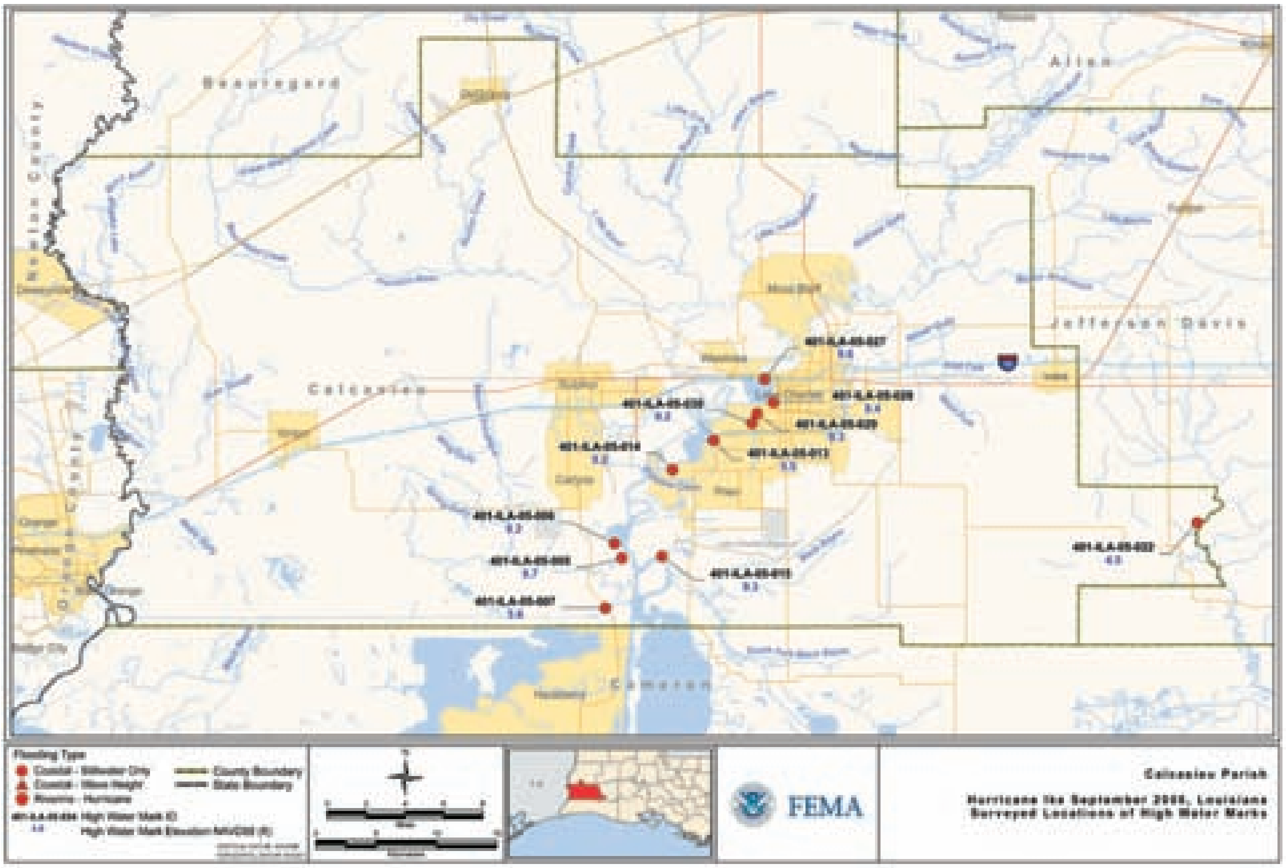
Summary of High Water Mark Survey Results					
HWM ID	Parish	Surveyed Elevation (feet) NAVD 88	Surveyed Latitude	Surveyed Longitude	Flood Type
401-ILA-08-011	Vermilion	7.9	29.6573	-92.3693	Coastal - Wave Height
401-ILA-08-012	Vermilion	7.8	29.6468	-92.4342	Coastal - Wave Height
401-ILA-08-015	Vermilion	6.1	29.8386	-92.3282	Coastal - Stillwater Only
401-ILA-08-016	Vermilion	8.3	29.6308	-92.3820	Coastal - Wave Height
401-ILA-08-017	Vermilion	8.1	29.9749	-92.1395	Coastal - Stillwater Only
401-ILA-08-018	Vermilion	3.5	30.0413	-92.7226	Coastal - Stillwater Only
401-ILA-08-019	Vermilion	3.3	30.0713	-92.6571	Coastal - Stillwater Only
401-ILA-08-020	Vermilion	3.6	30.1004	-92.5321	Coastal - Stillwater Only
401-ILA-08-021	Vermilion	3.2	29.9192	-92.5138	Coastal - Stillwater Only
401-ILA-08-022	Vermilion	2.8	29.9782	-92.4621	Coastal - Stillwater Only
401-ILA-08-025	Vermilion	7.8	29.8825	-92.0378	Coastal - Stillwater Only
401-ILA-08-026	Vermilion	9.0	29.8770	-92.1269	Coastal - Stillwater Only
401-ILA-08-027	Vermilion	8.8	29.9751	-91.9940	Coastal - Stillwater Only

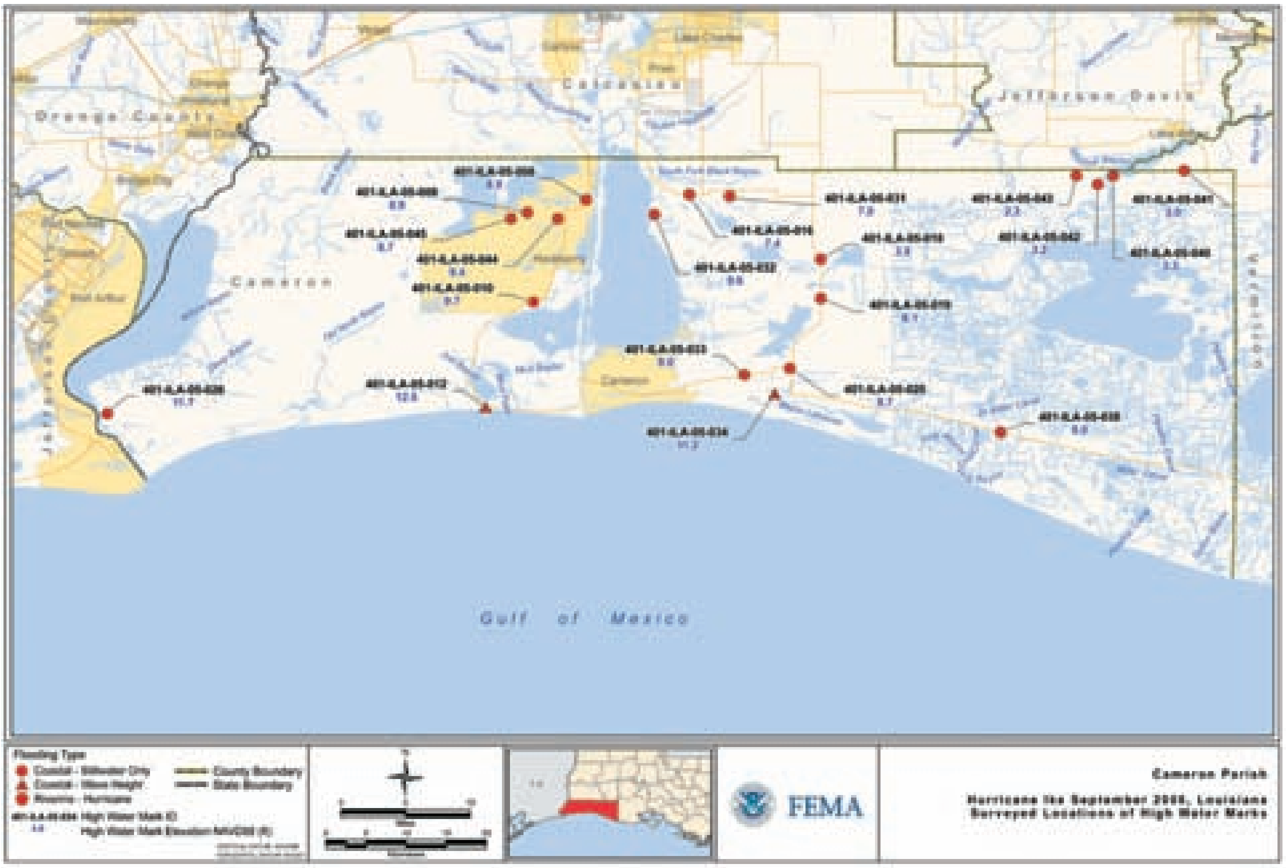

T X
M S
L A
Gulf of Mexico
Parish with High Water Mark
FEMA
Index Map
Hurricane Ike September 2008, Louisiana
Surveyed Locations of High Water Marks

