Hurricane Mitigation Summary Report On Building Performance

Course# ST602

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Summary Report on Building Performance

Hurricane Katrina 2005

FEMA 548 / April 2006

FEMA

In response to Hurricane Katrina, 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 flood and wind forces. The MAT included engineers and other experts from FEMA Headquarters and Regional Offices, and from the design and construction industry.

This is a summary of the information that can be found in the full MAT report Hurricane Katrina in the Gulf Coast: Building Performance Observations, Recommendations, and Technical Guidance *(FEMA 549, 2006).*

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Executive Summary

Hurricane Katrina was one of the strongest storms to impact the coast of the United States during the past 100 years. Katrina reached Category 5 levels over the Gulf of Mexico, then weakened and made landfall in Louisiana and Mississippi with strong Category 3 storm winds. The storm surge, however, did not diminish before landfall, and the record surge caused widespread devastation in the coastal areas of Alabama, Louisiana, and Mississippi. The storm surge caused failures of the levee system that protects the City of New Orleans from Lake Pontchartrain, and 80 percent of the city subsequently flooded.

Prior to Hurricane Katrina, Alabama, Louisiana, and Mississippi did not have statewide building codes for non-state-owned buildings. Many of the communities in areas that were heavily impacted by Hurricane Katrina had either not adopted up-to-date model building codes that incorporate flood and wind protection or had no building codes at all. The lack of adequate building codes greatly compounded the effect of Hurricane Katrina on building performance. Dauphin Island, Alabama, recently adopted an amendment for deeper pile embedment, and Louisiana and Mississippi have taken steps toward improving building codes.

Storm surge and wave crest elevations from Hurricane Katrina exceeded the mapped base flood elevations (BFEs) in many coastal areas of Alabama, Louisiana, and Mississippi and flood damage was severe in these areas. The elevation of a building was the most critical factor in its success at withstanding the storm surge. Where Katrina's record surge and waves rose above the foundation and impacted floor beams and walls, most buildings were destroyed, regardless of foundation type. In some instances, however, buildings that were constructed using structural frames that are continuous with foundations survived even when storm surge and waves exceeded the first floor elevation.

The failure of levees and floodwalls that protect the City of New Orleans resulted in catastrophic flooding in the Greater New Orleans area, with flooding in many areas up to 8 feet above the lowest floor of the building. The BFEs for the levee-protected area are determined based on the certification that the levee will provide protection from the base flood event. Many buildings constructed with the first floor elevation above the BFE were severely damaged or destroyed when the floodwaters rose well above the first floor. The duration of the floodwaters in New Orleans contributed to further damages, with some areas remaining under floodwaters for several weeks. This long-duration flooding saturated some types of building materials beyond the point where they could be salvaged and contaminated the materials with chemical and biological substances in the floodwaters. The rampant growth of mold in flood-saturated buildings was another effect of the long-duration flooding.

Hurricane Katrina was less than a design-level storm for wind in most areas; however, wind damage was widespread and was severe in some areas. Most of the wind damage observed was not structural. Buildings that experienced substantial structural damage typically were built before wind effects were adequately considered in building design and construction. Most of the wind damage observed was associated with the failure of building envelopes and rooftop equipment. Building envelope damage was observed as far west as the New Orleans area and as far east as Dauphin Island, Alabama (an east-to-west distance of approximately 140 miles). Roof coverings, in particular, performed poorly. Only limited use of glazing protection was observed and, consequently, there was also significant damage to building glazing.

The poor performance of critical and essential facilities during and after Katrina was widespread throughout the impacted area. Facilities were severely damaged and many were completely destroyed. While most of the damage to critical facilities was caused by storm surge, high winds also damaged many facilities.

The Significance of Hurricane Katrina

Hurricane Katrina was the most severe hurricane to strike the Louisiana/Mississippi Gulf Coast since Hurricane Camille in 1969 and the most significant hurricane to strike the New Orleans area since Hurricane Betsy in 1965. The significance of Katrina and its effects are summarized below:

- Katrina significantly exceeded the base flood elevations (BFEs) by as much as 15 feet along parts of the Louisiana and Mississippi Gulf Coast. Flooding extended well beyond the inland limits of the Special Flood Hazard Area (SFHA), and the highest storm surge in U.S. history was recorded on the Mississippi coast.
- The American Red Cross estimated that Katrina destroyed over 300,000 single-family homes throughout Louisiana and Mississippi.
- Coastal flood impacts covered a wide area, with severe flood damage extending along coastal Alabama and totally destroying over 100 houses on Dauphin Island.
- Levee failures led to severe flood damage throughout the City of New Orleans and surrounding areas of Plaquemines and St. Bernard Parishes. Hundreds of thousands of people are now displaced due to damage caused by the flooding.
- Katrina's wind speeds were estimated to be at the design level in only a few areas and were less than the current code-specified speeds (per the 2000/2003 International Building Code [IBC] and the International Residential Code [IRC]) in most areas. These codes use a design wind speed map developed for the 1998 edition of the American Society of Civil Engineers (ASCE) 7, *Minimum Design Loads for Buildings and Other Structures* design standard.
- Wind damage to both commercial and residential buildings was widespread throughout the southern portions of Louisiana and Mississippi.
- In general, buildings functioning as critical and essential facilities did not perform well, and experienced significant wind and flood damage (with damages similar in nature to their commercial counterparts). The operation of many critical and essential facilities was hampered or eliminated as a result of storm-induced damage or isolation due to coastal flooding.

Flood Recommendations

Based on the widespread devastation of buildings resulting primarily from floodwater and waves that exceeded first floor elevations, it is strongly recommended that buildings be constructed in anticipation of flood levels that exceed the current BFE. A few of the main recommendations include:

- Adoption of modern building codes, such as the IBC, IRC, or National Fire Protection Association (NFPA) 5000 are recommended. These codes include up-to-date design and construction provisions that are consistent with the National Flood Insurance Program (NFIP). The IBC and NFPA 5000 incorporate flood load (ASCE 7-05) and flood-resistant construction (ASCE 24-05) standards. The 2003 IRC currently does not reference explicitly ASCE 7 and ASCE 24 for flood loads and flood-resistant construction. Thus, it is recommended that communities containing land within the estimated 100-year floodplain shown on the Katrina Flood Recovery Maps use ASCE 7-05 for flood load calculations and ASCE 24-05 for flood-resistant one- and two-family residential construction purposes. Adoption of any model code or standard should keep intact the minimum criteria established by the parent or expert document such as ASCE 7 or ASCE 24.

- Use *Recommended Residential Construction for the Gulf Coast: Building on Strong and Safe Foundations* (FEMA 550, publication available May 2006).

- Review the storm surge data and conduct a revised tide frequency analysis. Use modern storm surge models to estimate the BFEs throughout the Katrina impact area.

- Consider mapping Coastal A Zones onto new Flood Insurance Rate Maps (FIRMs). Utilize ASCE 24-05 for design and construction of buildings located in Coastal A Zones. As an interim step, use the Katrina Flood Recovery Maps to determine the approximate location of the Coastal A Zone hazard. As shown on the Recovery Maps for Mississippi, the Coastal A Zone will be the area between the approximate limit of the 1.5-foot Wave Zone line and the approximate limit of the 3-foot Wave Zone line.

- Consider evaluating and revising flood hazard mapping and levee certification procedures for areas behind levees.

- For rebuilding efforts, use the Katrina Flood Recovery Maps until the new flood maps are released.

Wind Recommendations

The wind impacts from the storm caused widespread damage to building envelopes as a result of inadequate design, outdated codes, building age, lack of maintenance, and/or poor construction/code enforcement. A few of the main recommendations include:

- Adopt the 2006 IBC and IRC, or 2006 NFPA 5000, for all jurisdictions in each state.

- Roof covering systems, soffits, wall coverings, doors, windows, and rooftop equipment need additional attention by designers, architects, and contractors as specified in Section 4.6. Testing improvements are recommended to assess the performance of external insulation and finish systems (EIFS), vinyl siding, and soffits.

Critical and Essential Facility Recommendations

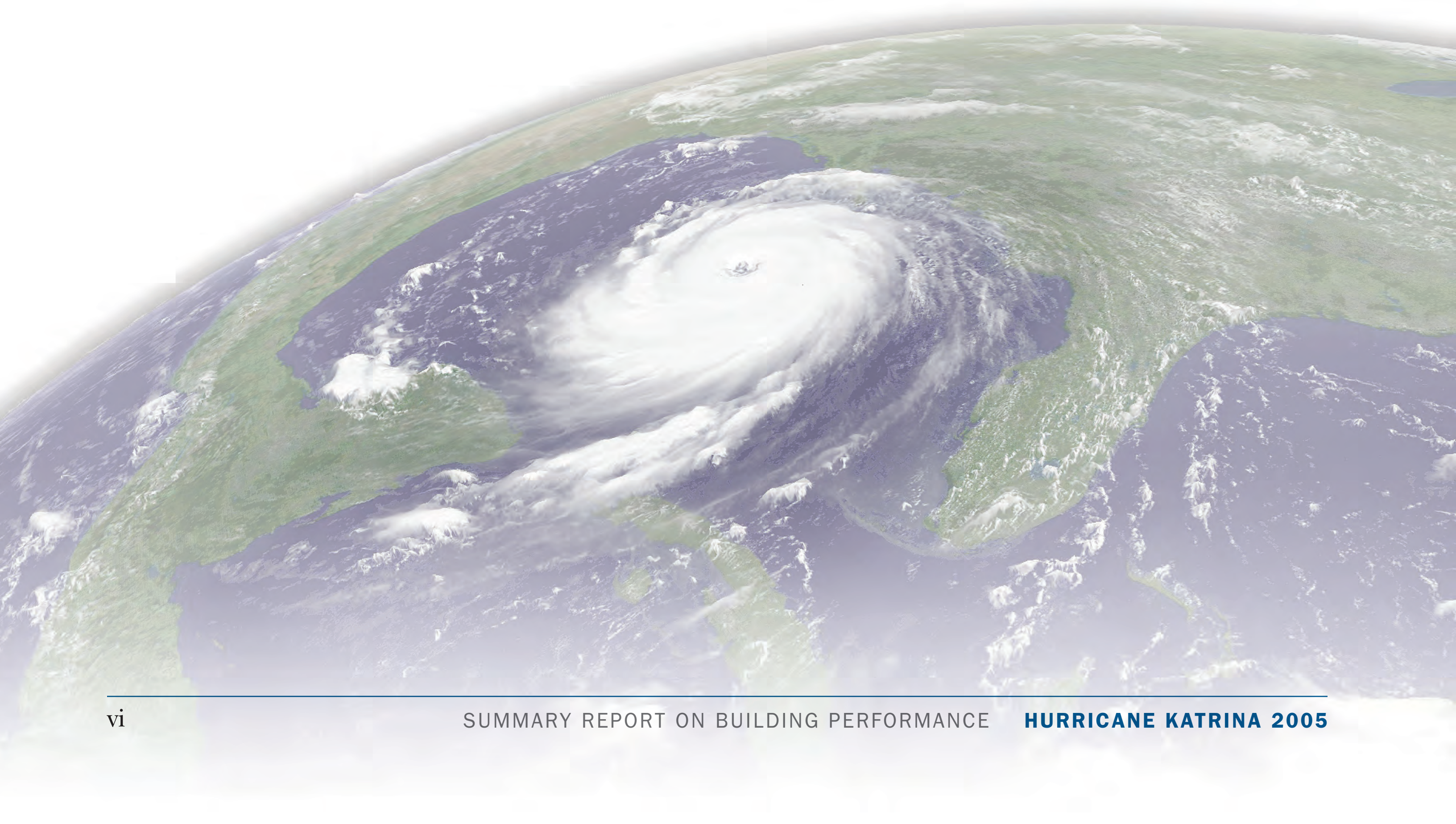
A few of the main recommendations related to improving the performance of critical and essential facilities include:

- Locate all new critical and essential facilities that must remain operational during an event above the 500-year flood elevation and on sites that will not be isolated by floodwaters.

- Develop emergency operation plans that allow building occupants and operations of existing facilities located within the SFHA to be relocated to sites outside of SFHAs before the onset of the storm. If personnel are relocated away from the facility, relocate equipment as well.

- Evaluate flood and wind resistance of existing facilities; where inadequacies are found, either retrofit or build a new facility.

- Design to standards that exceed current code, conduct peer reviews when designing new facilities or retrofitting existing facilities, and implement special inspections during construction.



1. Purpose and Background

The purpose of this report is to summarize the observations, conclusions, and recommendations that were developed from FEMA's Mitigation Assessment Team's post-disaster building performance assessments following Hurricane Katrina. The conclusions and recommendations of the Mitigation Assessment Team will assist local communities, businesses, and individuals in reconstructing and will help reduce the impact from future hurricanes.

1.1 Introduction

On August 29, 2005, Hurricane Katrina struck the shorelines of Alabama, Louisiana, and Mississippi, and began a path of destruction that would result in the most financially devastating and one of the deadliest natural disasters in the history of the United States. In the weeks following the hurricane, a Mitigation Assessment Team (MAT) was deployed by the Federal Emergency Management Agency (FEMA) to these states to assess the performance of buildings in areas affected by the hurricane (see Figure 1-1). Based on the observed damage, the MAT also evaluated the adequacy of current building codes, manufacturers' construction requirements, National Flood Insurance Program (NFIP) standards, flood zones, and building practices and materials in the affected regions.

The MAT included FEMA Headquarters and Regional Office engineers and experts in flood and wind hazard issues from the design and construction industry. Team members included structural engineers, architects, wind engineers, civil engineers, coastal scientists, building code experts, and flood preservation specialists. In addition, representatives from the International Code Council (ICC) and wind engineers and scientists from Texas Tech University, Louisiana State University, and the University of Mississippi also participated. To observe and assess the damage to structures from the levee breach in New Orleans, the MAT for New Orleans also included experts from the flood restoration industry.

Figure 1-1. Locations visited by the MAT

The Mitigation Assessment Team Report, *Hurricane Katrina in the Gulf Coast: Building Performance Observations, Recommendations, and Technical Guidance* (FEMA 549, 2006), documents the MAT's findings and provides recommendations for improving the performance of buildings and reducing the impact of future hurricanes. The observations, conclusions, and recommendations contained in the MAT report are summarized herein.

1.2 Background

Hurricane Katrina was a powerful storm that caused unprecedented damage in the United States. The hurricane made landfall in Louisiana and Mississippi as a powerful Category 3 hurricane, but it maintained the surge levels of a Category 5 storm as it hit the Gulf Coa st. Both the characteristics of a storm and regulatory mechanics, like floodplain management regulations and building codes, influence the performance of buildings in a storm. The following sections describe the storm event and the regulatory framework in the areas affected by Hurricane Katrina.

1.2.1 Storm Event Description

The North Atlantic hurricane season for 2005 began early and was an unusually active season, breaking the previous recorded hurricane season records for the number of named storms, hurricanes, Category 5 hurricanes, major hurricanes making U.S. landfall, and early-season storms (see Table 1-1). On average, about six North Atlantic hurricanes occur every year; by the end of 2005, there had been 15. The annual hurricane season, which generally lasts from June 1 through November 30, was longer than average for the 2005 hurricane season with Tropical Storm Zeta (the 27th named storm) persisting until January 2006.

Hurricane Katrina began as Tropical Depression Twelve, which formed over the Bahamas on August 23, 2005. On August 24, the storm strengthened and became known as Tropical Storm Katrina, the 11th named storm of the 2005 hurricane season. The storm traveled northwest from the Bahamas. A few hours before making landfall in Florida on August 25, Tropical Storm Katrina reached 74 miles per hour winds and was upgraded to a Category 1 hurricane.