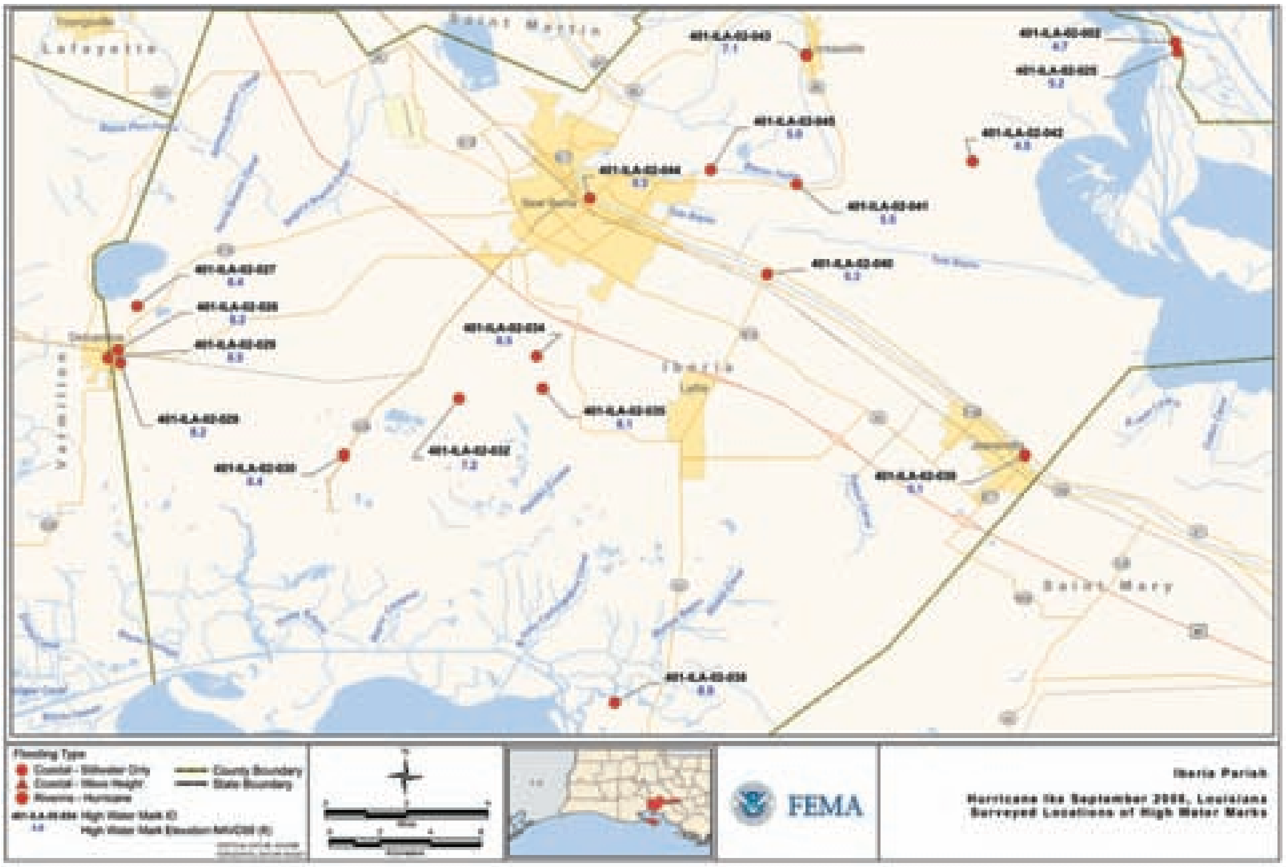

Jefferson Davis
Acadia
Vermilion
Lake Arthur
Flooding Type
Coastal - Stillwater Only
Coastal - Wave Height
Riverine - Hurricane
County Boundary
State Boundary
High Water Mark ID
High Water Mark Elevation NAVD88 (ft)
FEMA
Acadia Parish
Hurricane Ike September 2008, Louisiana
Surveyed Locations of High Water Marks

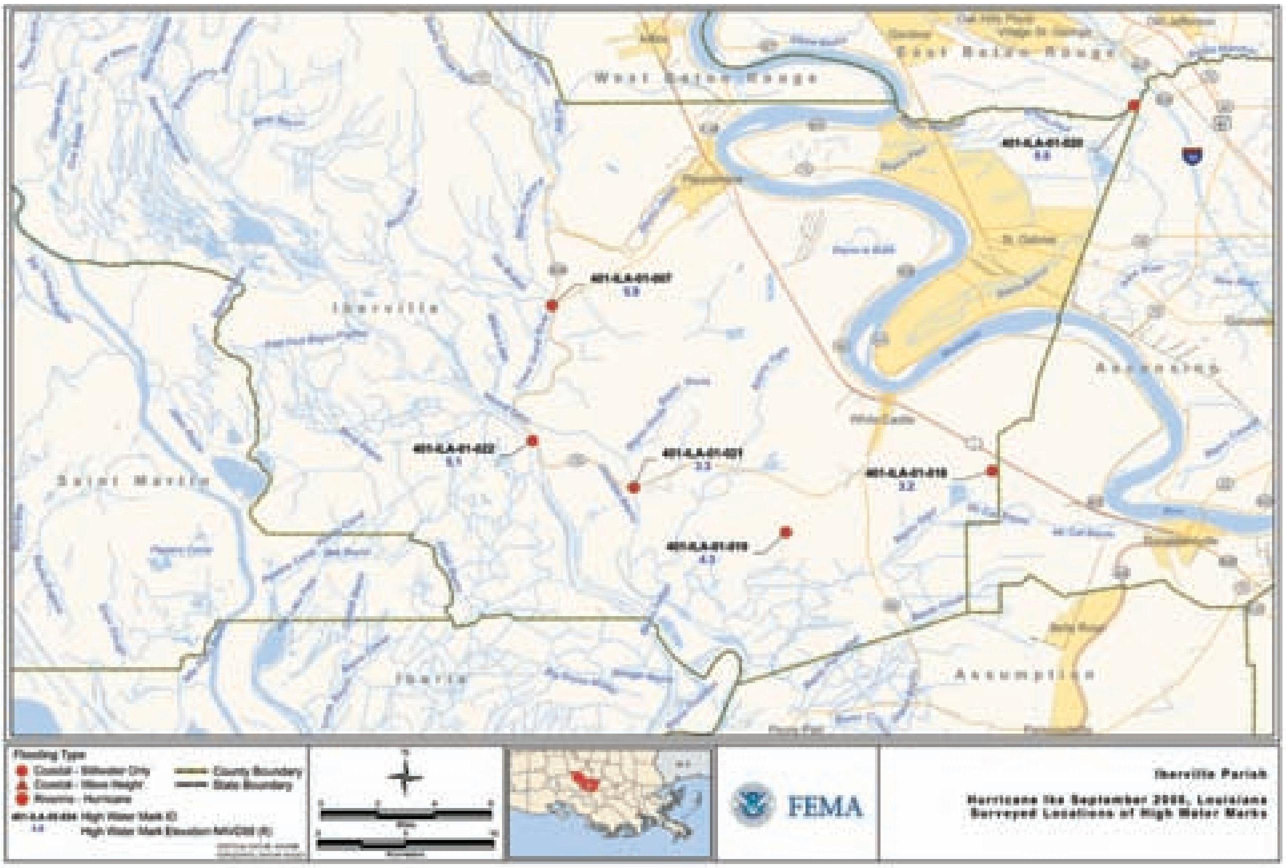

Livingston
Ascension
Iberville
Saint James
Assumption
FEMA

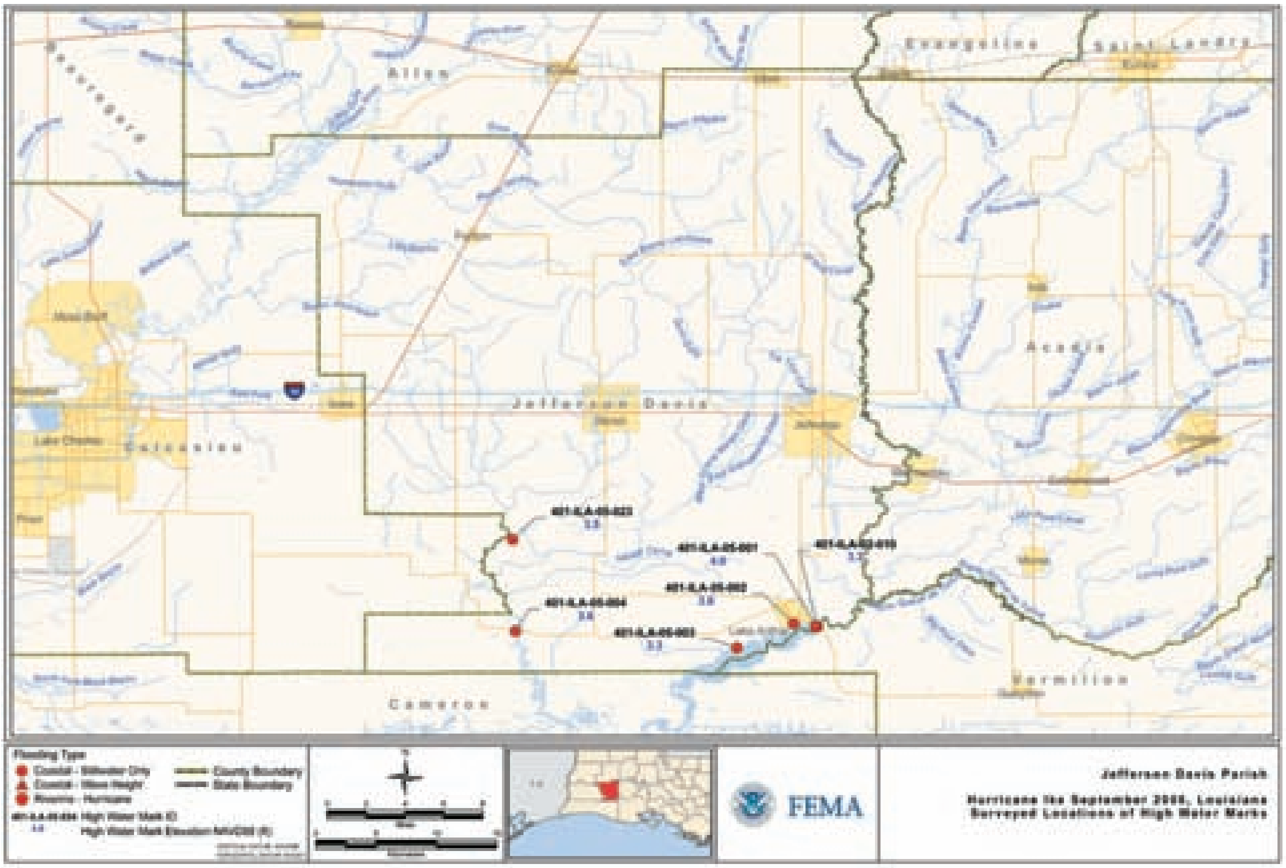

Iberville
Iberia
Saint James
Assumption
Saint Martin
Lafourche
Saint Mary
Terrebonne
Flooding Type
Coastal - Stillwater Only
Coastal - Wave Height
Riverine - Hurricane
County Boundary
State Boundary
Assumption Parish
Hurricane Ike September 2008, Louisiana
Surveyed Locations of High Water Marks
FEMA

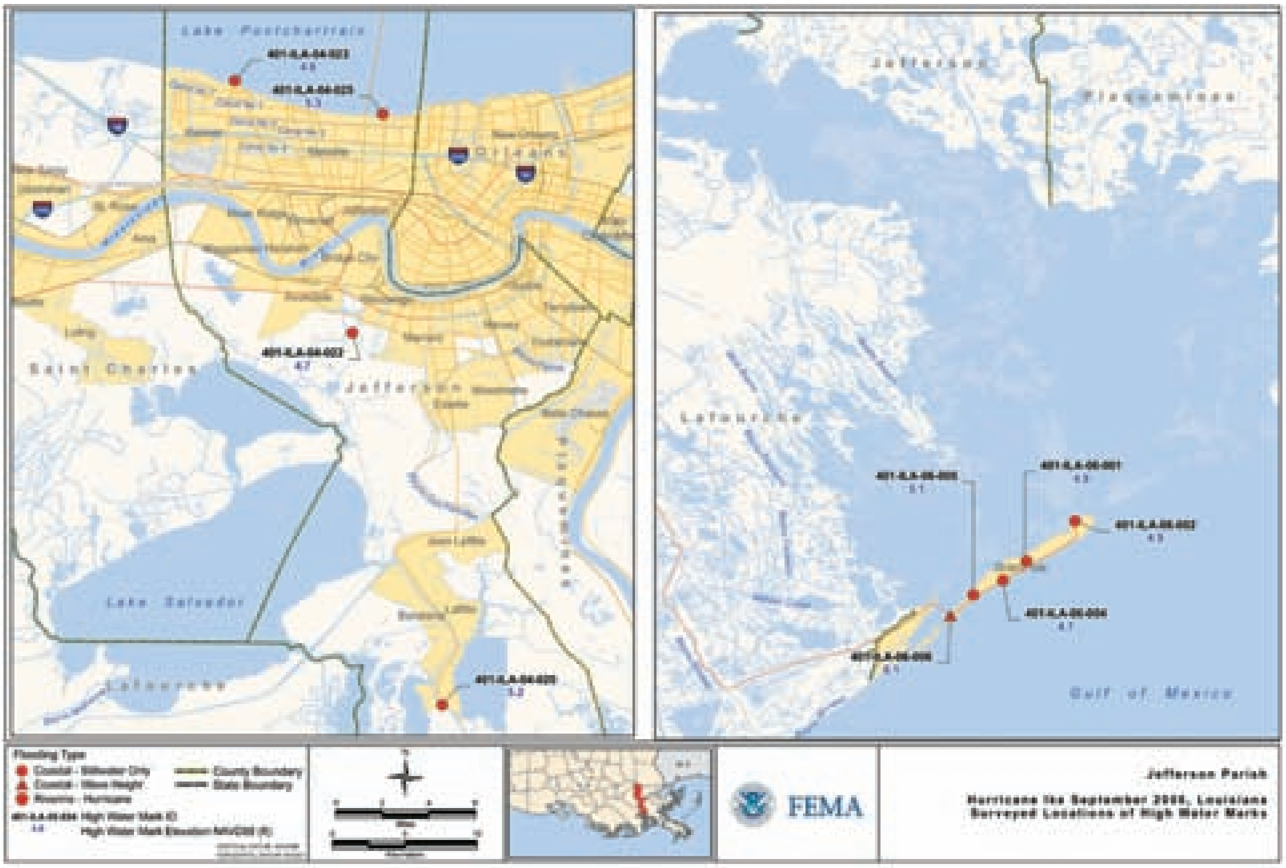

Beauregard
Allen
Jefferson Davis
Calcasieu
Cameron
Calcasieu Parish
Hurricane Ike September 2008, Louisiana
Surveyed Locations of High Water Marks
FEMA