The hurricane made its first landfall on the southeast coast of Florida around 6:30 p.m. Eastern Daylight Time (EDT) with approximately 80 mph, 1-minute sustained winds. The storm weakened as it passed over land, becoming a tropical storm once again as it tracked southwest through Everglades National Park and exited the southern tip of Florida. Once over the warm waters of the Gulf of Mexico, Katrina rapidly gained strength. By August 28, the storm had reached Category 5 hurricane status with sustained winds of 175 mph (gusts of 215 mph) and a central minimum pressure of 902 mb.[1]

At 6:10 a.m. Central Daylight Time (CDT) on August 29, Hurricane Katrina made landfall for the second time, near Buras, Louisiana, in Plaquemines Parish. According to the National Climatic Data Center (NCDC), Hurricane Katrina had 1-minute sustained winds estimated at 127 mph upon landfall and a minimum central pressure of 920 millibars (mb), making it the third lowest landfall pressure on record for the United States and placing it as a strong Category 3 hurricane. After making landfall, Katrina moved northward up the Louisiana coast, its storm surge and strong winds affecting much of Plaquemines and St. Bernard Parishes, as

Table 1-1. 2005 Hurricane Season Records

Statistic	2005 Total	Previous Record/Year	
Number of named storms	27	21	1933
Number of hurricanes	15	12	1969
Number of Category 5 hurricanes	4	2	1960 and 1961
Major hurricanes making U.S. landfall	4	3	2004
Number of tropical storms before August 1	7	5	1997
Strongest hurricane in the Atlantic Basin	882 mb (Wilma)	888 mb (Gilbert)	1988

mb = millibars

[1] Central pressure measurements are from the National Hurricane Center's *Tropical Cyclone Report for Hurricane Katrina*, dated December 20, 2005.

well as the community of Slidell in St. Tammany Parish. After passing New Orleans, Hurricane Katrina moved across the open waters of Breton Sound and the western edge of the Mississippi Sound and made a third and final landfall along the Louisiana/Mississippi border near Pearlington, Mississippi, as a Category 3 hurricane with 120-mph, 1-minute sustained winds.

After traveling more than 150 miles inland and reaching Jackson, Mississippi, Hurricane Katrina weakened and lost hurricane strength, with sustained wind speeds dropping below 74 mph. Katrina continued to move northward, affecting weather in the central United States, until it was absorbed by a frontal boundary near southeast Quebec and northern New Brunswick, Canada, on August 31.

What is a Hurricane?

A hurricane is a tropical cyclone with winds that have reached a constant speed of 74 miles per hour (mph) or more. Hurricanes are categorized according to their relative strength as measured by wind speed and minimum central pressure. The Saffir-Simpson Scale is the standard for categorizing hurricanes and consists of five separate categories. The term "major hurricane" is used for hurricanes that reach maximum 1-minute sustained surface winds of at least 111 mph over open water (National Hurricane Center – NHC). Category 3, 4, and 5 hurricanes are all considered major hurricanes.

Saffir-Simpson Hurricane Scale Wind Speeds and Pressures

Strength	Sustained Wind Speed (mph)*	Gust Wind Speed (mph)**	Pressure (millibars)
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

1.2.2 Storm Effect

Hurricane Katrina caused widespread devastation along the Gulf Coast of the United States, with southeast Louisiana and the coasts of Mississippi and Alabama bearing the brunt of the catastrophic damage. Although the storm weakened from a powerful Category 5 storm to a Category 3 storm just before making landfall in Louisiana and Mississippi, the storm surge appears to have maintained a level associated with a Category 5 hurricane. The surge generated by the storm could not dissipate as rapidly as the wind speeds decreased, and the shallow depth of the offshore shelf and shape of the shoreline contributed to the high surge elevations. Storm surge pounded the coastline from southeast Louisiana to the Florida panhandle, with the Mississippi coastline experiencing the highest storm surges on record. Some of the highest recorded surge elevations exceeded 25 feet North American Vertical Datum of 1988 (NAVD 88) along the Mississippi coast from Waveland east to Long Beach.

Although the eye of Hurricane Katrina did not directly hit New Orleans, catastrophic destruction occurred throughout the southeast portion of Louisiana. As the eye of the storm moved inland to the northeast of New Orleans on the morning of August 29, winds began to blow from the north and, with surge levels already high in Lake Pontchartrain and Lake Borgne, additional pressure was put on the levee system that protects New Orleans. Based on early investigations by the U.S. Army Corps of Engineers (USACE) Interagency Performance Evaluation Task Force (USACE, 2006 a,b), there were three major levee breaches on Monday, August 29. By August 31, at least 80 percent of the City of New Orleans was under floodwaters.

The estimated death toll from Hurricane Katrina exceeds 1,300, with approximately 1,067 of those deaths occurring in Louisiana and approximately 230 in Mississippi.[2] Other deaths attributed both directly and indirectly to Katrina were reported in Florida, Alabama, Georgia, Kentucky, and Ohio. Hurricane Katrina ranks as the third deadliest hurricane in the United States, surpassed only by the Texas Hurricane at Galveston in 1900, where at least 6,000 lives were lost, and the Florida Hurricane in 1928 where 2,500 lives were lost at Lake Okeechobee.

Estimated total economic losses from Hurricane Katrina are in excess of $125 billion and insured losses are estimated at $35 billion. As of February 15, 2006, the number of flood insurance claims exceeded 210,000, covering Alabama, Louisiana, Mississippi, and Florida, with over 175,000 of those claims coming from Louisiana. Preliminary estimates indicate that Hurricane Katrina resulted in the following:[3]

- 450,000 displaced people
- 800,000 Louisiana citizens requesting assistance from various Federal and state relief programs and agencies
- $5.5 billion in damage to infrastructure, including roads and bridges
- 300,000 to 350,000 vehicles and approximately 2,400 ships and vessels destroyed

Table 1-2 summarizes the housing damage from Hurricane Katrina.

Table 1-2. Hurricane Katrina Housing Damage Summary

Location	Dwelling Type	Destroyed	Major	Minor
Alabama	Single-Family	363	966	345
	Manufactured	-	1	26
	Apartment	-	-	-
	Subtotal	**363**	**967**	**371**
Louisiana	Single-Family	241,524	38,350	40,066
	Manufactured	1,552	1,146	1,855
	Apartment	40,762	33,676	27,842
	Subtotal	**283,838**	**73,172**	**69,763**
Mississippi	Single-Family	68,466	62,981	95,468
	Manufactured	263	2,241	4,811
	Apartment	-	15	39
	Subtotal	**68,729**	**65,237**	**100,318**
Hurricane Katrina TOTALS	Single-Family	310,353	102,297	135,879
	Manufactured	1,815	3,388	6,692
	Apartment	40,762	33,691	27,881
	Total	**352,930**	**139,376**	**170,452**

SOURCES: American Red Cross (ARC) , National Association of Home Builders (NAHB), 10/05, <www.redcross.org>, <www.nahb.org>.

[2] The death toll of 1,067 issued by the Louisiana Department of Health and Hospitals includes at least 14 who died prior to Katrina, and some people who were elderly or terminally ill and who died outside of New Orleans after its evacuation, possibly due to stress, as reported by The Times-Picayune on 11/02/05 <www.nola.com/search/index.ssf?/base/library-89/113091548771970.xml?nola>.

[3] Data were obtained from the FEMA *Hurricane Katrina Rapid Response Wind Water Line Reports* for Alabama, Louisiana, and Mississippi (January 30, 2006).

1.2.3 Floodplain Management Regulations

Floodplain management regulations, along with building codes and standards, are adopted by communities and enforced to regulate construction. Under the National Flood Insurance Program, FEMA provides flood insurance to communities that adopt and enforce floodplain management regulations that meet or exceed the floodplain management criteria established by the NFIP.[4]

The NFIP identifies and maps the floodplains of participating communities on Flood Insurance Rate Maps (FIRMs). Areas of varying flood hazard are identified on FIRMs as Special Flood Hazard Areas (SFHAs). SFHAs are designated as Zones A or V on the FIRMs (see box on page 1-7). The SFHAs are expected to be inundated by the flood event with a 1-percent probability of being equaled or exceeded in any given year. This flood is also referred to as the base flood or 100-year flood. SFHAs labeled as Zone AE (as well as A1-30, VE, and V1-30) on FIRMs have been studied by detailed hydraulic analyses that determine base flood elevations (BFEs), which are shown on the FIRMs. BFEs are the minimum elevations to which the lowest floors, as defined by the NFIP, are required to be elevated.[5]

The SFHA zone designation and the BFE are critical factors in determining what building requirements apply to a structure. NFIP regulations provide minimum building requirements for structures built in each of the SFHAs. When a community joins the NFIP and adopts its FIRM, the community is also adopting minimum floodplain standards.

In Louisiana, many buildings were constructed behind levees that were intended to protect them from the 100-year flood. SFHA zone designations for areas protected by the levees are based on the certification by the levee owner that the levee provides protection from the base flood event in conformance with 44 CFR65.10. In areas protected by levees that were impacted by Hurricane Katrina, the mapped BFE was -1.5 to 4.5 feet National Geodetic Vertical Datum (NGVD).6 However, in many of the non-protected areas, the BFE was generally 14 feet NGVD.

1.2.4 Building Codes and Standards

The primary model building code in the United States is developed and maintained by the International Code Council. The ICC codes include the International Building Code (IBC), the International Residential Code (IRC), the International Existing Building Code (IEBC), and a series of codes for mechanical, plumbing, fuel gas, and on-site sewage installations. The National Fire Protection Association (NFPA) issued the first edition of their *Building Construction and Safety Code* (NFPA 5000) in July 2003. The 2006 edition has been available since August 2005. Another recent addition is NFPA's *Model Manufactured Home Installation Standard* (NFPA 225, 2005 edition), the first such standard to include provisions for installation in flood hazard areas. The IBC, IRC, and 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 design and construction of buildings.

Prior to Hurricane Katrina, Alabama, Louisiana, and Mississippi had statewide building codes for state-owned buildings only. Local jurisdictions in these states have the authority to adopt building codes for non-state-owned buildings. Many of the

4 Floodplain management criteria are established in Section 1361(c) of the National Flood Insurance Act of 1968 and 44 Code of Federal Regulations (CFR) Part 60.

5 A Zone BFEs apply to the lowest floor elevation; V Zone BFEs apply to the bottom of the lowest horizontal structural member. In A Zones, the lowest floor is to be elevated to or above the BFE; in V Zones, the bottom of the lowest horizontal structural member is to be elevated to or above the BFE.

6 NGVD (National Geodetic Vertical Datum of 1929) is the national datum used by the NFIP in this area. NGVD is based on mean sea level; the difference between NAVD 88 and NGVD is <0.3 feet.

communities in areas that were heavily impacted by Hurricane Katrina had not adopted current model building codes and were enforcing various editions of the Standard Building Code (SBC) or had no building codes at all.

In Alabama, the City of Mobile, Mobile County, and the City of Orange Beach had adopted editions of the IBC before Katrina. After Katrina, Dauphin Island adopted the IBC and recently adopted provisions requiring deeper pile embedment. Most other affected communities still enforce the 1997 or 1999 SBC.

Prior to Hurricane Katrina, Louisiana had taken steps toward improving building codes. Because of the devastation caused by Hurricane Katrina, the adoption of a statewide building code has been a major priority. On November 29, 2005, Governor Blanco signed into effect a new law (SB44) requiring enforcement of the 2003 IBC and IRC statewide. Emergency flood and wind provisions were required to be effective within 30 days of the new law (December 29, 2005) for parishes and municipalities in the affected areas that are already enforcing building codes, and within 90 days (March 2, 2006) for other

Description of Flood Zones

V Zones. 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.

V1-30. Coastal areas with a 1 percent or greater chance of flooding and an additional hazard associated with storm waves.

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

A1-30. Areas of 100-year flood; base flood elevations and flood hazard factors are determined.

AO. Areas of 100-year shallow flooding where depths are between 1 and 3 feet.

AH. Shallow flooding SFHA. Base flood elevations in relation to NGVD are provided.

A99. An area inundated by 100-year flooding, for which no BFEs have been determined. This is an area to be protected from the 100-year flood by a Federal flood protection system under construction.*

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

* Refer to 44 CFR 61.12

communities. The emergency flood and wind mitigation requirements will remain in effect until the Louisiana State Uniform Construction Code Council adopts the latest editions of both the IBC and the IRC.

A number of jurisdictions in Mississippi have adopted the 2003 editions of the IBC and IRC put forth by the ICC but, as of this report, a state-wide building code for non-state-owned buildings had not been adopted. Since Hurricane Katrina, there have been efforts to promote adoption of a state-wide building code. A Governor's Commission report issued on December 31, 2005, recommended adopting local building codes as a primary hazard mitigation strategy.

2. Building Performance

Hurricane Katrina tested building performance by causing substantial flood damage over large areas of coastal Alabama, Louisiana, and Mississippi. Destructive flood conditions included storm surge, wave action, erosive forces, floodborne debris, and long-duration flooding. The flood conditions of Hurricane Katrina exceeded flood depths and loads used in building design. Although less significant than flood damage, widespread wind damage to buildings also occurred even though Katrina's wind speeds were generally at or below the building code design wind speeds.

The MAT surveyed damaged buildings throughout the impacted areas to document building failures, successes, and opportunities for improvement. The dominant causes of failure observed by the MAT included storm surge, waves, floodborne debris, and wind. Structural damage due to erosion was also common on the barrier islands. Damage occurred to residential buildings (single- and multi-family housing), commercial buildings, and critical and essential facilities .

2.1 Flood Hazard Observations

The coastal areas of Alabama, Louisiana, and Mississippi were heavily impacted by high storm surge. The surge caused severe flood damage to structures within the impact area. The areas of greatest surge impact in Louisiana were St. Bernard Parish on the open Gulf Coast and the parishes surrounding Lake Pontchartrain. In Mississippi, the surge levels, which were more than 20 feet above the normal tide levels, brought high waves and carried floodborne debris that significantly impacted and destroyed buildings. The data collected after Hurricane Katrina indicate coastal storm surge and wave-related high water conditions reached historical proportions and covered significant portions of the Mississippi study area.

2.1.1 Relating Observed Flood Damage to the FIRMs

One of the goals of the MAT was to investigate building failures from coastal flooding inside and outside the SFHAs shown on the effective FIRMs. The MAT observed that flood elevations in many areas exceeded the 100-year BFEs shown on FIRMs by 15 feet or more. Storm surge and wave damage typically associated with Coastal V Zones also occurred in Coastal A Zones and in areas outside SFHAs. As part of the rebuilding effort, FEMA issued interim Hurricane Katrina Flood Recovery Maps for Louisiana and Mississippi that include recommended BFEs to provide guidance during the rebuilding process.

Advisory Base Flood Elevations (ABFEs)

FEMA established ABFEs after Hurricane Katrina to help expedite the rebuilding process in Lousiana and Mississippi areas that were most severely impacted by coastal flooding. The ABFEs shown on the Katrina Flood Recovery Maps are a result of an updated analysis of storm tides in the region, taking into consideration an additional 25+ years of data since the previous analysis was completed. The s and maps are interim map products and provide communities with better flood hazard information than shown on the pre-Katrina FIRMs. Communities are not required to adopt the Katrina Flood Recovery Maps but, when the official maps are completed, the maps must be adopted or the local government will be suspended from the NFIP.

For additional information, refer to the *Reconstruction Guidance Using Hurricane Katrina Surge Inundation and Advisory Base Flood Elevations* in Appendix D.