Gulf of Mexico
FEMA
Cameron Parish
Hurricane Ike September 2008, Louisiana
Surveyed Locations of High Water Marks

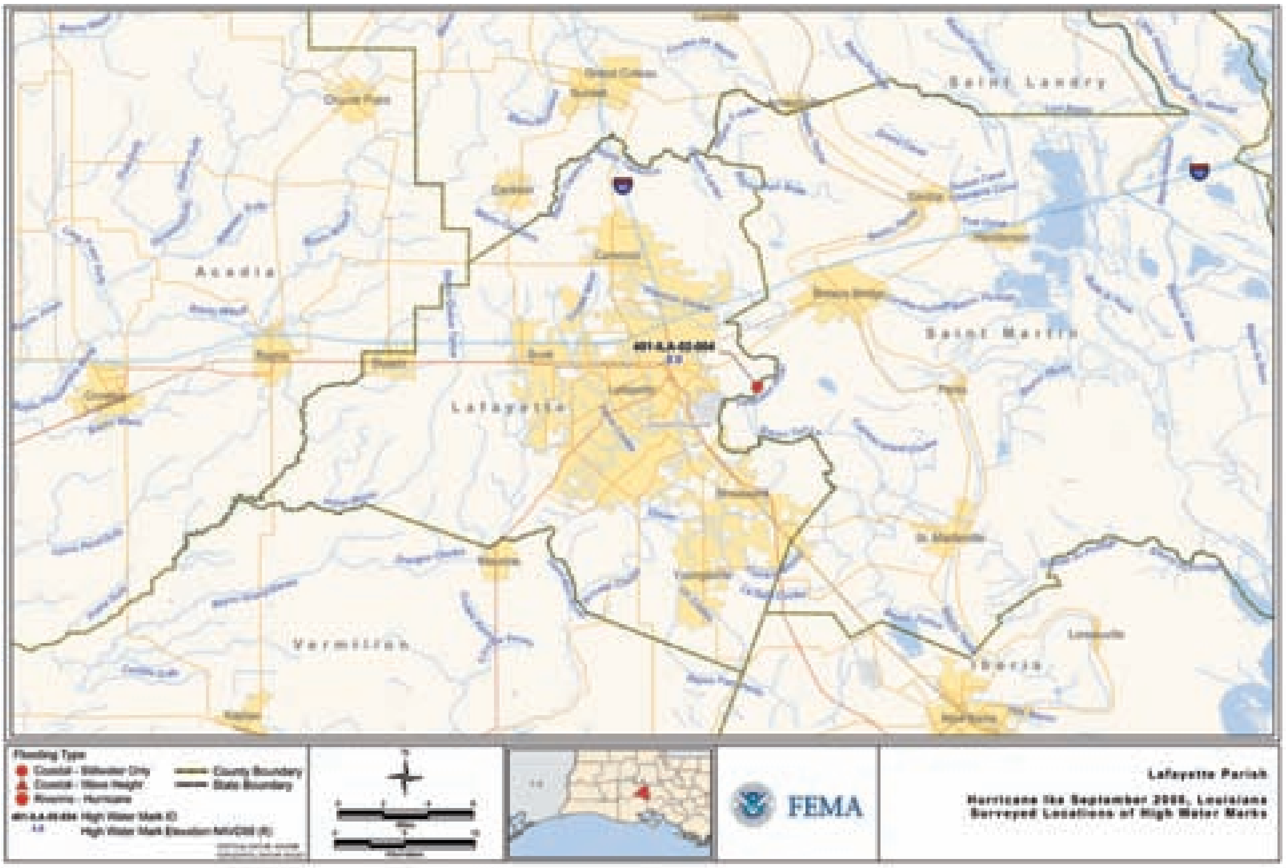

Lafayette
Saint Martin
Iberia
Saint Mary
FEMA

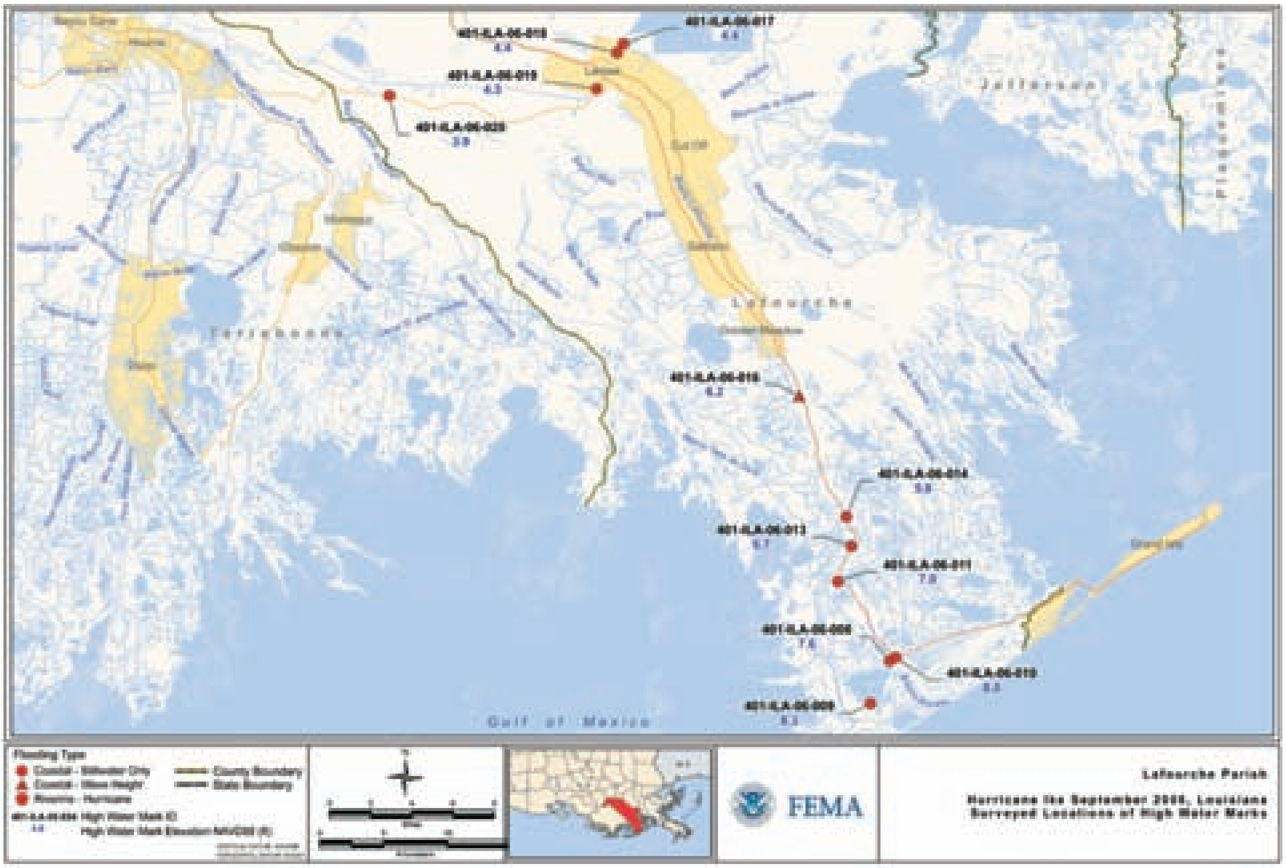

West Baton Rouge
East Baton Rouge
Iberville
Ascension
Saint Martin
Iberia
Assumption
FEMA
Iberville Parish
Hurricane Ike September 2008, Louisiana
Surveyed Locations of High Water Marks


Allen
Evangeline
Saint Landry
Acadia
Jefferson Davis
Calcasieu
Cameron
Vermilion
Flooding Type
Coastal - Stillwater Only
Coastal - Wave Height
Riverine - Hurricane
County Boundary
State Boundary
High Water Mark Elevation NAVD88 (ft)
FEMA
Jefferson Davis Parish
Surveyed Locations of High Water Marks