Web site for ABFEs: <www.fema.gov/hazards/floods/recoverydata/katrina_index.shtm>

Alabama: Severe flooding occurred in many areas within Mobile County, including areas in the cities of Mobile and Bayou La Batre, and the town of Dauphin Island. Many buildings, except those on Dauphin Island, were pre-FIRM and were constructed to much lower elevations compared to the current BFE. In Bayou La Batre, many of the pre-FIRM buildings were destroyed. Buildings constructed to the current floodplain regulations performed well. In Fairhope and Daphne, damages were limited to water-dependent structures (e.g., piers and boat houses) and older pre-FIRM residences. On the west end of Dauphin Island, the storm surge and waves were several feet higher than the mapped BFEs. Post-FIRM houses failed when piles that were not sufficiently embedded were impacted by storm surge, waves, and erosion.

Louisiana: The areas of greatest surge impact in Louisiana were the southeast open Gulf Coast, in particular St. Bernard, LaFouche, and Plaquemines Parishes, and the parishes surrounding Lake Ponchartrain. The surge and waves from Hurricane Katrina caused widespread destruction in these areas, especially where the storm surge and wave crest elevations exceeded mapped BFEs.

In the City of New Orleans, unprecedented flooding occurred when levees that protect the City from Lake Pontchartrain failed. The BFEs in the levee-protected areas of the City were based on the USACE certification that the levees would provide protection from the 100-year (base flood) event. As a result, the FIRMs do not include flooding effects from water bodies on the non-protected side of the levee, such as Lake Pontchartrain; SFHAs in the levee-protected areas reflect only flooding from precipitation that falls on and accumulates inside these areas.

When the levees failed, water levels in the City exceeded the mapped BFEs by many feet in some areas. Flooding caused severe damage to both pre-FIRM and post-FIRM buildings in the levee-protected areas, with flood depths in some neighborhoods more than 8 feet above the lowest floor.

Mississippi: Along the Mississippi Gulf Coast, many recent buildings that were apparently constructed in compliance with the minimum requirements of the NFIP failed due to storm surge and wave crest elevations that far exceeded the mapped BFEs. Water marks and building damage throughout the region, especially in Hancock and Harrison Counties, show that surge/wave crest elevations along the shore were in the range of 25 to 30 feet NAVD, while BFEs shown on the effective FIRMs were generally 11 to 15 feet NGVD.[7]

2.1.2 Long-Duration Flood Impacts in the New Orleans Area

The New Orleans Flood Team conducted ground inspections throughout the New Orleans area, including the City of New Orleans and Orleans Parish, as well as the nearby communities of Chalmette in St. Bernard Parish and Metairie in Jefferson Parish. The Flood Team visited a total of 23 residential buildings and critical facilities in the New Orleans area on October 4-8, 2005. The focus of the site inspections for the Flood Team was to assess and evaluate opportunities for flood restoration. Based on the preliminary investigation, it was determined that contamination of building materials would be a major issue in the restoration process.

Characterization of Flooding in the New Orleans Area

With the three levee failures, there was widespread flooding throughout the City of New Orleans and surrounding areas, with up to 80 percent of the City under water. The depth of flooding within the Greater New Orleans area varied greatly, as did damage to structures. Elevated areas by the Mississippi River and the high ground along Lake Pontchartrain between the 17th Street Canal and the Industrial Canal were essentially free of flooding. Although there were reports of flood depths in excess of 12 feet, most of the flood depths ranged from less than 1 foot to a depth of 8 feet. In all areas affected by flooding resulting from Hurricane Katrina, property elevation was the key difference in the magnitude of damage. In areas of New Orleans that were at the same grade elevation, buildings elevated on crawlspaces generally sustained less flood damage than slab-on-grade buildings.

> ### Pre-FIRM and Post-FIRM
>
> As used in this report, 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. Post-FIRM buildings should have been designed and built in compliance with the NFIP's minimum floodplain management standards.

2.1.2.1 Characterization of Building Damage in New Orleans

Impacts to Residential Buildings

Widespread flood damage to residential neighborhoods occurred throughout the New Orleans area as a result of the levee floodwall failures. Floodwaters remained in most New Orleans neighborhoods for approximately 2 to 3 weeks after the failures. Most one- and two-family dwellings the MAT observed were constructed on vented crawlspaces or slab-on-grade foundations with wood framed walls covered by brick veneer.

Structural Damage: In general, most of the residential buildings in the City of New Orleans did not experience structural damage, but were impacted by high flood levels. The flooding experienced by most

7 NGVD (National Geodetic Vertical Datum of 1929) is the national datum used by the NFIP in this area. The difference between NAVD 88 and NGVD is <0.3 feet.

buildings was slow-moving, which greatly reduced or eliminated the damaging effects of hydrodynamic forces and floodborne debris impacts on buildings. Additionally, the crawlspaces, foundation vents, and other openings allowed hydrostatic pressures on walls and floors from floodwaters to equalize as floodwaters slowly rose and receded, which greatly reduced the net hydrostatic force on load-bearing walls, floors, and other structural elements.

Four exceptions were observed:

- The failure of the Industrial Canal and overtopping of coastal levees produced severe flooding, which caused structural damage to buildings in eastern New Orleans and St. Bernard Parish. The most severe structural damage in these two areas was evident in the Lower Ninth Ward of New Orleans and Chalmette in St. Bernard Parish. The Flood Team did not perform detailed structural analyses of the buildings, since their purpose was to assess restoration opportunities.

- Residences sited immediately behind failed sections of levees or other flood control structures suffered significant structural damage, failure of load-bearing walls, and excessive scour around slab foundations. The damages were caused by large hydrodynamic forces and floodborne debris impacts that were generated by the levee breach.

- Residences sited on poor foundation soils suffered structural damage, and cracking of load-bearing walls and sagging floors due to subsidence or differential settlement of saturated soils that support one or more foundation walls and/or piers.

- Moisture readings taken inside various residential buildings indicated that excess moisture remained trapped in the walls and floors following the flood. Continued entrapment of moisture within the wall and floor systems due to a lack of drying could induce rotting of the structural framing in the long term.

Non-Structural Damage: Typical flood damages to residential buildings included damaged or destroyed interior drywall, plaster, fiber insulation, flooring, wall finishes, carpets, furniture, electrical wiring, and HVAC systems. Mold growth observed in flooded residences varied from light to extensive (refer also to Section 2.1.2.2).

Visual observations of interior walls of both older (more than 50 years old) and newer (less than 5 years old) residential buildings showed little to no evidence of deterioration of the exposed portions of the wall studs due to long-duration flood exposure, except for some water staining and slight bowing of some sheathing boards.

Impacts to Critical Facilities

Widespread flood damage to critical public facilities occurred throughout the New Orleans area. Most critical facilities observed by the MAT were constructed on slab-on-grade foundations with wood framed or masonry walls covered by brick veneer or stucco.

Structural Damage: Only minimal structural damage was observed in the majority of critical facilities in New Orleans as a result of flooding from Hurricane Katrina. There were occasional instances of moderate to heavy structural damage to load-bearing walls or columns from boats and other vehicles that struck the buildings during post-storm rescue operations or evacuations. While most of the observed structural damages triggered by impact from rescue vessels did not constitute an imminent danger of collapse, such damages typically require analysis by a structural engineer and can be expensive to stabilize and repair.

Visual observations of interior walls of selected critical facilities indicated little to no evidence of deterioration of the exposed portions of the structural wall studs due to long-duration flood exposure, except for some water staining. Continued entrapment of moisture within the wall and floor systems could induce rotting of the structural framing in the long term.

Non-Structural Damage: Typical flood damages to critical facilities included damaged or destroyed interior drywall, plaster, fiber insulation, metal studs, flooring, wall finishes, carpets, and equipment. Mold growth observed in flooded critical facilities was light to moderate, depending on the depth of flooding, the type of interior wall finishes, and the amount of drying that occurred after the floodwaters receded.

Several fire stations in New Orleans suffered flood damage to garage bay doors. Many New Orleans hospitals suffered interior damage, such as collapsed drop ceilings due to a loss of emergency power generators, which shut down HVAC systems used to control temperature and humidity.

2.1.2.2 Biological and Chemical Contamination of Building Materials

The long-duration flooding caused homes and businesses in the areas that were inundated by floodwaters to become contaminated with biological and chemical substances, including bacteria, mold, heavy metals, petroleum hydrocarbons, and pesticides.

Mold and contaminants can pose a risk to residents. To determine if contaminants were present in structures after the floodwaters receded, selected buildings in flood-impacted areas were visually inspected and samples of materials were collected from the buildings. The samples were analyzed for a number of biological and chemical contaminants. Analytical parameters were chosen following a review of U.S. Environmental Protection Agency (EPA) data regarding floodwater contaminants in the New Orleans area.[8]

Biological Contamination

Bacterial Contamination: Environments where building materials have been wet for more than 7 days, or where the source of the water was impacted by sewage, pose the most risk for potential bacterial contamination. Gram Negative Bacilli (e.g., E. coli, Salmonella) dominated the sample results. Samples dominated by this bacteria type generally indicate contact with sewage or animal feces. These bacteria often cause stomach problems, dehydration, internal and skin infections, and respiratory difficulties in exposed individuals. Standard flood response activities, such as pumping or mopping water and agitating the air, can put restoration workers and occupants at risk, while simultaneously contaminating areas of the building that were previously not affected. However, following proper protocols for personal hygiene and cleaning procedures for buildings should minimize risk of infection.

A total of 47 material samples taken from nine facilities were analyzed for bacterial growth. Bacterial contamination was found in most of the structures and typically ranged from high to extreme (high: 1,000 – 20,000 colony-forming units per square centimeter [cfu/cm^2]; extreme: 20,000+ cfu/cm^2).

Fungal Growth (Mold): Fungal growth and contamination is a secondary health risk following flooding; the floodwater acts as a source of moisture, wicking into materials by capillary action, and stimulating fungal growth. Substantial fungal contamination was observed in all of the inspected facilities. A total of 44 material samples taken from nine facilities were analyzed for fungal growth. In most cases, the fungal types detected in the samples were dominated by Aspergillus/Penicillium or Chaetomium; various strains of these fungal types are linked to health problems, primarily skin irritation and respiratory distress.

Chemical Contamination

Heavy Metal Contamination: Forty-four material samples were analyzed for 13 priority element pollutants designated in the Clean Water Act. The 13 elements (which are all heavy metals) are antimony, arsenic, beryllium, cadmium, chromium, copper, lead, mercury, nickel, selenium, silver, thallium, and zinc. A wide variety of heavy metal contamination was observed in the samples collected. In some of the samples, concentrations of heavy metals exceeded

8 For a detailed description of sampling and analytical methods, refer to the MAT report *Hurricane Katrina in the Gulf Coast: Building Performance Observations, Recommendations, and Technical Guidance* (FEMA 549, 2006).

Louisiana's Risk Evaluation/Corrective Action Program (RECAP) action levels for soil.

High levels of heavy metals could pose a health hazard to individuals exposed to the contaminants during cleanup. The potential for inhalation and ingestion of the metals exists particularly for the building owner or contractor performing restoration. This exposure is potentially much more serious for children, where hand-to-mouth activity is greater and the smaller body mass means that small amounts of heavy metal contamination can have a greater negative impact.

Diesel Range Organics (DROs): All 35 samples analyzed for DROs had measurable quantities of DROs, with concentrations ranging from 18,000 to 3,100,000 micrograms per kilograms (µg/kg) of hydrocarbons. Many of these samples far exceeded the RECAP action level for DROs of 65,000 µg/kg. The highest concentrations were found in wallpaper and sludge samples. From a health standpoint, DROs in building materials can impact individuals in two ways. First, skin irritation commonly occurs with frequent contact. Second, and more importantly, the organics in DROs may liberate pesticides trapped in other building materials.

Pesticide Contamination: Older pesticides, such as dichloro-diphenyl-trichloroethane (DDT) and chlordane, are generally oil-soluble organochlorine compounds that are not as water soluble as newer organophosphate pesticides. Historically, pesticide applications for termites generally involved applying a barrier of organochlorine pesticides into the soil surrounding a building. Depending on the size of the property, it was not unusual to apply 100 gallons or more of the insecticide.

Measurable levels were found in 74 percent of the 35 samples analyzed for organochlorine pesticides, despite the fact that organochlorine pesticides were banned in the United States over 20 years ago. Chlordane was the most consistent contaminant in the samples analyzed, with levels as high as 17,000 µg/kg (along with an additional 2,100 µg/kg of alpha-chlordane and 2,900 µg/kg of gamma chlordane on the same sample). Chlordane levels in the hundreds and thousands of µg/kg were common; many of these levels exceeded the RECAP action level for chlordane of 1,600 µg/kg.

Results indicate a relationship between the age of the house and chlordane levels. Older houses, more likely to be originally protected with chlordane, showed higher levels of chlordane, while newer houses generally had much lower levels. Because the major route of entry for chlordane is absorption through the skin, there is potential for exposure to people working to demolish or renovate flooded structures.

PCBs: Polychlorinated biphenyls (PCBs) are long-lasting chemicals often used as transformer oils and in other industrial processes. Because they are carcinogens, exposure to PCBs has been documented to cause long-term health problems. However, no PCBs were detected in any of the 35 samples collected and analyzed.

2.1.3 Structural Performance

The performance of structural systems was closely tied to the severity and variability of the storm surge, erosion, and wave and debris impacts. As typically is the case, older, low-elevation buildings were the most likely to be flooded and more severely damaged. Structural damage was less in areas where flooding was near or below the design conditions. The MAT also observed differences in building damage based on the structural system and foundation type employed.

2.1.3.1 Residential Buildings

Single-family and other light-frame buildings are generally incapable of resisting coastal flood loads and, are therefore, designed to avoid those flood loads through elevation above the design flood level (including wave effects) and by limiting flood loads to the building foundation. In coastal areas, foundations must be designed to resist wave forces, wave-induced erosion and localized scour, and floodborne debris, all of which can threaten the stability of the foundation (and therefore the building). Thus, foundation type can make a significant difference in the ability of a structure to resist a variety of flood conditions and flood loads. Where Katrina's storm surge level exceeded the lowest floor level and where waves were present, virtually all of the buildings were destroyed or heavily damaged, regardless of foundation type. However, some foundation types exhibited clear advantages during Katrina, such as those buildings constructed with foundations that are integral to the structural building frame.

Low-rise, multi-family, residential buildings were constructed on the same types of foundations used for single-family houses. Performance of these buildings during flooding was also similar to single-family houses. Katrina's high surge levels completely destroyed apartment buildings constructed on slab foundations.

Pile Foundations: Deep pile foundations are generally the most effective choice on barrier islands and open bay shorelines where waves, high velocity flow, and storm-induced erosion and scour are anticipated, as long as the top of the pile foundation is at or above the wave elevation. Where Katrina's storm surge and waves exceeded the first floor elevations of pile-supported buildings, building destruction or significant building damage usually occurred.

Where Katrina's storm surge and waves were below the building's first floor elevation, pile foundations consistently supported a wide-range of small building designs. Slender cross-section piles minimize the wave force transferred to the elevated building up to the point where the wave height reaches the floor beams and joists. The most commonly observed piles were wooden, but piles made of concrete and other materials were also observed.

To perform successfully, piles must be adequately embedded. Where piles were not adequately embedded, pile foundation failure occurred and resulted in destroyed or missing houses or racked piles and leaning buildings (see Figures 2-1 and 2-2).

Figure 2-1.
Successful example of well-elevated and embedded pile foundation following Katrina. Note adjacent building failures where foundations were not high enough or where pile embedment was insufficient (Dauphin Island, Alabama).

Figure 2-2.
House that nearly failed due to insufficient pile embedment (Dauphin Island, Alabama)

Erosion compounded the stress from the surge and caused pile foundations that were not adequately embedded to fail even when the surge did not exceed the first floor elevation. On Dauphin Island, Alabama, more pile-supported houses were destroyed by Katrina (108) than by Hurricane Ivan (17). Two-thirds of the 150 houses on the far west side of the island were totally destroyed and many of the remaining houses were significantly damaged. Many of these homes were not flooded to the first floor level. The failure of the pile systems was likely due to erosion and loss of foundation support from successive storms (Hurricanes Ivan, Dennis, and Katrina) that made the buildings more susceptible to pile failure.

Foundations Integral with Structural Frames: Residential buildings that survived Katrina's worst storm surge and wave conditions typically had heavier-than-normal open foundations that were part of the structural frame, with the frame extending above the lowest floor and, in some cases, to the roof. Examples of other surviving buildings that had foundations that are integral to the structural frames include steel frame buildings in Mississippi that survived storm surge and wave action above the first floor level, wood frame buildings along Mississippi's Jourdan River, and houses with reinforced concrete frames and walls in Long Beach, Mississippi. These houses, though heavily damaged, survived next to destroyed houses on slab foundations or houses on elevated piers or piles that had first floor elevations below the wave elevation.

Masonry Pier Foundations: Masonry piers were the most common foundation type used to elevate small buildings above grade in Louisiana and Mississippi. When properly designed and constructed, these piers were effective foundations as long as storm surge and waves remained below the floor beam and floor system components, and as long as erosion did not undermine the shallow foundations. As with pile foundations, when Katrina's storm surge and even small waves exceeded the pier height and impacted the elevated building, damage was severe (see Figure 2-3). Losses of houses elevated on piers 9 to 12 feet above grade were widespread across coastal Louisiana and Mississippi near the Gulf and around larger bays.

Figure 2-3.
Typical building failures when surge and waves exceeded pier foundation height (Long Beach, Mississippi)

Information provided by local contractors and designers suggested that some of the masonry pier and concrete slab foundations observed by the MAT could have incorporated grade beams with reinforced concrete masonry unit (CMU) columns. Grade beams and discrete columns (with or without slabs at grade) provide a good foundation option for areas where little scour and erosion are anticipated during a design flood. The addition of grade beams to a pier foundation provides increased resistance to lateral loads and overturning moments.

Common pier failures observed by the MAT were due to a combination of factors such as insufficient reinforcement (size or number or placement of bars) or inadequate splicing, shallow footings, or poor connections between the pier and the footing. Failures usually took the form of pier breakage or pier separation from the footing (see Figure 2-4).

The MAT also observed instances where lateral flood and wind forces acting on the building caused failure in the connections between the piers and the building before the foundation itself failed. Pier performance was best in flood conditions where erosion was minimal and waves were small. However, when the flood elevation exceeded the floor elevation, buoyant forces acted on the buildings and, in conjunction with lack of adequate uplift anchoring in floor framing, caused some buildings to float off of their pier foundations.

For example, 19 of 32 new houses in a Pass Christian subdivision (approximately 1 mile from the Gulf shoreline) floated off of their pier foundations due to flood heights of approximately 8 feet above the BFE and poor connections between the building and the floor beams or the floor beams and the piers (see Figure 2-5). Buildings that remained attached were flooded to approximately 8 feet above the floor elevations, but received minimal structural damage and appeared repairable.

Figure 2-4.
Pier connection failure (Belle Fontaine Point, Jackson County, Mississippi)

Foundation and Structural Frame Success

In an example of timber pole-type construction, the wave heights exceeded the elevated floor level by about 4 feet, lateral waves destroyed walls, and wave uplift damaged floors; however, the upper portion of the structure and the roof remained connected due to the nature of the foundation and structural frame.

Storm surge and waves reached at least 4 feet (red line) above the elevated floor (Waveland, Mississippi).

Wave damage to floors and walls, but pole construction left a repairable, surviving building.

Figure 2-5.
Buildings floated off of pier foundations (Pass Christian, Mississippi)

Slab-on-Grade Foundations: Slab-on-grade foundations were very common in coastal Louisiana and Mississippi, especially for pre-FIRM buildings, and for post-FIRM buildings where the ground elevation was above the mapped BFE. Buildings constructed with slab-on-grade designs were severely damaged when floodwaters and waves reached above the slab. Where storm surge exceeded the slab elevation by more than about 3 feet and where breaking wave heights are believed to have exceeded 1.5 feet, wave damage to load-bearing walls resulted in severe building damage or total loss. As an example, in Biloxi, Mississippi, high surge elevations and floodborne debris impacts caused total destruction of buildings supported on slab-on-grade foundations (see Figure 2-6).

Figure 2-6.
Waves, surge, and floating debris destroyed many single-family homes on slab foundations. Note the debris from houses that washed landward into other buildings (Biloxi, Mississippi).

Elevation Success

This house in Lacombe, Louisiana, was elevated above the flood depths associated with Katrina using FEMA mitigation grant funding. Note the estimated water line associated with Hurricane Katrina (red line).

Stem Wall Foundations: Stem walls typically use a masonry wall to contain and elevate compacted fill, which, in turn, supports a slab. The higher elevation above surrounding grade makes the foundation preferable to a slab-on-grade, and adds a safety factor against local stormwater flooding. Stem wall foundations are frequently used to meet the elevation requirements when the BFE is several feet above grade. Similar to buildings with slab-on-grade foundations, buildings with stem wall foundations experienced severe damage when flood levels and wave heights exceeded the top of the slab (see Figure 2-7). As with other shallow foundations, stem wall foundations are susceptible to undermining due to erosion or localized scour.

Figure 2-7.
Stem wall foundation survived intact, but waves and surge above the floor destroyed the house, sweeping it off the foundation (Waveland, Mississippi).

Manufactured Housing: Many of the manufactured homes that experienced damage were separated from their foundations or the foundations shifted. Foundation type tended to affect whether manufactured homes were displaced from their foundations. Manufactured homes placed on, and secured to, poured concrete foundations generally remained intact (although with flood damage from inundation). Homes placed on dry-stacked or unmortared piers and secured with helical ground anchors were often pushed off of their foundations by floodwaters and destroyed.

2.1.3.2 Low-Rise Commercial Buildings

A wide variety of commercial buildings experienced flooding and severe damage from the storm. These buildings included downtown storefronts in the older business districts, stand-alone food service/resort retail businesses, motels, churches, seafood handling/processing facilities near the harbors, strip malls, and larger retailers. No type of commercial building constructed on slab foundations near the coastline escaped damage when the storm surge or wave elevations exceeded the first floor levels (see Figure 2-8).

Figure 2-8.
Steel frame strip mall construction with exterior wave damage (Gulfport, Mississippi)

Elevation Success

This building in Mandeville, Louisiana, was relocated from New Orleans for use as a restaurant. The local building inspector recommended the elevation seen here, which protected this building from flood damage. Note the estimated flood depth in relation to the first floor (red line).

2.1.3.3 High-Rise Buildings

The MAT observed generally good structural performance of high-rise buildings located near the Gulf shoreline. The buildings observed included casinos/hotels, office buildings, and condominiums. High-rise foundation systems were generally not impacted by storm surge and wave impacts due to their location on high ground and building elevations. As an example, a high-rise building in Gulfport was sited on higher ground with a lower level office floor at elevation 20 feet NGVD. The cast-in-place concrete shear walls, aligned perpendicular to the shoreline, allowed waves to pass through the lower level, only damaging the office and other non-structural walls on the ground floor. The higher floors were undamaged (see Figure 2-9).

Some of the high-rise casino hotels and condominiums close to the shoreline experienced some of the worst storm surge depths and wave heights. The foundation stability of the large buildings was not affected; most were cast-in-place, reinforced concrete. Although sited near the shoreline and experiencing the worst flood conditions, the high-rises were some of the better examples of successes. However, some of the high-rise casino hotels were damaged when adjacent casino barges were pushed into them by storm surge (see Figure 2-10).

Figure 2-9.
High-rise buildings along Beach Boulevard received non-structural flood damage to the lower floor, and no apparent flood or wind damage to higher residential floors (Gulfport, Mississippi)

Historic Building Success

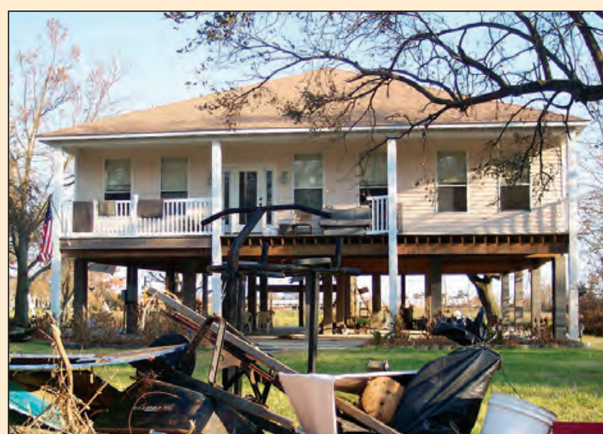
This 100-year-old building on the National Register of Historic Places sustained minimal flood damage due to elevation on taller piers (an architectural choice, not a requirement when the building was constructed in 1905). Note the estimated flood depth in relation to the first floor (red line) (Mandeville, Louisiana).

Figure 2-10.
Parking deck collapse due to impact by casino barge, on left (Biloxi, Mississippi)

Regulatory Standard Success

Following Hurricane Georges in 1998, the City of Pascagoula, Mississippi, established an elevation standard higher than the BFEs stated on the community's FIRMs. In some cases, this represented up to a 5-foot increase above mapped BFEs. As a result, buildings impacted by Hurricane Katrina that were built to this standard suffered less flood damage than older housing built to lower elevation requirements. According to the effective FIRM at the time of Hurricane Katrina, the building is located in Zone V with a BFE of 12 feet.

This photo was taken pre-Katrina c.1999/2000. Note the "Build Safe!" sign in front yard (circle), (Pascagoula, Mississippi).



This photo was taken post-Katrina, illustrating the survival of this elevated building.

Wind Retrofit Success

Ocean Springs Middle School in Ocean Springs, Mississippi, was awarded FEMA mitigation grant funding in September 1998 for the installation of roll-down storm shutters on all exterior classroom windows to protect students and faculty in the event hurricane-force winds should affect the area. The school was used as a shelter during Hurricane Katrina for as many as 400 people. Following Hurricane Katrina, the MAT observed only minimal damage to the facility. In addition to the use of the storm shutters, other windows on the building were observed to have polycarbonate glazing.

2.2 Wind Hazard Observations

According to the National Weather Service (NWS) December 20, 2005, report, Hurricane Katrina made landfall in Buras, Louisiana, with an estimated 1-minute sustained wind speed of 110 knots (127 mph) or approximately 150 mph 3-second gust. After landfall in Louisiana, Katrina traveled almost 100 miles across the Louisiana Delta before reaching the Mississippi coast where it made a third landfall (one in Florida and two in the Gulf) near Poplarville, Mississippi. The National Weather Service (NWS) estimated 1-minute sustained surface winds of 105 knots (120 mph) or approximately 145 mph 3-second gust.

The estimates were higher than any recorded by land-based instruments. The highest land-based wind speed recorded was 117 mph (3-second gust) from a Texas Tech University tower located at the Stennis International Airport, approximately 8 miles west-northwest of Bay St. Louis, Mississippi. However, like many previous storms the MAT has investigated, ground-based anemometers either failed before they recorded maximum winds or were located great distances from the storm's path. As a result, no wind speed instruments likely recorded the maximum winds produced by Katrina.

To help fill in the gaps that exist in ground-based wind data, wind speeds are estimated using a variety of methods. One of the better known products for representing hurricane winds is H*Wind from the National Ocean ic and Atmospheric Administration (NOAA) Hurricane Research Division (HRD).

H*Wind is an experimental research product developed by the HRD. H*Wind employs estimates of surface level winds obtained from a variety of sources and yields near real-time analyses of the surface winds produced by tropical cyclones. Based on past experience of comparing modeled estimates with actual recorded wind speeds, H*Wind provides reasonably accurate estimates of maximum wind speeds over large areas impacted by a storm. Contours of 1-minute sustained wind speeds from Katrina were developed utilizing the H*Wind model by HRD.

FEMA's wind model used in HAZUS-MH (Hazards U.S. - Multi-Hazard) is also used to estimate wind speeds. HAZUS was developed as a loss estimation model, but produces reasonable estimates of maximum speed and the lateral distribution of wind. Wind swath contour plots based on HAZUS-MH methodology were modeled by Applied Research Associates (ARA) (see Figure 2-11). ARA's model uses a series of surface level observations of wind speeds and pressures obtained from portable towers, from buoys, and from Automated Surface Observing Systems (ASOS) stations to obtain estimates of the time variation in the storm's radius to maximum winds and the Holland B parameter (a function of the shape of the storm). Measured wind speeds are adjusted to "standard conditions" (that is 10 meter instrument height in open terrain) using either estimates of the surrounding roughness from aerial photography or from estimates of the turbulence intensity where full digital time series are available. The variation of the Holland parameter B is used with NHC position and central pressure estimates and pre-computed solutions of a numerical hurricane model to develop estimates of wind speeds as a function of time and location.

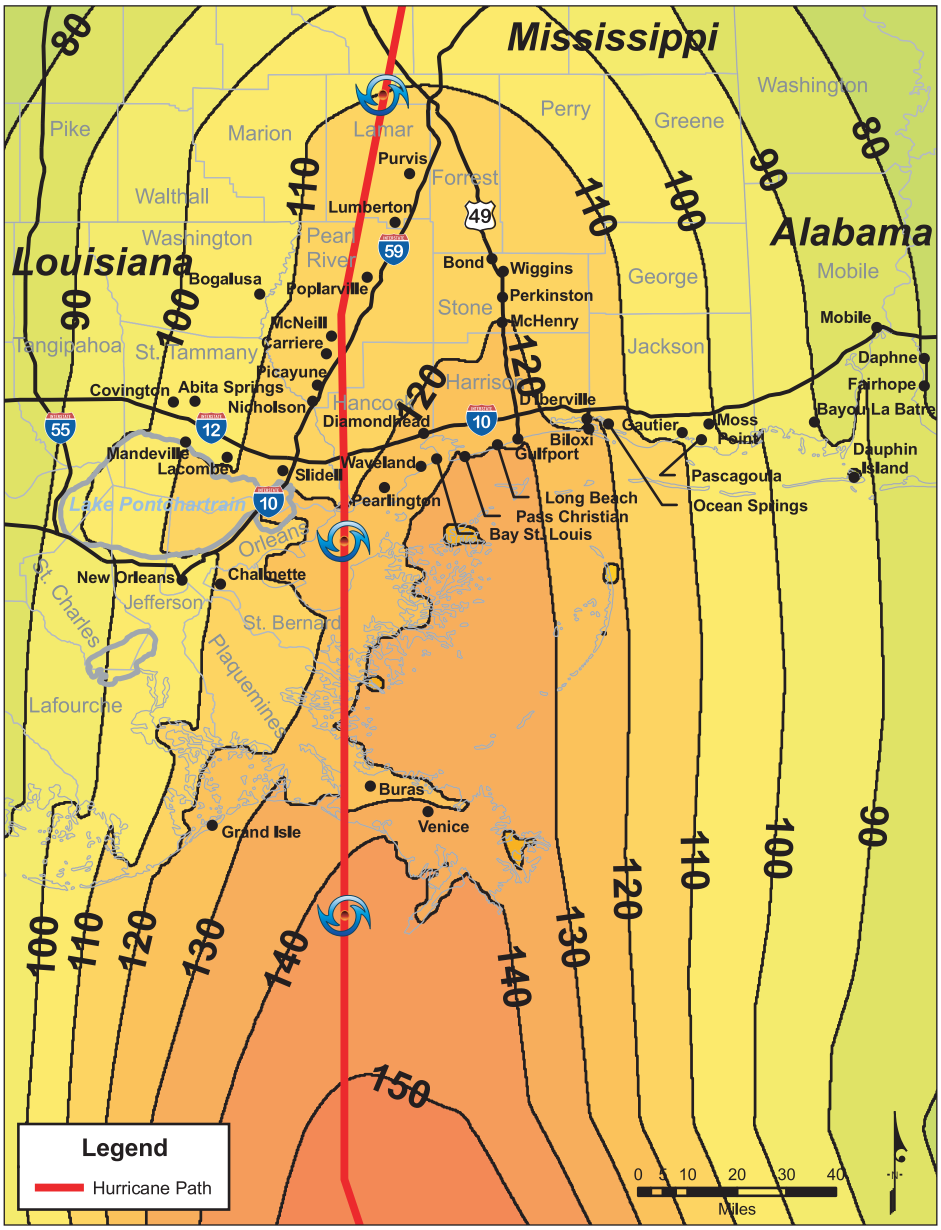


Figure 2-11.
Wind swath contour plot of 3-second gust wind speeds in mph at a height of 10 meters above ground (open exposure) based on HAZUS-MH wind field methodology.