Lake Pontchartrain
Orleans
Saint Charles
Jefferson
Lake Salvador
Lafourche
Plaquemines
Gulf of Mexico
Jefferson Parish
Hurricane Ike September 2008, Louisiana
Surveyed Locations of High Water Marks
FEMA

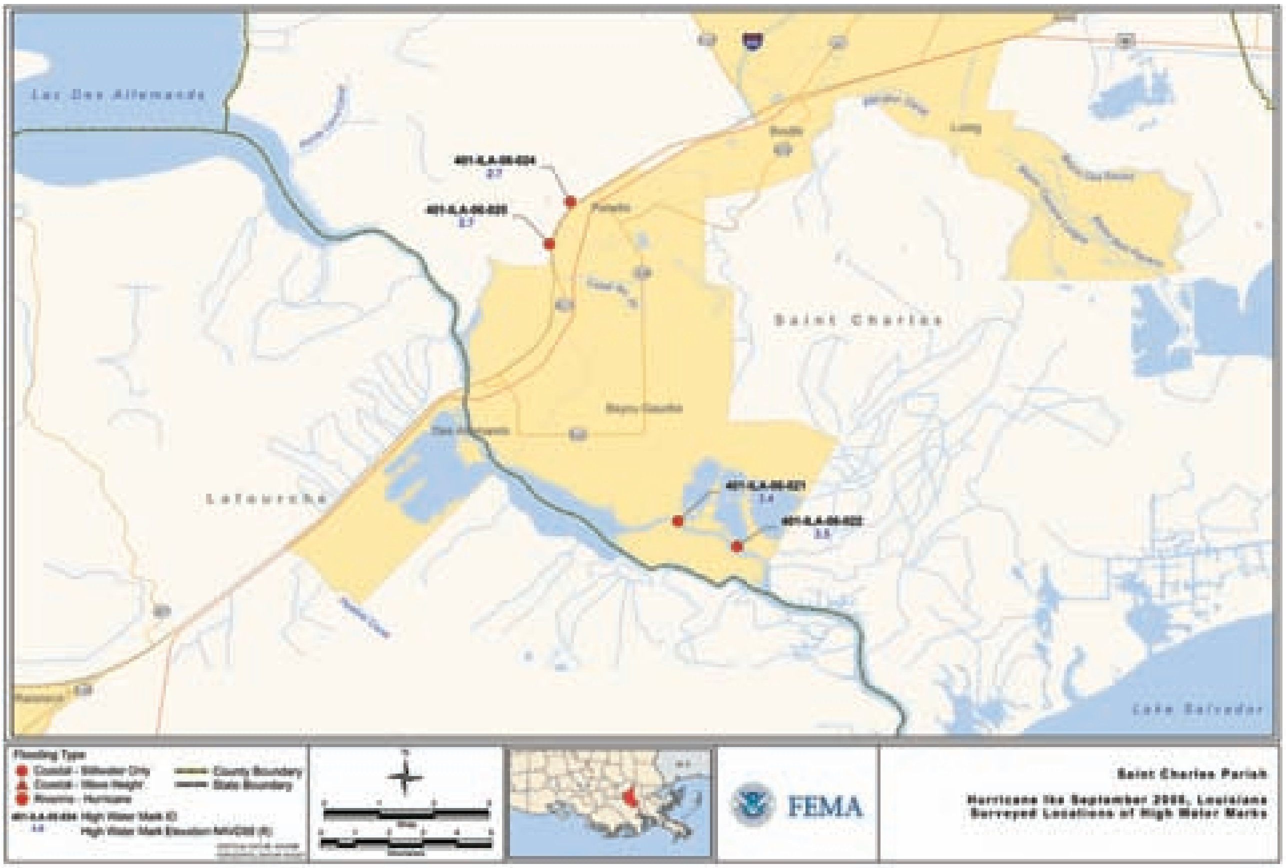

Saint Landry
Acadia
Saint Martin
Lafayette
Vermilion
Iberia
Flooding Type
County Boundary
State Boundary
FEMA
Lafayette Parish
Hurricane Ike September 2008, Louisiana
Surveyed Locations of High Water Marks

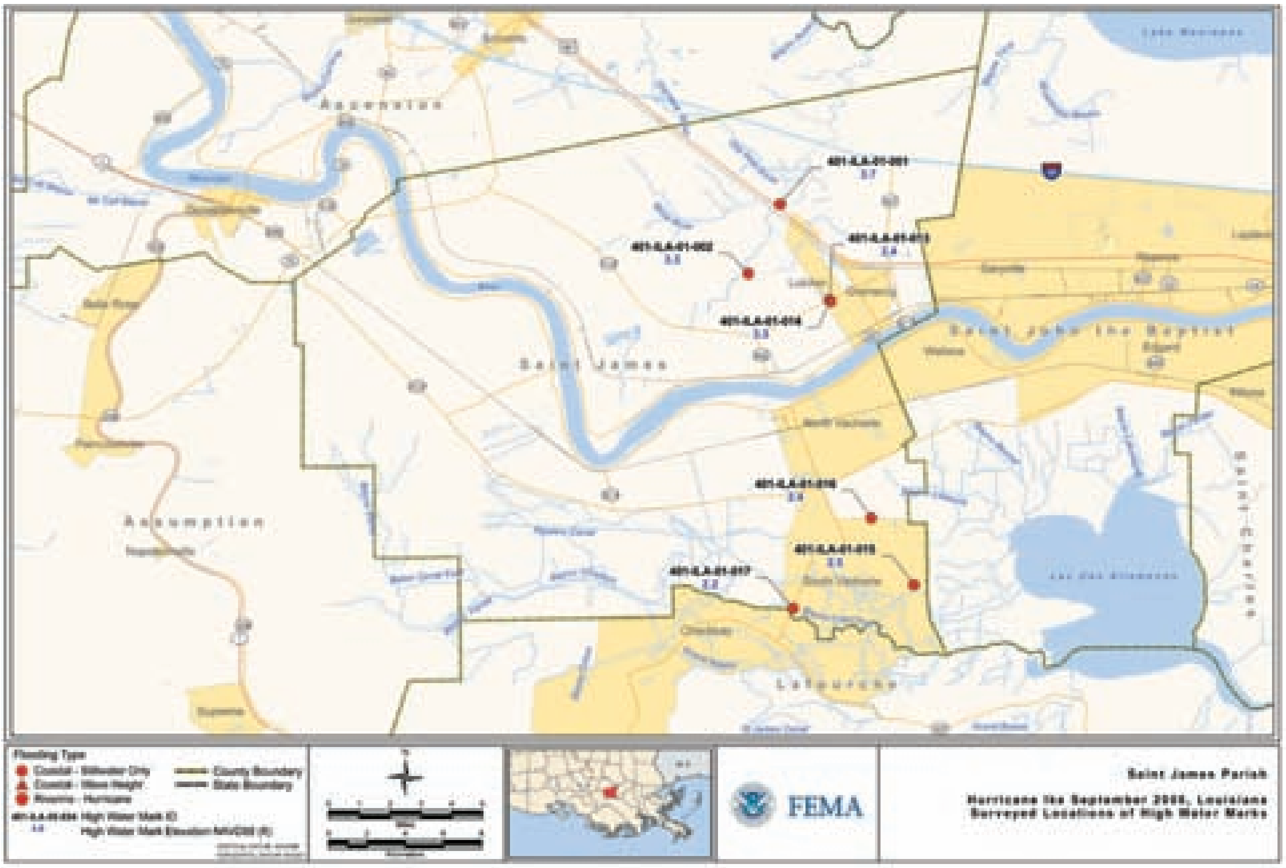

Jefferson
Lafourche
Terrebonne
Gulf of Mexico
Flooding Type
Coastal - Stillwater Only
Coastal - Wave Height
Riverine - Hurricane
County Boundary
State Boundary
High Water Mark ID
High Water Mark Elevation NAVD88 (ft)
FEMA
Lafourche Parish
Hurricane Ike September 2008, Louisiana
Surveyed Locations of High Water Marks