SOURCE: ARA

In the case of Hurricane Katrina, there was very little wind speed and pressure data inland and, as a result, estimates of wind speeds farther inland have greater uncertainty than those near the coast. Comparisons to anemometer data suggest the model has an uncertainty (estimated using the standard deviation of the observed minus modeled winds speeds) of about 6 percent, indicating that in most cases the modeled wind should be accurate to about 10 percent or better.

With Katrina, wind speeds generated by the HAZUS model and those estimated utilizing the H*Wind results compare favorably to each other. Also, both methods suggest that, except for a few areas along the Mississippi coast, Katrina's winds failed to reach the design wind speeds specified by ASCE 7 (the wind standard referenced by the latest building codes).

The modeled wind speeds also generally correlate with damages observed by the MAT, particularly when the model results are adjusted for exposure (HAZUS and H*Wind depict wind speeds in Exposure C (open terrain) areas; most of the MAT observations were in the more protected Exposure B areas). Exceptions to this general correlation occurred in some areas east of Gulfport and north of Picayune. In those areas, HAZUS predicted higher wind speeds than what the observed ground-based damages would appear to support. For example, HAZUS predicted wind speeds in Biloxi only 5 mph less than Bay St. Louis, but the observed wind damages in Biloxi were significantly less than those in Bay St. Louis. Also, HAZUS predicted 115 mph Exposure C wind speeds in Poplarville, but the damages observed in that area were more typical of lower wind speeds. The apparent lack of correlation between ground-based damage observations and the computer models in these areas may result from terrain effects, from construction variations, or from the uncertainty of the computer models.

Much of the wind-based damage from Hurricane Katrina occurred in areas where the wind speeds were well below the design levels specified in the latest codes. In discussing wind damage, it is important to differentiate between structural damage and building envelope damage. Many buildings experienced little or no structural damage, but may be total losses due to water entry that resulted from building envelope failure. It is also important to differentiate between the design wind speeds and their resulting design pressures specified by the latest code and the design wind speeds/pressures specified by the older codes that were in effect when many of the buildings the MAT investigated were constructed. In many areas, the design wind pressures specified in current codes are higher than those specified in older codes.

2.2.1 Structural Performance

Common types of structural damage included roof decking blow-off; gable end wall failures; collapse of unreinforced, load-bearing masonry walls; and purlin and moment frame failure of older (pre-1980) pre-engineered metal buildings (PEMBs). Damages were observed on all types of buildings, with older residential and commercial buildings generally affected the worst. Some of the key observations about the structural performance of various building types follow.

2.2.1.1 Wood Frame Buildings

Most of the wood frame buildings observed by the MAT were residential buildings (both single-family homes and low-rise apartment buildings), but some commercial buildings were also wood frame structures. The predominant structural damage to these types of buildings was failure of wall and roof elements. Failures were observed in both new and old construction. Insufficient attachment of roof sheathing panels to the supporting framing was the most common problem. Once the sheathing attachments fail, a variety of other failure modes can occur. Attics that have been breached become pressurized and other structural elements may then become overstressed. This can lead to an “unzipping” effect or progressive failure where one failure leads to a series of subsequent failures. Wood frame commercial buildings failed similarly to wood frame residential buildings. Figures 2-12 and 2-13 are examples of wind-related failure in residential and commercial buildings.

Figure 2-12.
Failure of the gable end wall of this apartment building led to pressurization of the attic and the release of sheets of plywood sheathing. Note the plywood roof sheathing “unzipped” by wind pressures (arrows), (Ocean Springs, Mississippi).

Figure 2-13.
Failure in a wood frame commercial building. Trusses lost roof sheathing, allowing trusses to tip over (Ocean Springs, Mississippi).

2.2.1.2 Manufactured Housing

While most of the damage to manufactured housing was from flooding, wind damage was noted in both older and newer manufactured homes. The styles of manufactured home installations impacted performance during Hurricane Katrina. When properly anchored, manufactured home damage under wind loads was less significant. Unanchored or improperly anchored homes or homes with damaged anchors were prone to wind-related damage (see Figure 2-14).

Figure 2-14.
Manufactured home rolled over by Hurricane Katrina’s winds (Chalmette, Louisiana)

2.2.1.3 Reinforced Concrete and Heavy Steel Buildings

In general, reinforced concrete and heavy steel buildings observed by the MAT performed well structurally (see Figure 2-15). While the MAT noted little structural damage to most buildings constructed with reinforced concrete frames, extensive damage to unreinforced masonry buildings was observed.

Figure 2-15.
Reinforced concrete/steel frame building that performed well structurally, but did have some building envelope damage and roof mounted HVAC equipment damage (Gulfport, Mississippi)

Figure 2-16.
Pre-engineered metal building failure (Gulfport, Mississippi)

2.2.1.4 Pre-Engineered Metal Buildings

PEMBs are normally used for purposes such as warehouses, storage facilities, airplane hangars, and other similar open interior uses. Secondary structural members, consisting of girts and purlins, are installed to support the metal siding and roofing panels. Most failures either involved connections between the metal roof panels and their supporting purlins, or between the purlins and the steel moment frames (see Figure 2-16). Connection failures between the base of the moment frames and supporting footings were observed, but were much less common than connection failures higher up in the structure. Several low-rise commercial buildings that sustained significant wind damage were older (generally constructed before 1980) PEMBs. While many older PEMBs were heavily damaged, newer ones performed much better.

2.2.2 Building Envelope

A significant amount of wind-related building envelope damage was observed in Katrina-impacted areas; much of the damage occurred where wind speeds were below current building design levels. Roof coverings, in particular, performed poorly. Only limited use of glazing protection was observed and, consequently, there was also significant damage to building glazing. Damage to building glazing may lead to internal pressurization, resulting in significant structural failures. A significant factor in poor building envelope performance is the secondary damage that can be caused from building envelope failures. When breached envelopes remain open for several weeks, even small breaches can allow a significant amount of water to leak into buildings, damage building contents, and allow mold to develop. Another secondary result of envelope failure is windborne debris. Blow-off of building envelope components and rooftop equipment frequently results in damage to adjacent buildings and vehicles. Common windborne building envelope debris during Hurricane Katrina included roof coverings (particularly aggregate surfacings and asphalt shingles) and vinyl siding. For example, many high-rise buildings in Louisiana and Mississippi suffered substantial glazing damage from windborne roof aggregate.

Some of the key building envelope wind damage observations are highlighted below.

2.2.2.1 Roof Coverings

Damage to roof coverings can cause major building performance problems during hurricanes. Rainwater entering a building through damaged roofs causes significant damage to the building contents and interior. Throughout the areas observed by the MAT, many of the residential buildings had asphalt shingle roof coverings. The vast majority of the observed roofs experienced damage, ranging from loss of a few hip trim shingles or tabs to loss of a large number of shingles and underlayment (see Figure 2-17). Failures of hip/ridge trim shingles and failures along the eaves and rakes were common.

Figure 2-17.
Extensive loss of roof covering and underlayment (Slidell, Mississippi)

2.2.2.2 Wall Coverings

Though there were some observed failures of brick veneers, the most common wall covering damage was to exterior insulation and finish systems (EIFS) and vinyl siding. A large number of EIFS failures were observed on low-rise and high-rise buildings (see Figure 2-18). In addition to puncture by windborne debris, common planes of failure of EIFS assemblies included separation of the synthetic stucco from the insulation, detachment of the insulation from the gypsum board, detachment of the gypsum board from the studs, and failure of the studs.

Figure 2-18.
Multi-story building showing severe EIFS damage. In some areas, the gypsum board on the interior side of the studs was also blown away (Biloxi, Mississippi).

Performance of vinyl siding and soffits was extremely poor. There were numerous significant failures on both new and old buildings throughout the areas observed by the MAT. When vinyl siding was blown off, the underlayment (either asphalt-saturated felt or housewrap) was also often blown away. With loss of the siding and underlayment, wind-driven rainwater was then able to enter the wall cavity, causing water damage and initiating mold growth. High pressures under overhangs and building soffits often lead to progressive structural failures (see Figure 2-19).

2.2.2.3 Glazing

When the MAT observed broken glazing, often only one or a few of a building's windows were broken. This type of isolated damage occurred when there was a limited amount of natural or manmade debris (such as tree limbs or building components) flying in the vicinity of the building. In other instances when the MAT observed broken glazing, a large number of a building's windows were broken. In these instances, the building was pummeled with vinyl siding, asphalt shingles, or aggregate from roofs. Unprotected glazing located down-wind of an aggregate-surfaced roof is very susceptible to breakage due to aggregate blow-off.

At a hospital in Gulfport, approximately 400 windows and spandrel panels were broken by aggregate blown from the hospital's own roofs (see Figure 2-20). A few buildings in downtown New Orleans had extensive glazing damage that was indicative of damage caused by windborne roof aggregate.

Figure 2-19.
Loss of vinyl siding and foam insulation at a gable end wall. Note the missing vinyl soffit (red arrow). Not visible was the loss of roof sheathing caused by progressive failure that was initiated by soffit loss (Long Beach, Mississippi).

Figure 2-20.
The black panels are painted plywood installed after spandrel panels at the Memorial Hospital were damaged by windborne roof aggregate (Gulfport, Mississippi).

2.2.2.4 Rooftop Equipment

The MAT observed many damages to mechanical and electrical devices mounted on the exterior of buildings. Lost equipment included fan units and HVAC units, electrical and communications equipment, and lightning protection systems. There are several effects due to loss of this equipment. In many instances, the displaced equipment left large openings through the roof and/or punctured the roof membrane. Equipment loss often affected the operational functions of the facilities. Blown-off equipment became high-momentum windborne debris in some cases. The equipment observed on critical and essential facilities was not anchored more effectively than the equipment on common commercial buildings (see Figure 2-21).

Figure 2-21.
The equipment on this new Federal courthouse blew away because it was resting on vibration isolators that provided lateral resistance, but no uplift resistance. Two large openings through the roof were left after the ductwork blew away (temporary covers had been placed over the openings).

3. Critical and Essential Facilities Observations

Throughout the Gulf Coast, the poor performance of critical and essential facilities during and after Katrina was widespread. Facilities such as hurricane evacuation shelters, police and fire stations, hospitals, and Emergency Operations Centers (EOCs) were severely damaged and many were completely destroyed. Some facilities experienced loss of function when critical support equipment such as vehicles and communication equipment was damaged or destroyed. While most of the damage to critical facilities was caused by storm surge, high winds also damaged many other facilities.

Most critical and essential facilities did not perform any better than their commercial-use counterparts in areas impacted by wind, storm surge, and waves. Facilities that sustained damage from flooding had not been designed to withstand the level of flooding that occurred. When flood levels exceeded BFEs or the first floor elevations of critical and essential facilities, the buildings were heavily damaged or destroyed.

The majority of wind damage to buildings was to envelope systems and older facilities, although a few structural and new building failures did occur. 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 (see Figures 2-20 and 2-21). Observations about the performance of critical and essential facilities subjected to long-duration flooding in the New Orleans area are presented in Section 2.1.2.1. Figures 3-1 through 3-6 provide additional examples of the performance of critical facilities.

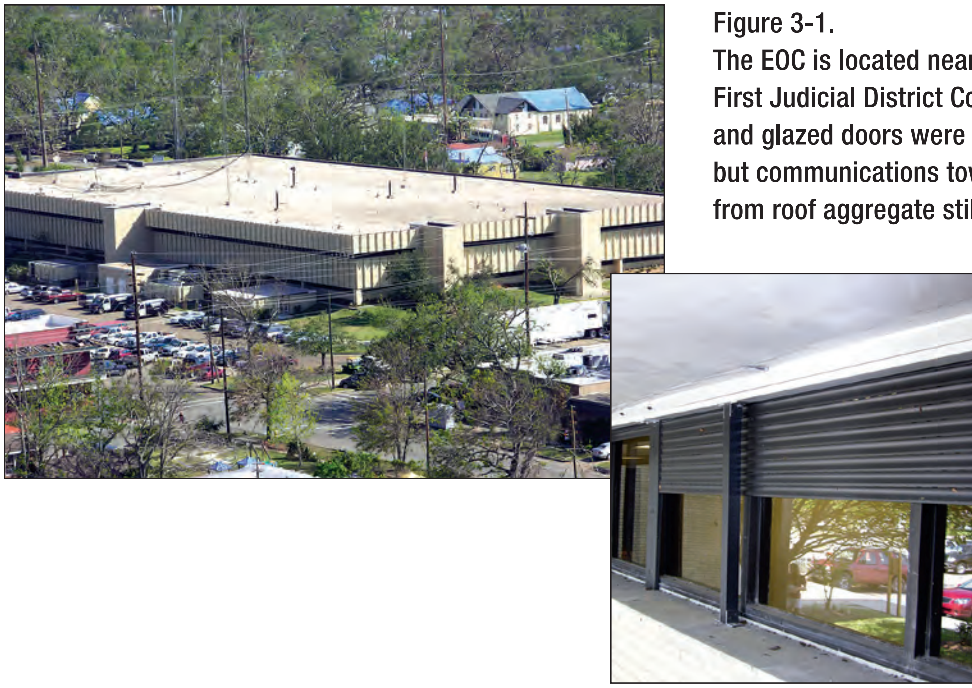


Figure 3-1.
The EOC is located near the center of the first floor of the First Judicial District Courthouse in Gulfport. The windows and glazed doors were retrofitted with roll-down shutters, but communications tower damage and vehicle damage from roof aggregate still occurred (Gulfport, Mississippi).

Figure 3-2.
Newly constructed Gulfport Fire Station 7 destroyed by waves and storm surge (Gulfport, Mississippi)

Figure 3-3.
Police department destroyed by storm surge (Pass Christian, Mississippi)

Figure 3-4.
General view of the Buras Volunteer Fire Department (Buras, Louisiana)

Figure 3-5.
General view of Garden Park Medical Center. EIFS repairs were underway at the time the photograph was taken. The entire fourth floor nursing unit was taken off-line for about 1 month due to water leaks caused by roof membrane blow-off (Gulfport, Mississippi).

Figure 3-6.
Storm surge damage to the St. Bernard Parish Coastal Government Complex (Delacroix, Louisiana)

4. Conclusions and Recommendations

The conclusions and recommendations presented in the MAT report, Hurricane Katrina in the Gulf Coast: Building Performance Observations, Recommendations, and Technical Guidance *(FEMA 549, 2006), are based on the MAT's observations in the areas studied; evaluations of relevant codes, standards, and regulations; and meetings with state and local officials, business and trade associations, contractors, and other interested parties.*

4.1 Flood Hazard Conclusions

As discussed previously, flood levels from Hurricane Katrina throughout parts of the Alabama, Louisiana, and Mississippi coasts were often much higher than the FEMA-mapped BFEs. Flood and wave effects extended well beyond the SFHAs in most communities investigated. As a result, a significant number of buildings inside and outside of the SFHA, were destroyed or heavily damaged.