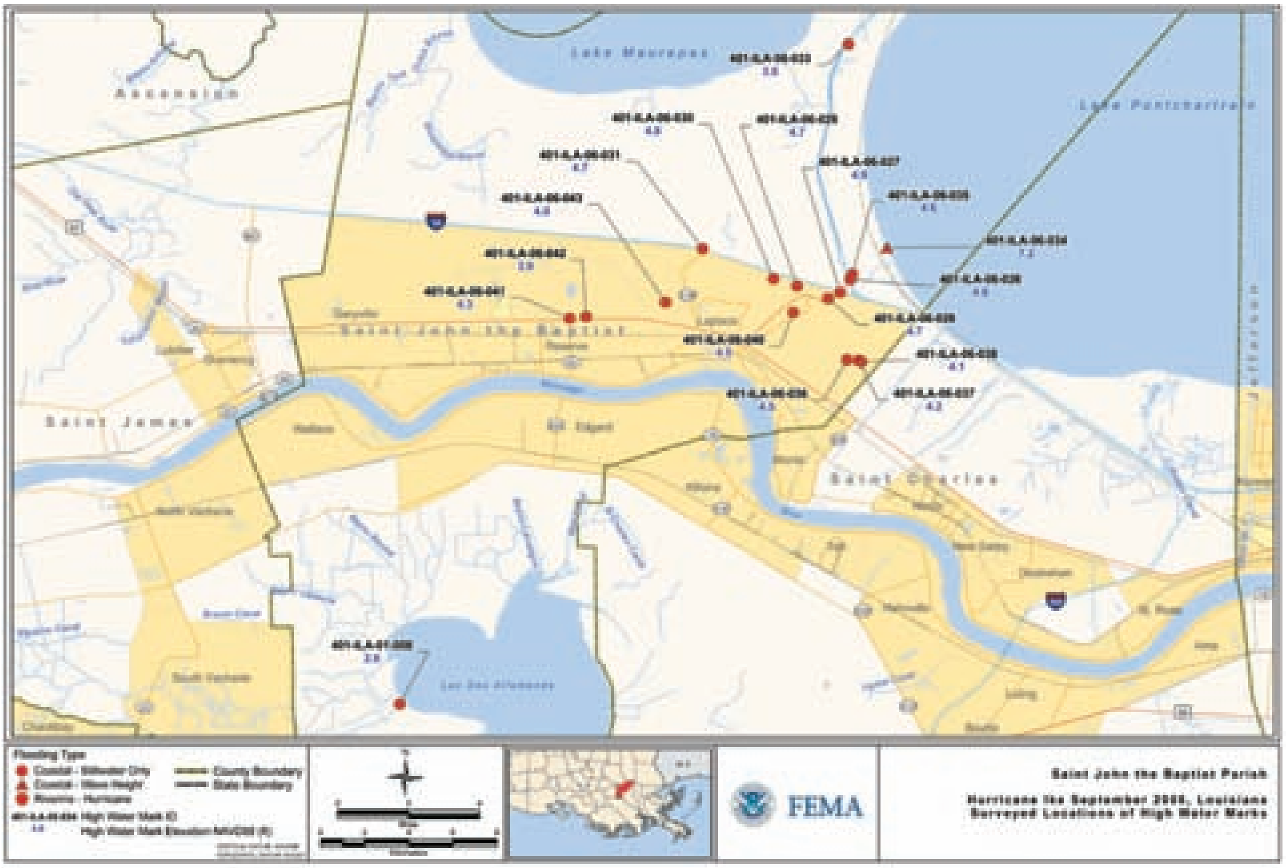

Tangipahoa
Livingston
Ascension
Lake Maurepas
Saint John the Baptist
Flooding Type
County Boundary
State Boundary
FEMA
Livingston Parish
Hurricane Ike September 2008, Louisiana
Surveyed Locations of High Water Marks

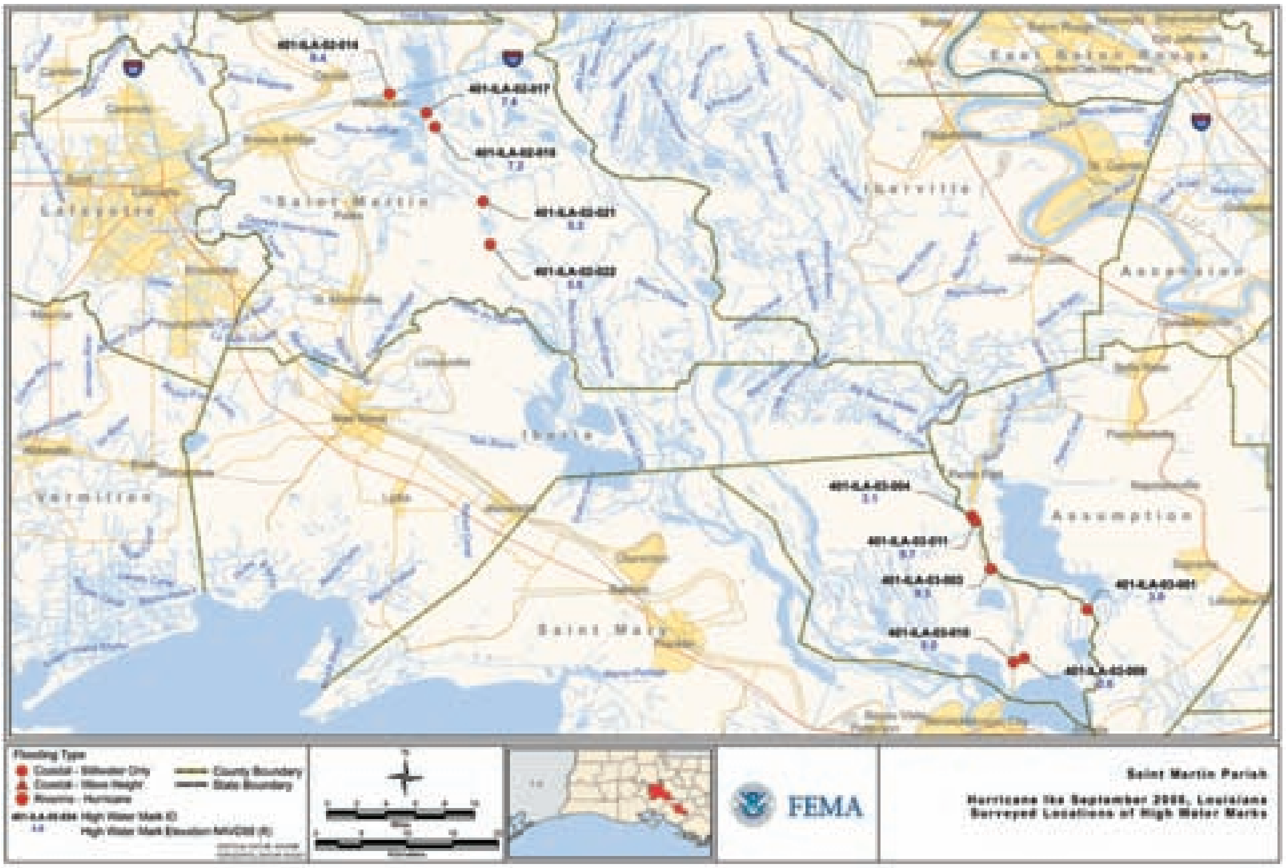

Saint Bernard
Jefferson
Plaquemines
Lafourche
Gulf of Mexico
Gulf of Mexico
Flooding Type
Coastal - Stillwater Only
Coastal - Wave Height
Riverine - Hurricane
County Boundary
State Boundary
High Water Mark ID
High Water Mark Elevation NAVD88 (ft)
FEMA
Plaquemines Parish
Hurricane Ike September 2008, Louisiana
Surveyed Locations of High Water Marks

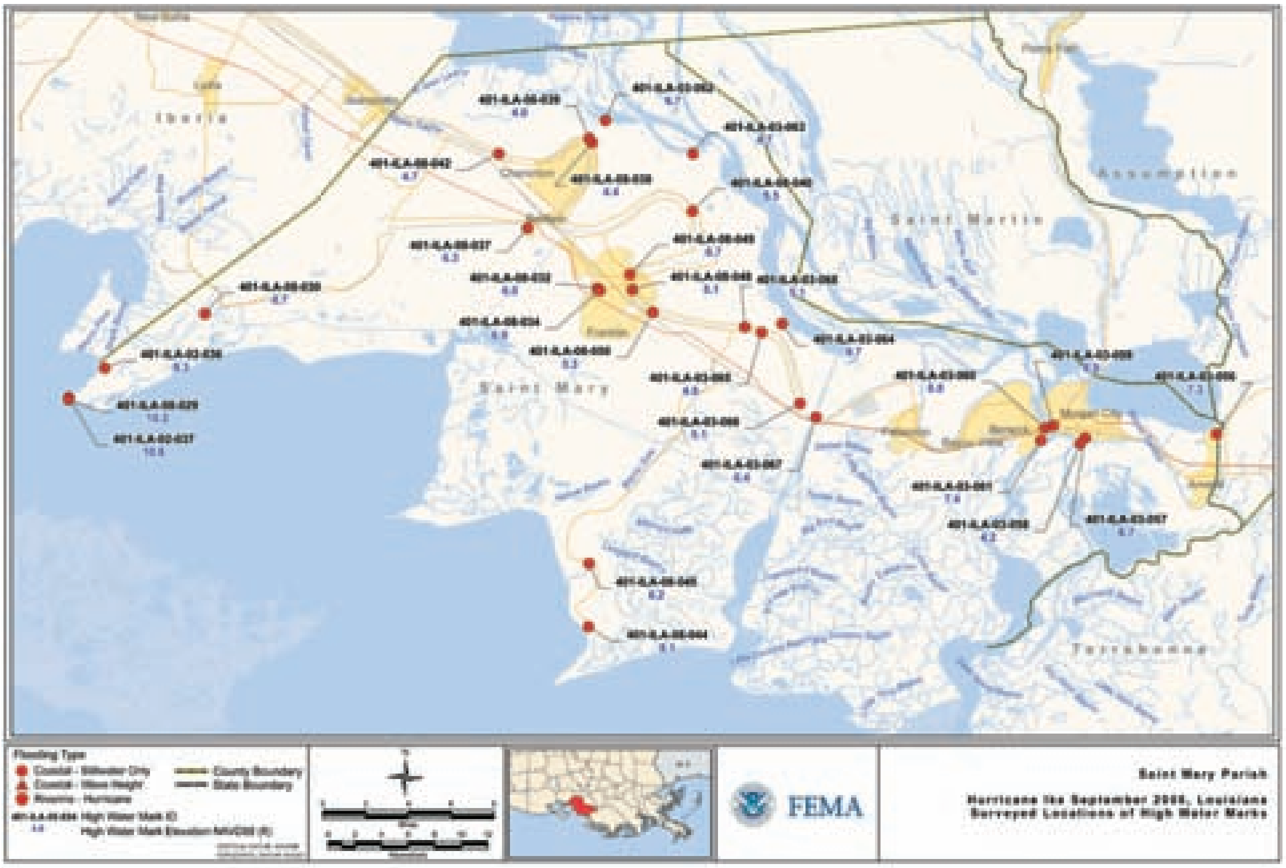

Lake Borgne
Saint Bernard
Plaquemines
Saint Bernard Parish
FEMA


Lac Des Allemands
Saint Charles
Lafourche
Lake Salvador
Flooding Type
County Boundary
State Boundary
FEMA
Saint Charles Parish
Hurricane Ike September 2008, Louisiana
Surveyed Locations of High Water Marks

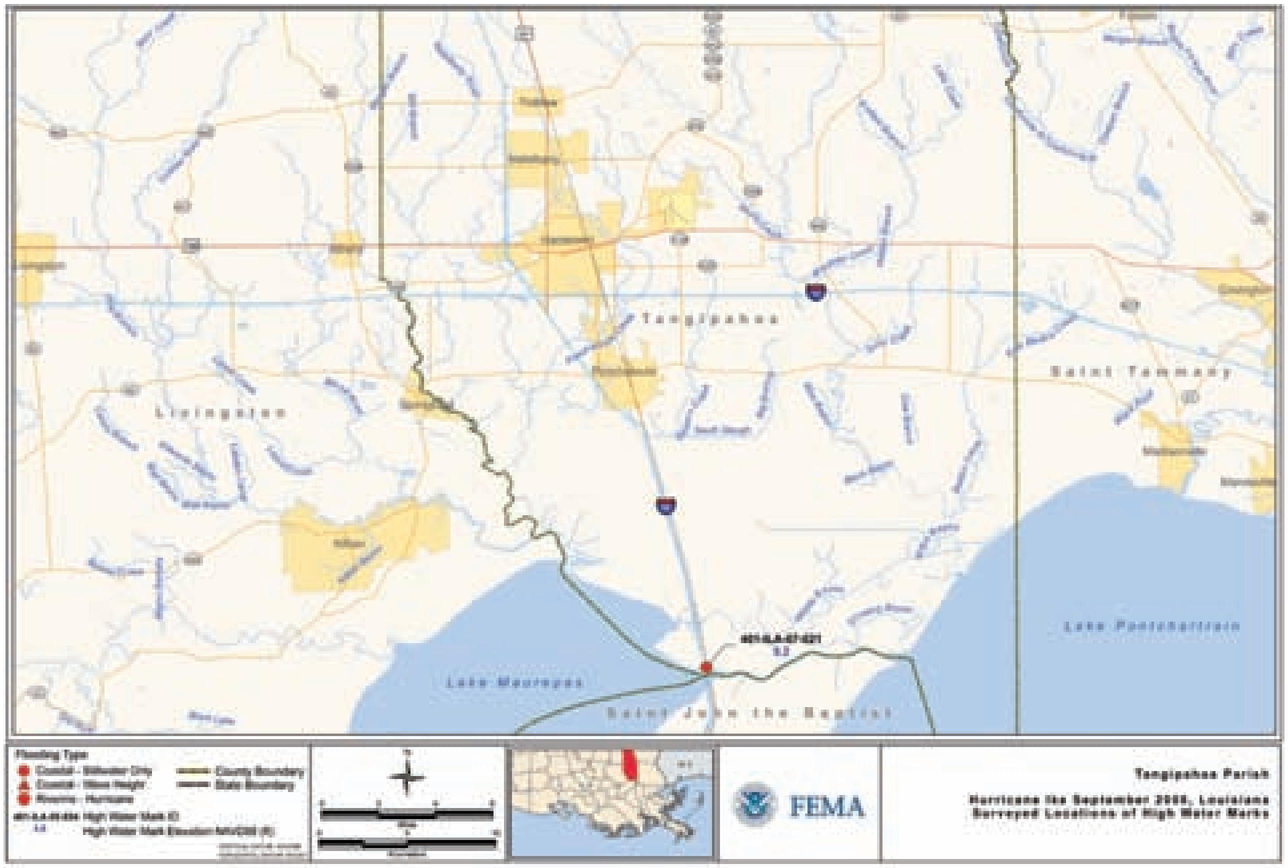

Ascension
Saint James
Saint John the Baptist
Assumption
Lafourche
FEMA
Saint James Parish
Hurricane Ike September 2008, Louisiana
Surveyed Locations of High Water Marks