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

1) The region's storm history, which served as the basis for the effective BFEs, was prepared in the early 1980s. Since that time, numerous storms in addition to Katrina have impacted the area. Consideration of the more recent storms can be expected to significantly increase the BFEs.

2) BFEs in the levee-protected areas of New Orleans were based on the assumption that the levees and floodwalls would protect the surrounded buildings. When developing BFEs, current NFIP standards require that a levee be certified that it has been adequately designed and constructed to provide protection against the base flood. Since the levees protecting New Orleans are USACE-certified, the BFEs for the levee-protected areas of the City (which are currently mapped with BFEs of -1.5 to 4.5 feet NGVD) only reflect flooding from precipitation that falls on and accumulates inside these areas; the BFEs do not include flooding effects from waterbodies on the non-protected side of the levee, such as Lake Pontchartrain. When levees and flood walls were overtopped or failed in Katrina's storm surge, deep water flooding was widespread behind the levees.

Additional damage was attributed to erosion and floodborne debris, and on Dauphin Island, Alabama, erosion and scour were severe. The erosion undermined shallow foundations and piles with shallow embedment. Many areas had been weakened by prior coastal storms, which made the areas susceptible to Hurricane Katrina. The methodology used to develop the FIRMs takes into account the erosion that would likely occur during a single 100-year event. Long-term erosion and the effects of multiple storms that alter the shoreline position or dunes are not considered in the flood maps.

Along the developed shorelines of Louisiana and Mississippi, erosion and scour were occasionally a localized problem but, considering the severity of the storm surge and wave heights, were surprisingly mild. In those areas, the height and rapid rise of the storm surge, and the relatively flat slope of the land appeared to be the factors that likely moderated the erosion.

Floodborne debris and wave damage characteristic of V Zone damage was widespread in A and X Zones in Mississippi. The unprecedented debris and resultant debris field of Hurricane Katrina included shipping containers, lumber, and bulk paper, as well as casino barges that broke from their moorings and severely impacted several buildings. Most of the floating debris field was produced as the storm surge and waves moved inland and progressively destroyed buildings, increasing the speed and severity of damage. However, the debris field eventually reached sufficient proportions in the most heavily damaged areas to function as a floating breakwater, damping the wave heights farther landward, and served to protect the landward areas from even more severe wave damage.

4.1.1 Lowest Floor Elevations

Many of the damaged buildings were pre-FIRM construction and built on slab foundations that do not satisfy current NFIP requirements. Structures next to each other in impacted neighborhoods had varied elevations and buildings that were constructed to the BFE or below (for the pre-FIRM buildings) experienced greater impacts from flood levels, damaging waves, and floodborne debris compared to structures situated well above the BFE.

4.1.2 Foundations and Structures

Structural failure was caused by severe high surge elevations, and wave and debris impacts. In areas subjected to coastal erosion and scour, shallow foundation damage was extensive and the structural failures were dramatic. Overall, since scour and erosion was not a major factor in most areas of Louisiana and Mississippi, newer stem-wall and pile foundations performed well; however, once the flood levels and wave heights exceeded the lowest floor, severe building damage resulted. The only buildings that survived the event were those with high first floor elevations that were constructed with a well-embedded deep pile foundation structurally connected to the building frame or with deep piles that extended from the ground to the roof, or fully-engineered mid- and high- rise buildings elevated on pile, column, or shear wall foundations.

Current NFIP regulations require elevation of V Zone buildings on pilings and columns (i.e., open foundations, which allow water and waves to pass beneath the elevated building). However, the NFIP has allowed some V Zone buildings, particularly mid- and high-rise buildings, to be constructed using some solid foundation walls beneath the BFE. These walls, called shear walls, are necessary to transfer large lateral loads (e.g., wind and seismic loads) from the upper stories into the ground. Use of properly constructed, shore-perpendicular shear walls in these large V Zone buildings has not been observed by the MAT to lead to building damage or failure during coastal flood events. Some one- and two-family residential buildings require elevation above the ground in excess of one story. For these residential buildings, the technical, policy, and financial implications of using shore-perpendicular foundation walls, such as the shear walls used by mid- and high-rise buildings, should be considered. The use of any solid foundation walls beneath a V Zone building will complicate the flood insurance rating process and may lead to substantially higher flood insurance premiums than those for a building supported entirely on piles or columns.

4.1.3 Long-Duration Flood Impacts in the New Orleans Area

The failure of the levee/floodwalls protecting the City of New Orleans led to deep floodwaters and long-duration flooding throughout the levee-protected areas. Directly behind the point of levee failure, some buildings experienced structural failure and were knocked off their foundations when impacted by floodwaters. The majority of the buildings observed in New Orleans, however, did not sustain significant structural damage due to high velocity floodwaters. Most of the impacted buildings had extensive damage to the interior contents and building materials from the long-duration flooding. The long-duration flooding led to moisture entrapment within the walls and floors of flooded buildings, which could impact the structural integrity of building materials over time. The long-duration flooding also caused inundated homes and businesses to become contaminated with biological and chemical contaminants.

4.2 Flood Related Recommendations

The recommendations from the MAT report, summarized in this report, are intended to assist the states of Alabama, Louisiana, and Mississippi; communities; businesses; and individuals in the reconstruction process, and to help reduce future damage and impact from flood and design level wind events. The 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 required. A few of the main recommendations are outlined in the following section; details and additional recommendations are provided in Section 4.6. Refer to the National Institute of Building Sciences (NIBS) *Whole Building Design Guide* for more flood recomdations (http://www.wbdg.org/design/env_flood.php).

4.2.1 Codes and Standards Recommendations

Adoption of modern building codes, such as the IBC, IRC, or NFPA 5000 are recommended. These codes include up-to-date design and construction provisions that are consistent with the NFIP. The IBC and NFPA 5000 incorporate flood load (ASCE 7-05) and flood-resistant construction (ASCE 24-05) standards. The IRC currently does not reference explicitly ASCE 7 and ASCE 24 for flood loads and flood-resistant construction. Thus, it is recommended that communities containing land within the estimated 100-year floodplain shown on the Katrina Flood Recovery Maps use ASCE 7-05 for flood load calculations and ASCE 24-05 for flood-resistant one- and two-family residential construction purposes. Adoption of any model code or standard should keep intact the minimum criteria established by the parent or expert document such as ASCE 7 or ASCE 24.

4.2.2 General Hazard Identification Recommendations

- **Evaluate existing storm surge modeling**: Review the storm surge data and modeling procedures that served as the basis for the effective FIRMs. Conduct a revised tide frequency analysis, update storm climatology for the area, and use modern storm surge models to estimate the BFEs throughout the Katrina impact area.

- **Katrina Flood Recovery Maps:** As an interim approach (pending completion of coastal flood restudies), adopt the ABFEs and flood hazard areas shown on the Katrina Flood Recovery Maps. This approach is preferable to adding freeboard within the SFHA on the pre-Katrina effective FIRM, since the latter approach does not address known flood hazards outside the mapped SFHA.

- **Re-evaluate the hazard identification/mapping approaches in coastal flood hazard zones:** Re-evaluate and revise the methodology used to determine flood zones and flood elevations in coastal areas.

  - Consider post-hurricane investigations that reveal damage to A Zone type structures exposed to less than 3-foot waves. Consider adoption of the 1.5-foot breaking wave height as the basis for requiring V Zone type building standards (the distinction currently is based on a 3-foot breaking wave height).

  - Revise coastal flood hazard identification/mapping procedures to consider future conditions and incorporate them into flood hazard identification and mapping. The future conditions should include the effects of long-term erosion, wetland loss, sea level rise, and subsidence.

- **Revise flood hazard mapping procedures and maps for areas behind levees:** Refer to Section 4.2.3 for recommendation.

- **Develop "What If" Maps**: Maps should be developed that illustrate the effects of various disaster scenarios, such as floods that exceed design levels. These maps, to be developed by state or local agencies, can help educate local officials and the public, and can be used as a planning and decision-making tool. Coordination of "what-if" mapping with local mitigation strategies and evacuation planning will be required.

4.2.3 Long-Duration Flooding Impact Recommendations

In order to adequately portray the risk to buildings within levee-protected areas, the guidance and procedures for hazard mapping in areas protected by levees need to be re-evaluated. Specific recommendations include:

- **Revise flood hazard mapping procedures and maps for areas behind levees:** As guidance in carrying out the requirements of 44.CFR 65.10, FEMA issued an August 22, 2005, memo titled "Procedure Memorandum No. 34 – Interim Guidance for Studies Including Levees," (FEMA, David I. Maurstad, August 22, 2005) for immediate implementation. This memo provides guidance and standards in properly identifying flood hazards in areas possibly protected by levees. The procedure includes working with local entities responsible for levees to determine the accreditation of the levee providing flood protection. If a levee is not accredited, the area behind the levee will be identified as SFHA and will reflect the actual BFE. A copy of the memo is included in *Hurricane Katrina in the Gulf Coast: Building Performance Observations Recommendations, and Technical Guidance* (FEMA 549, 2006).

- **Consider future conditions:** Revise hazard identification and mapping procedures to consider predicted rates of sea level rise and subsidence.

- **Develop "What If" maps for levee-protected areas:** Maps should be developed that illustrate the effects of various disaster scenarios, such as floods that exceed design levels and levee failures. These maps, to be developed by state and local agencies, can be used to: 1) educate local officials and the public, and 2) provide a tool for planning and decision-making. Coordination of "what-if" mapping with local mitigation strategies and evacuation planning will be required.

- **Restoration of Long-Duration Flooded Structures:** Safety precautions (including the use of personal protective equipment) will need to be taken by homeowners and restoration workers during repair and reconstruction work to minimize the health risks from biological and chemical contaminants. To facilitate restoration of flooded buildings, building owners should:
  - Open windows and doors to maximize air flow
  - Remove contents for restoration or disposal
  - Remove porous wall materials, fibrous wall insulation, carpeting, vinyl flooring, and electrical components that were impacted by floodwaters
  - Thoroughly clean and sanitize interior surfaces
  - Allow sufficient time for drying prior to initiating reconstruction activities

For additional details on safety precautions and flood restoration techniques, refer to the FEMA Hurricane Recovery Advisories, *The ABCs of Returning to Flooded Buildings*, and *Initial Restoration of Flooded Buildings*. FEMA Recovery advisories can be found at www.fema.gov/fima/mat/mat_katrina.shtm

4.2.4 Design and Construction Recommendations

It is highly recommended that buildings be constructed to survive flood levels that exceed the base flood design conditions. This can be done by elevating the lowest floor above the BFE (preferably to the ABFE), choosing a foundation that is more resistant to flood forces and erosion, and using flood damage-resistant materials above the BFE.

- Although not mandated by the IRC, use the 2005 edition of the ASCE 24 for flood-resistant design of one- and two-family structures in coastal areas.
- Use ASCE 7-05, Chapter 5, and its associated commentary, for calculating flood conditions and loads during a base flood event. The commentary of the 2005 edition provides updated guidance for characterizing and calculating floodborne debris loads.
- Use the *Home Builder's Guide to Coastal Construction Technical Fact Sheets* (FEMA 499) found at www.fema.gov/fima/mat/fema499.shtm and the *Coastal Construction Manual* (FEMA 55) for additional guidance related to flood- and wind-resistant design and construction.

4.2.5 Foundation Recommendations

- Select and design foundations based on AFBEs shown on Katrina Flood Recovery Maps, not the pre-Katrina FIRMs, until such time that revised regulatory floodmaps become available for the Gulf Coast.
- Elevate the bottom of the lowest horizontal structural member above the BFE in all coastal flood hazard zones (preferably to the ABFE).
- Use the *Recommended Residential Construction for the Gulf Coast: Building on Strong and Safe Foundations*, (FEMA 550) when building new homes in coastal areas. FEMA 550 contains schematic designs for several foundation styles to assist local engineers, builders, and code officials in designing and constructing flood and wind resistant residential foundations. FEMA 550 is being developed with input from the Gulf Coast

Homebuilding Industry and is scheduled to be issued in May 2006.

- The NFIP should investigate the technical, policy, and financial implications of allowing shore-perpendicular foundation walls beneath one- and two- family residential buildings in V Zones where the required lowest floor elevation above the ground is in excess of one story.

- New and replacement manufactured homes should be elevated with their lowest floor in accordance with the requirements of NFPA 225 (2005 ed.), Chapter 12. Note that this recommendation is consistent with current NFIP requirements with one exception, the change in A Zone lowest floor reference from the top of the floor to the bottom of the main chassis frame beam. This recommendation is not intended to eliminate the 3-foot pier exception allowed for new and replacement homes on sites in existing manufactured home parks that have not previously experienced substantial damage due to flooding. However, this report suggests that new and replacement homes in existing parks be elevated higher than the 3-foot pier exception allows, preferably with the bottom of the main chassis frame beam at the ABFE.

- **Freeboard:** Freeboard is recommended for all buildings in all special flood hazard zones. At a minimum, the freeboard specified in ASCE 24-05 should be considered (freeboard amounts in ASCE 24-05 depend on the building importance, flood hazard zone, and floor beam orientation). Consider using more freeboard than ASCE 24-05 specifies if AFBEs are not adopted by a community.

- **Coastal A Zones:** Require V Zone design and construction standards, per ASCE 24-05, for new construction in Coastal A Zones subject to erosion, scour, velocity flow, and/or wave heights greater than 1.5 feet. As an interim step, use the Katrina Flood Recovery Maps to determine the approximate location of the Coastal A Zone hazard. As shown on the Recovery Maps for Mississippi, the Coastal A Zone will be the area between the approximate limit of the 1.5-foot Wave Zone line and the approximate limit of the 3-foot Wave Zone line.

- **Foundations along the shoreline:** Pier foundation performance in coastal areas has been poor where erosion, waves, and/or debris impacts are present, especially during base flood events. Pier foundations should only be considered when these hazards are not present.

  - Use a deep pile and/or column foundation along the Gulf of Mexico shoreline if significant erosion is likely during the base flood. Use of other foundation types should be limited to those areas far from the shoreline and not subject to erosion.

  - Use a deep pile or column foundation along shorelines for bays and sounds if significant erosion is likely during a base flood event. Foundation selection should be based on several factors: erodibility of the soil; exposure to “damaging” waves (greater than 1.5 feet high); potential for velocity flow; potential for floodborne debris; and required resistance to lateral flood and wind forces.

- **Debris impacts:** Buildings should be designed and constructed to resist loads and conditions during the design flood. At a minimum, the design flood should be the base flood, but designing for more severe floods is recommended in accordance with ASCE 24-05. Floodborne debris characteristics and loads should be determined using section C.5 of ASCE 7-05.

- **Fully engineered, multi-story construction governed by the IBC:** The ground-level floor of a multi-story building (typically used for vehicle parking and building access) should either: 1) use a lowest floor slab or floor system that will not collapse and can support all design loads, if undermined, or 2) use a slab or floor system that will collapse and break into small pieces if undermined. Buildings governed by the IRC and in the V Zone should be restricted to the second option.

4.2.6 Public Outreach and Education Recommendations

Reconstruction of the Alabama, Louisiana, and Mississippi communities affected by Katrina will require adherence to the codes and best practices for building design and construction. Before that can occur, however, flood and wind hazards must be communicated to interested parties, reconstruction options must be determined and discussed, and the best option(s) must be identified. Public outreach and education on codes will be essential to this process, particularly with regard to identifying hazards and reconstruction options. A variety of audiences must be involved and engaged, including homeowners, contractors, designers, building officials, floodplain managers, and elected officials.