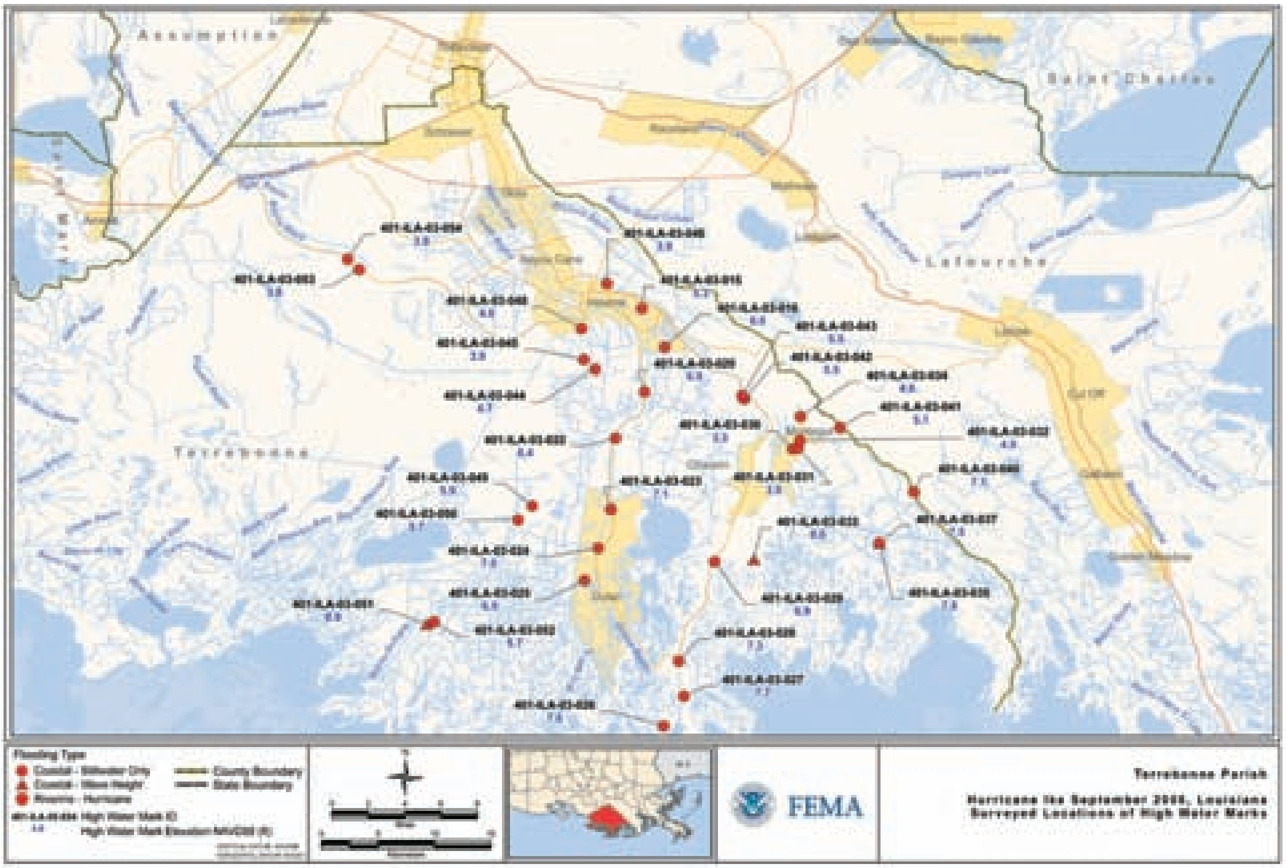

Lake Maurepas
Lake Pontchartrain
Saint John the Baptist
Saint James
Saint Charles
FEMA
Saint John the Baptist Parish
Hurricane Ike September 2008, Louisiana
Surveyed Locations of High Water Marks

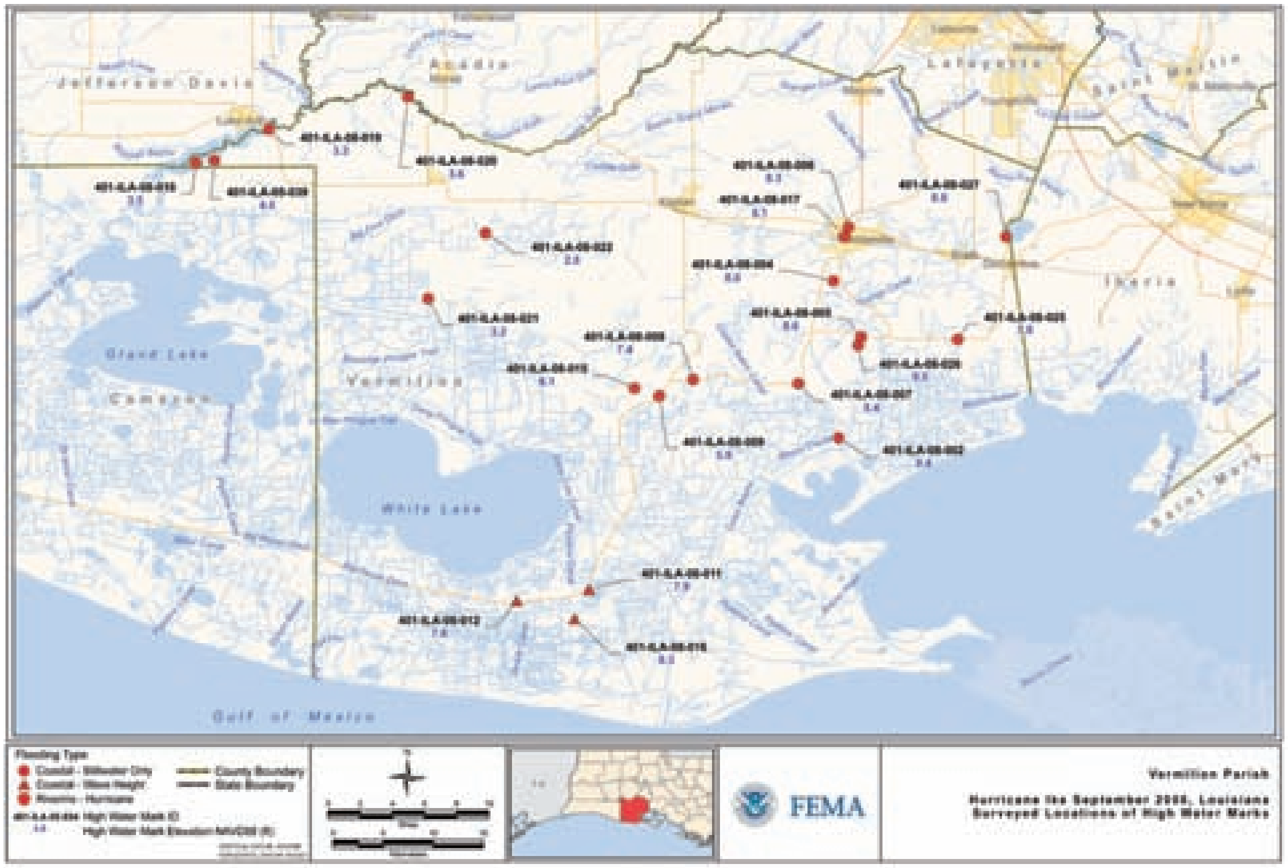

Lafayette
Saint Martin
Iberville
Ascension
Iberia
Vermilion
Assumption
Saint Mary
FEMA
Saint Martin Parish
Hurricane Ike September 2008, Louisiana
Surveyed Locations of High Water Marks


Iberia
Saint Martin
Assumption
Saint Mary
Terrebonne
FEMA
Saint Mary Parish
Hurricane Ike September 2008, Louisiana
Surveyed Locations of High Water Marks


Lake Pontchartrain
Saint Tammany
Jefferson
Orleans
Flooding Type
County Boundary
State Boundary
FEMA
Saint Tammany Parish
Hurricane Ike September 2008, Louisiana
Surveyed Locations of High Water Marks


Tangipahoa
Livingston
Saint Tammany
Lake Maurepas
Lake Pontchartrain
Saint John the Baptist
Flooding Type
County Boundary
State Boundary
FEMA
Tangipahoa Parish
Hurricane Ike September 2008, Louisiana
Surveyed Locations of High Water Marks


Assumption
Saint Charles
Lafourche
Terrebonne
Flooding Type
County Boundary
State Boundary
FEMA
Terrebonne Parish
Hurricane Ike September 2008, Louisiana
Surveyed Locations of High Water Marks


Jefferson Davis
Acadia
Lafayette
Grand Lake
Cameron
Vermilion
White Lake
Iberia
Saint Mary
Gulf of Mexico
FEMA
Vermilion Parish
Hurricane Ike September 2008, Louisiana
Surveyed Locations of High Water Marks