Key topics to be part of any effective outreach and education program should include:

- Mapping flood hazards: ongoing restudies and interim Katrina Flood Recovery Maps.
- Design and construction to resist future hurricanes, including consideration for storm impacts above design conditions.
- The costs, benefits, and consequences of employing (or not employing) best practices for design and construction.
- Provide training to local engineers, builders, and code enforcement officials on *Recommended Residential Construction for the Gulf Coast: Building on Strong and Safe Foundations* (FEMA 550, publication available May 2006).
- Provide training to local engineers, builders, and code enforcement officials on requirements of the latest adopted codes.

4.2.7 Flood Insurance Recommendations

Like flood hazard maps, flood insurance provisions and premiums should reflect the actual risk during base flood conditions. Flood insurance provisions and premiums should reward best practices for siting, design, and construction (such as through the use of the V Zone Risk Factor Rating Form).

4.3 Wind Hazard Conclusions

The wind speeds during Hurricane Katrina were below current design wind speeds in most areas, but the wind pressures exceeded some of the older code-level wind pressures. The wind conditions from the storm resulted in limited structural damage to buildings, but widespread damage to building envelopes. The wind-related building damage was generally a result of inadequate design, outdated codes, building age, lack of maintenance, and/or poor construction/code enforcement.

Buildings designed and constructed to resist wind loads prescribed in the IBC 2000, IBC 2003, and ASCE 7 performed well structurally and showed how improvements to the building codes can produce successful results. Based on the amount of wind damage observed by the MAT for buildings constructed in accordance with the 1979 and earlier editions of the SBC, it is evident that under-prediction of the design wind loads by past building codes for critical building areas, such as roof and wall corners, led to significant building envelope and structural damage. For buildings constructed in accordance with the 1982 and later editions of the SBC and IBC/IRC, investigation of the damage suggested that non-compliance with building codes was a major cause of that damage.

4.3.1 Performance of Structural Systems (Residential and Commercial Construction)

Most structural failures observed by the MAT appeared to be the result of inadequate design and construction methods commonly used before IBC 2000 and IRC 2000 were adopted and enforced. Only a relatively small number of structures that were observed in the areas affected by Hurricane Katrina were constructed in accordance with current model building codes; most that were observed were constructed in accordance with older codes such as the SBC or were not constructed to any building code standards.

Throughout the Hurricane Katrina damage zone, the limited structural wind damage was most commonly observed in residential wood roof framing. Inadequate nailing of roof sheathing panels, gable end wall failures, and lack of properly installed wood framing connectors were the major factors in these structural failures. Most heavy engineered commercial buildings (e.g., casino hotels, banks, hospitals) performed well structurally, which is attributed to the safety factors normally included in the performance of the engineering analysis conducted for the structures' designs. Older pre-engineered structures, generally constructed before 1980, performed poorly when faced with the high loads of Hurricane Katrina. These structures are often designed to minimum standards to reduce cost. Lack of building codes and older codes often resulted in structures being constructed to minimum design requirements.

4.3.2 Performance of Building Envelope

Building envelope damage was noted throughout all areas observed by the MAT. Poor performance of building envelopes was a function of both inadequate wind resistance and damage from windborne debris impact. Inadequate resistance to high-wind pressures on building envelopes and rooftop equipment was responsible for much of the damage caused by Hurricane Katrina. In addition, windborne debris caused significant envelope damage, and virtually all of the glazing damage that the MAT observed. In part, the building envelope failure problem is due to lack of high-wind design guides for envelope assemblies and various types of rooftop equipment.

Internal Pressurization: Structural damage was caused in some buildings when the building envelope was breached and significant changes of the internal pressures occurred. Failures of windows and doors on the windward face of a building have been correlated with subsequent failures of partition walls, windows, and doors on side and leeward walls, attic access panels, roof sheathing, and even whole roof structures. Numerous failures occurred at and below the design wind speed as the result of inadequate design and construction of the connections and internal pressurization.

Roof Coverings, Exterior Cladding, and Soffits: Roof coverings of many types failed during Hurricane Katrina. Some of these failures were due to the age of the coverings. Age-related failures were associated with weather-induced change in material properties and with testing limitations and design standards that were available years ago. Other failures were due to design and construction related issues or debris impact.

- In general, EIFS performed poorly. Greater attention is needed in the design and application of EIFS and improvements are needed in design guides and testing.

- In general, vinyl sidings performed poorly.

- Edge flashing, coping, and gutter/downspouts failure was common. Failure of these roofing components often initiated lifting and peeling of roof membranes. Failure was in part due to inadequate design and construction attention, and, in the case of gutters, due to lack of testing and design standards.

- In numerous buildings, rain was driven into attic spaces because of soffit failures.

Windows, Doors, and Shutters: Windows and glazed doors can be protected in all wind regions using shutter systems, laminated glazing systems, and other means of opening protection. Limited use of protective systems was observed in the affected areas. Damage to the contents of many homes and businesses would have been prevented if building openings had been protected.

4.4 Wind Related Recommendations

The recommendations from the MAT report, summarized in this report, are intended to assist the states of Alabama, Louisiana, and Mississippi; communities; businesses; and individuals lessen the impact of wind damage from future natural hazards. A few of the main recommendations are outlined in Sections 4.4.1 through 4.4.3; details and additional recommendations are provided in Section 4.6. Refer to NIBS *Whole Building Design Guide* for more flood recomdations (http://www.wbdg.org/design/env_flood.php).

4.4.1 Codes and Standards Recommendations

Buildings that had been designed or mitigated to resist high-wind loads were observed to perform substantially better than buildings constructed to earlier codes, but positive performance was not consistent. Incorporating the recommendations in this report into the next available code cycle is key to setting the new standard in hurricane-resistant construction in all hurricane-prone regions. If these recommendations are not adopted by the model codes, the recommended design changes should be considered "best practices" and incorporated in all new construction and mitigation projects.

- Adopt the 2006 IBC, IRC, or NFPA 5000 for all jurisdictions in Alabama, Louisiana, and Mississippi.
- Do not reduce the wind provisions of the 2006 IBC, IRC, NFPA 5000, and ASCE 7-05 with local amendments, as has been done in some jurisdictions.
- Ensure code compliance through increased enforcement of construction inspection requirements such as the IBC, IRC, and NFPA 5000. Ensure enforcement of Special Inspections Provisions per the IBC and NFPA 5000.

4.4.2 Building Envelope Recommendations

Roof covering and wall cladding failures were widespread during Hurricane Katrina, which was less than a design wind event in most areas. To ensure that components and cladding elements are being engineered and designed per the code requirements, additional focus should be given to the design and construction of the building envelope. Test method improvements are recommended to assess the performance of exterior systems like EIFS, vinyl siding, and soffit panels that historically have performed poorly during hurricanes. Specific recommendations related to roof systems, soffits, exterior cladding, windows, doors, and rooftop equipment are included Section 4.6.

4.4.3 General Recommendations

Building Owners: Creating a continuous load path from the roof to the foundation minimizes damage and may prevent failure of older buildings during future wind events. For owners, renovation work and roof replacement projects offer opportunities to perform mitigation retrofits to improve a building's continuous load path. The roof structure's top-of-wall connection is often made accessible during these projects and it is relatively easy to help create a continuous load path by installing extra clips, screws, or nails to secure decking to rafters or trusses for a minimal cost. These measures can significantly increase the future wind resistance of the structure.

- Refer to the NIBS *Whole Building Design Guide* (http://www.wbdg.org/design/env_wind.php).

- Involve a structural design engineer, architect, or professional-licensed contractor in designing and planning renovation or remodeling of structural or building envelope improvements.

- Perform follow-up inspections after a hurricane to look for moisture that may affect the structure or building envelope.

State and Federal Government Agencies:

- The government should place high priority on and allocate resources to hardening and providing backup power and data storage to surface weather monitoring systems. Continued support is also needed for maintenance, expansion, and deployment of stand-alone, unmanned surface observation systems that can be safely and reliably placed in advance of a land-falling hurricane. Support should be provided for the real-time communication of data from all these platforms to forecasters and wind-field modeling efforts.

- The government should place a high priority on continuing to fund the development of tools for estimating and mapping wind fields associated with hurricanes and make these products available to the public.

4.5 Performance of Critical and Essential Facilities (Including Shelters)

4.5.1 Conclusions

In general, buildings functioning as critical and essential facilities did not perform better than their commercial-use counterparts. The same construction issues observed in residential and commercial buildings were observed in critical and essential facilities. Facilities that sustained damage from flooding had not been designed to withstand the level of flooding that occurred. Some buildings designed to critical and essential facility requirements experienced damage and partial failures during the hurricane due to lack of protection from windborne debris. The flood- and wind-related building damage to critical and essential facilities experienced during Hurricane Katrina led to a significant, and avoidable, loss of function.

4.5.2 Recommendations

Detailed recommendations for mitigating flood- and wind-related hazards to critical and essential facilities are provided in Section 4.6. Some of the main recommendations are:

- Locate all new critical and essential facilities that must remain operational during an event above the 500-year flood elevation and on sites that will not be isolated by floodwaters, where possible. This is a current requirement per 44CFR Section 9.11 for reconstruction of existing facilities.

- For existing critical and essential facilities located within a SFHA, develop emergency operation plans that allow building occupants and operations to be re-located to sites outside of SFHAs before the onset of the storm. Do not occupy vulnerable facilities during an event.

- Evacuate emergency supplies and equipment to the extent possible if an existing facility is to be evacuated before hurricane landfall. For example, if personnel evacuate a fire station, also evacuate the equipment.

- Do not house critical facilities in older buildings unless they are investigated by qualified engineers and architects to ensure survival in design level storms. If weaknesses are identified, the building should not be occupied during the event.

- Design to standards that exceed current code, conduct peer reviews when designing new facilities or retrofitting existing facilities, and implement special inspections during construction.

4.6 Recommendation Tables for Flood and Wind

Flood-Related:

- Table 4-1. Flood Hazard - Building Code Recommendations
- Table 4-2. Flood Hazard - Design and Construction Recommendations
- Table 4-3. Flood Hazard - Hazard Identification and Regulations Recommendations for Government Agencies
- Table 4-4. Flood Hazard - Long-Duration Flooding Recommendations
- Table 4-5. Flood Hazard - Recommendations Specific to Critical and Essential Facilities

Wind-Related:

- Table 4-6. Wind Hazard - Design and Construction Recommendations
- Table 4-7. Wind Hazard - Recommendations for Building Codes/Standards and Adopting Agencies
- Table 4-8. Wind Hazard - Recommendations Specific to Critical and Essential Facilities

Flood- and Wind-Related:

- Table 4-9. Flood and Wind Hazard - Public Outreach Recommendations

Table 4-1. Flood Hazard - Building Code Recommendations

Flood Hazard	
Code	Recommendation*
General	
Code	Adopt the 2006 IBC, IRC, or NFPA 5000 building codes for all jurisdictions in Alabama, Louisiana, and Mississippi.
Code	Adopt the ASCE 24-05 for all jurisdictions in Alabama, Louisiana, and Mississippi.

* All recommendations are detailed in the FEMA 549 MAT report unless otherwise noted.

Table 4-2. Flood Hazard - Design and Construction Recommendations

Flood Hazard		
Building Component	Recommendation*	Action Required By**
Design, Foundations, and Structures		
Design guidance	Use ASCE 7-05, Chapter 5 for the calculation of flood loads during the base flood, including floodborne debris loads.	D, C, G
Design guidance	Use ASCE 24-05 for the flood-resistant design of all structures in flood hazard areas, including one- and two-family structures.	D, C, G
Design guidance	Use the *Home Builder's Guide to Coastal Construction Technical Fact Sheets* (FEMA 499) and the *Coastal Construction Manual* (FEMA 55) for additional guidance related to flood and wind resistant design and construction.	D, C, G
Design guidance	Use the guide: *Recommended Residential Construction for the Gulf Coast: Building on Strong and Safe Foundations* (FEMA 550, publication available May 2006).	D, C, G
Design guidance, manufactured homes	Use NFPA 225 for installation of new and replacement manufactured homes in flood hazard areas.	D, C, G
Coastal A Zones	Require V Zone standards for new construction, per ASCE 24-05, in Coastal A Zones subject to erosion, scour, velocity flow, and/or subject to wave heights greater than 1.5 feet.	D, C, G
Foundation type	Select the type of foundation based on the flood hazards depicted on the Katrina Flood Recovery Maps, not based on the flood hazard zones shown on the pre-Katrina FIRMs.	D, C, G
Shear wall foundation	Investigate the technical, policy and financial implications of allowing shore-perpendicular foundation walls beneath one- and two-family residential buildings in V Zones where the required lowest floor elevation above the ground is in excess of one story.	G
Lowest floor elevation	Elevate all new construction (including substantially improved structures and replacement of substantially damaged structures) in coastal flood hazard zones with the bottom of the lowest horizontal supporting member above the BFE (preferably to the ABFE). Freeboard for all buildings in all special flood hazard zones is desirable; the amount will vary with building importance, but ASCE 24-05 can provide guidance.	D, C, G
Ground level slabs, fully-engineered, multi-story construction (governed by the IBC)	The ground level floor of a multi-story building (typically used for parking or building access) should either: 1) use a lowest floor slab or floor system that will not collapse and can support all anticipated design loads and conditions, including undermining, or 2) use a slab or floor system that will collapse into small pieces.	D, C, G
Ground level slabs, buildings (governed by the IRC)	Within the V Zone, the grade-level slab must collapse and break into small pieces if undermined. The same performance is recommended for elevated buildings in Coastal A Zones subject to erosion, scour, velocity flow, and/or subject to wave heights greater than 1.5 feet. Slabs under elevated buildings in non-Coastal A Zones need not break up.	D, C, G

* All recommendations are detailed in the FEMA 549 MAT report unless otherwise noted.

** Action required by: Designer (D), Contractor (C), Government Official (G).

Table 4-2. Flood Hazard - Design and Construction Recommendations (continued)

Flood Hazard		
Building Component	Recommendation*	Action Required By**
Design, Foundations, and Structure (continued)s		
Debris impacts	Buildings should be designed, and constructed, to resist loads and conditions during the design flood. At a minimum, the design flood should be the base flood, but designing for more severe floods is recommended in accordance with ASCE 24-05. Floodborne debris characteristics and loads should be determined using Section C.5 of ASCE 7-05.	**D, C, G**
Foundations near bay and bayou shorelines	For sites near bay or bayou shorelines, foundation selection should be based on factors as described in Chapter 11 of the MAT report *Hurricane Katrina in the Gulf Coast: Building Performance Observations, Recommendations, and Technical Guidance* (FEMA 549, 2006).	**D, C, G**

Table 4-3. Flood Hazard - Hazard Identification and Regulations Recommendations for Government Agencies

Flood Hazard	
Parameter	Recommendation*
Hazard Identification and Regulation	
Storm surge	Review the storm surge data and modeling procedures that served as the basis for the effective FIRMs. Conduct a revised tide frequency analysis, update storm climatology for the area, and use modern storm surge model to estimate the BFEs throughout the Katrina impact area.
Katrina Flood Recovery Maps	Adopt the Katrina Flood Recovery Maps as an interim approach (pending completion of coastal flood restudies). This approach is preferable to adding freeboard within the SFHA on the pre-Katrina effective FIRM, since the latter approach does not address known flood hazards outside the mapped SFHA. Post-event flood recovery maps should delineate the 100-year and 500-year flood limits and hazard zones, including the landward limits of anticipated V Zone, Coastal A Zone, and A Zone conditions.
Mapping flood hazards in coastal areas	Re-evaluate the methodology to determine flood zones and flood elevations in coastal areas. Post-hurricane investigation revealed damage to A Zone-type structures exposed to less-than-3-foot waves. Consider adoption of the 1.5-foot breaking wave height as the basis for mapping Coastal A Zones and requiring V Zone type building standards (the distinction currently is based on a 3-foot breaking wave height).
Future conditions mapping	The effects of long-term erosion, wetland loss, sea level rise, and subsidence should be incorporated into flood hazard identification and mapping. Even if shown as optional data layers, the information will be available to communities, designers, lenders, and owners.
Flood insurance premiums	Flood insurance provisions and premiums should reflect the actual risk during base flood conditions. Actual risk refers to those flood conditions that would potentially exist if the levees provided minimum, or no, protection.
Flood insurance premiums	Flood insurance provisions and premiums should reward best practices for siting, design, and construction.
"What if" mapping	Maps should be developed that illustrate the effects of various disaster scenarios, such as floods that exceed design levels. These maps, to be developed by state and local agencies, can help educate local officials and the public, and can be used as a planning and decision-making tool. Coordination of "what if" mapping with local mitigation strategies and evacuation planning will be required.

* All recommendations are detailed in the FEMA 549 MAT report unless otherwise noted.

** Action required by: Designer (D), Contractor (C), Government Official (G).

Table 4-4. Flood Hazard - Long-Duration Flooding Impact Recommendations

Flood Hazard		
Category	**Recommendation***	**Action Required By****
Flooding within levee-protected areas	Implement FEMA Procedure Memorandum No. 34 - Interim Guidance for Studies Including Levees (FEMA, David I. Maurstad, August 22, 2005). This memo provides guidance and standards in properly identifying flood hazards in areas possibly protected by levees. The procedure includes working with local entities responsible for levees to determine the accreditation of the levee providing flood protection. If a levee is not accredited, the area behind the levee will be identified as a SFHA and will reflect the actual BFE.	**G**
	Revise hazard identification and mapping procedures to consider predicted rates of sea level rise and subsidence.	**G**
	Building owners should consider the savings in repair costs from damages that may occur in future events versus the initial cost in constructing the building to a higher elevation.	**C, O**
	Develop "What If" Maps for levee-protected areas to illustrate the effects of various disaster scenarios, such as floods that exceed design levels and levee failures. The maps, to be developed by state and local agencies, can help educate local officials and the public, and can be used as a planning and decision-making tool.	**G**
Biological and chemical contamination of building materials	For details on safety precautions and flood restoration techniques, refer to the FEMA Hurricane Recovery Advisories: *The ABCs of Returning to Flooded Buildings* and *Initial Restoration of Flooded Buildings.* Recovery Advisories can be found at: www.fema.gov/fima/mat/mat_katrina.shtm	**C, O**
	To facilitate restoration of flooded buildings, building owners should: ■ Open windows and doors to maximize air flow ■ Remove contents for restoration or disposal ■ Remove porous wall materials, fibrous wall insulation, carpeting, vinyl flooring, and electrical components that were impacted by floodwaters ■ Thoroughly clean and sanitize interior surfaces ■ Allow sufficient time for drying prior to initiating reconstruction activities	**C, O**
	Take appropriate safety precautions (including the use of personal protective equipment) during repair and reconstruction work to minimize the health risks from biological and chemical contaminants.	**C, O**

* All recommendations are detailed in the FEMA 549 MAT report unless otherwise noted.

** Action required by: Contractor (C), Government Official (G), Building Owner (O).

Table 4-5. Flood Hazard - Recommendations Specific to Critical and Essential Facilities

Flood Hazard		
Parameter	Recommendation*	Action Required By**
Critical/Essential Facilities		
Public shelters	Do not open shelters located in potential storm-surge inundation zones until after the hurricane makes landfall.	**G, CFO**
New critical and essential facilities (reconstruction of existing facilities)	At a minimum, elevate or protect new facilities in flood hazard areas to the 500-year (0.2% annual exceedance) flood level, or based on ASCE 24-05, whichever is higher. This is a current requirement per 44CFR Section 9.11 for reconstructing existing facilities. Areas below this elevation can be used for vehicle and equipment storage, but plans should be made to relocate vehicles and equipment in the event of a severe storm. Floodproofing of vehicle and equipment storage areas may be an alternate approach for facilities located outside the V Zone and Coastal A Zone.	**D, G, CFO**
Existing critical and essential facilities	For facilities located within a SFHA, develop emergency operation plans that allow building occupants and operations to be re-located to sites outside SFHA before onset of storm. Do not occupy vulnerable facilities during an event.	**G, CFO**
Existing critical and essential facilities	Evacuate emergency supplies and equipment to the extent possible if an existing facility is to be evacuated before hurricane landfall.	**G, CFO**
Existing critical and essential facilities	Evaluate vulnerability of existing facilities in light of recent damage to similar facilities; strengthen and floodproof structures where feasible.	**D, G, CFO**

Table 4-6. Wind Hazard - Design and Construction Recommendations

Wind Hazard		
Building Component	Recommendation*	Action Required By**
Building Envelope		
General	Involve a structural design engineer, architect, or professional-licensed contractor in designing and planning renovation or remodeling of structural or building envelope improvements.	**O**
General	Perform follow-up inspections after a hurricane to look for moisture that may affect the structure or building envelope.	**C, O**
Asphalt shingles	Ensure manufacturers' installation instructions are followed (i.e., starter strips and nail locations) and use Fact Sheets 19 and 20 (FEMA 499).	**D, C**

* All recommendations are detailed in the FEMA 549 MAT report unless otherwise noted.

** Action required by: Designer (D), Contractor (C), Manufacturer (M), Government Official (G), Building Owner (O), Critical Facilities Operator (CFO).

Table 4-6. Wind Hazard - Design and Construction Recommendations (continued)

Wind Hazard		
Building Component	Recommendation*	Action Required By**
Building Envelope (continued)		
Metal panel roof system	Specify close spacing of fasteners at eaves, and hip and ridge flashings.	**D**
Tile roof system	Use Fact Sheet 21 (FEMA 499).	**D, C**
Edge flashings and copings	Comply with American National Standards Institute (ANSI)/ SPRI ES-1 (2003). Use safety factor of 2 for Category II buildings and a safety factor of 3 for Category III and IV buildings.	**D**
Edge flashings and copings	Place a bar over roof membrane near edge of flashing and coping to provide secondary protection (see FEMA 424, *Design Guide for Improving School Safety in Earthquakes, Floods, and High Winds*).	**D, C**
Gutters and downspouts	Develop design guide for wind resistant gutters; include attachment of downspouts.	**M, C**
Brick veneer	Use Hurricane Katrina Recovery Advisory: *Attachment of Brick Veneer in High-Wind Regions*.†	**M, G**
EIFS	Manufacturers should re-evaluate their training programs to ensure that EIFS assemblies are installed properly by adequately-trained workers.	**M**
EIFS	EIFS Industry Members Association (EIMA) should consider all elements of the EIFS assembly. Although EIMA members may not manufacture or supply assembly components such as metal framing, sheathing, or sheathing fasteners, these elements are also critical in achieving suitable wind performance.	**M**
EIFS	When EIFS is installed over sheathing, designers should specify attachment requirements for all elements of the assembly, including framing and sheathing attachment.	**D**
EIFS	Designers should specify special inspections to ensure proper application of all elements of the assembly.	**D**
EIFS	Develop design guidance for EIFS attachment.	**M, G**
Vinyl siding	Develop design guidance for vinyl siding attachment.	**M, G**
Soffits	Design guidance: Develop design guidance for attaching soffits, including design of baffles or filter media to prevent wind-driven rain from entering attics.	**M, G**
Asphalt shingles	Ensure manufacturers' installation instructions are followed (i.e., starter strips and nail locations) and use Fact Sheets 19 and 20 (FEMA 499).	**D, C**

* All recommendations are detailed in the FEMA 549 MAT report unless otherwise noted.
** Action required by: Designer (D), Contractor (C), Manufacturer (M), Government Official (G), Building Owner (O).
† The Hurricane Katrina Recovery Advisories can be accessed on-line at: www.fema.gov/fima/mat/mat_katrina.shtm

Table 4-6. Wind Hazard - Design and Construction Recommendations (continued)

Wind Hazard		
Building Component	**Recommendation***	**Action Required By****
Exterior Equipment		
General	For all rooftop equipment, see Hurricane Katrina Recovery Advisory: *Attachment of Rooftop Equipment in High-Wind Regions* (publication available in May 2006).†	**D**
Lightning protection systems	See Hurricane Katrina Recovery Advisory: *Rooftop Attachment of Lightning Protection Systems in High-Wind Regions* (publication available in May 2006).†	**M, D, G**
Doors		
Exterior doors	Specify wind-driven rain-resistant weather stripping at exterior doors (see FEMA 424).	**D**
Entrance vestibules	Design entrance vestibules for high-wind resistance in areas where basic wind speed exceeds 120 mph (see FEMA 424).	**D**
Rolling and sectional doors	Consider type, size, and spacing of door, frame, and frame fasteners to loads. If frame is attached to wood blocking, attention should also be given to the blocking attachment. Maintain adequate edge distances for frame fasteners placed in concrete or masonry.	**D, C**

* All recommendations are detailed in the FEMA 549 MAT report unless otherwise noted.

** Action required by: Designer (D), Contractor (C), Manufacturer (M), Government Official (G), Building Owner (O).

† The Hurricane Katrina Recovery Advisories can be accessed on-line at: www.fema.gov/fima/mat/mat_katrina.shtm

Table 4-7. Wind Hazard - Recommendations for Building Codes/Standards and Adopting Agencies

Wind Hazard	
Building Component	**Recommendation***
General	
Code	Adopt the 2006 IBC, IRC, or NFPA 5000, for all affected jurisdictions in Alabama, Louisiana, and Mississippi.
Code	Do not reduce the wind provisions of the 2006 IBC and IRC, ASCE 7-05, or NFPA 5000 with local amendments.
Code	Ensure code compliance through increased enforcement of construction inspection requirements such as the IBC, IRC, and NFPA 5000. Ensure enforcement of Special Inspections Provisions per the IBC and NFPA 5000.
Building Envelope	
Soffit	Develop and adopt wind resistance and wind-load criteria regarding wind resistance for soffits. Wind-driven rain resistance of ventilated soffit panels should also be added. Testing Application Standard (TAS) 110 may be a suitable test method, although it may require modification.[a]
EIFS	Revise test method ASTM E 330: Use a 60-second load duration instead of a 10-second load duration. Incorporate deflection criteria specified in test method ASTM E 1592 into ASTM E 330.
Vinyl siding	Revise test method ASTM D 5206: Use a 60-second load duration instead of a 30-second load duration. Incorporate the deflection criteria specified in test method ASTM E 1592 into ASTM D 5206.
Vinyl siding	The ASTM task group responsible for ASTM D 5206 should give consideration to dynamic testing of vinyl siding in lieu of the static testing now prescribed in ASTM D 5206.
Vinyl siding	Revise ASTM D 3679 to require a minimum safety factor of 2 versus the 1.5 factor currently specified. Revise ASTM D 4756 to require installation of a water-shedding underlayment (e.g., asphalt-saturated felt or housewrap).
Gutters and downspouts	Develop and add criteria for uplift resistance of gutters and downspouts.
Reroofing	Except for minor repairs, require removal of existing roof covering down to the deck and replacement of deteriorated decking in areas where basic wind speed is 110 mph or greater. If existing decking attachment does not comply with loads derived from Chapter 16 of the IBC, require installation of additional fasteners to meet loads.
Asphalt shingles	Require compliance with ASTM D 7158.[b] Also require six nails per shingle and require use of asphalt roof cement at eaves, rakes, hips, and ridges where basic wind speed is 110 mph or greater (refer to FEMA 499, Fact Sheet 20).
Windows and Shutters	
Shutters	Add requirement to label shutters (other than wood) to indicate compliance with ASTM E 1886. Without labels, building owner does not know if shutters are suitable.

* All recommendations are detailed in the FEMA 549 MAT report unless otherwise noted.
a TAS is a Florida document: http://infosolutions.com/icce/gateway.dll?f=templates$fn=default.htm$vid=icc:florida_hurricane
b ASTM D 7158 was published in 2006 as a replacement for UL 2390.

Table 4-8. Wind Hazard - Recommendations Specific to Critical and Essential Facilities

Wind Hazard		
Building Component	Recommendation*	Action Required By**
New Construction		
General	Emphasize best practices for schools and shelters described in FEMA 424 and FEMA 361, respectively, and in the latest codes and standards for wind resistance (ASCE 7).	D, CFO
General	Develop additional criteria to help ensure continuity of function. See FEMA 424 and FEMA 361.	D, CFO
General	For some important facilities, such as shelters, design using a 40-mph increase with an importance factor of 1.	D
Design loads	Use a Directionality Factor of 1.0 for the building envelope and rooftop equipment, and 0.85 for the main wind-force resisting system.	D, CFO
Material selection	Reinforced concrete roof deck and reinforced concrete and/or reinforced and fully-grouted CMU exterior walls are recommended. FEMA 424 and FEMA 361 provide detailed guidance on material selection for structural and building envelope systems.	D, C, CFO
Detailing and notations on the building plans	Facility plans should delineate the facility area designed to function as a shelter or hardened area. Details of the shelter or hardened area and the envelope elements should be provided to ensure that the construction requirements are clearly understood by the builder and building official. Provide facility design criteria and maximum design pressures for the main wind force resisting system (MWFRS) and for components and cladding.	D, C, CFO
Roof system	Design a roof system that will prevent or reduce water infiltration if roof is hit by windborne debris.	D
Gutters and downspouts	Secure gutters to resist wind uplift and to avoid membrane blow-off.	D, C, CFO
Rolling and sectional doors	Install high-wind-rated, sectional, or rolling doors to protect against high wind.	D, C, CFO
Windows	Implement window protection systems to protect critical facilities from windborne debris.	D
General	Incorporate hazard mitigation peer review into design approval process to ensure that critical and essential facilities are adequately designed to resist extreme winds.	D, CFO
General	Contract drawings and specifications for new construction and remedial work on existing building envelopes and rooftop equipment should undergo rigorous peer review, submittal review, field observation (inspection), and testing prior to construction.	D, CFO
General	Conduct special inspections for key structural items and connections to ensure performance of critical facilities.	D, C, CFO

* All recommendations are detailed in the FEMA 549 MAT report unless otherwise noted.
** Action required by: Designer (D), Contractor (C), Government Official (G), Critical Facilities Operator (CFO).
*** See applicable items under New Construction

Table 4-8 . Wind Hazard - Recommendations Specific to Critical and Essential Facilities (continued)

Wind Hazard		
Building Component	Recommendation*	Action Required By**
Existing Facilities***		
Vulnerability assessment	Perform vulnerability assessment to ensure continuity of operations. The assessment should evaluate the building performance and utilities that service critical/essential facilities, so that the building owner understands potential impacts to the facility during a storm, and operational impacts resulting from limited utility services.	D, CFO
General	American Red Cross 4496 provides a baseline for a shelter's integrity and performance, but meeting this criterion does not guarantee that the building will resist wind and windborne debris associated with hurricanes. Emphasize best practices for shelters described in FEMA 361.	D, CFO
General	Implement mitigation measures or structurally retrofit critical/essential facilities to design levels other than minimum code requirements for general use buildings. Do not house critical facilities in buildings that have not received thorough architectural and engineering attention.	D, CFO
Roof structure	Install hurricane clips or straps on inadequately connected roof beams and joists in those buildings that will be occupied during a hurricane.	D, C, CFO
Roofing	Replace aggregate-surfaced roof systems with non-aggregate systems.	D, C, CFO
Edge flashings and copings	Install exposed fasteners on the vertical face of weak metal edge flashings and copings (see FEMA 424).	D, C, CFO
Rolling and sectional doors	Ensure sectional and rolling doors are properly installed and reinforced to prevent catastrophic door failure and building pressurization. Replace or retrofit existing doors that lack adequate resistance.	D, C, CFO
Shutters	In windborne-debris regions (as defined in ASCE 7), install shuttering system on all exterior glazing that is not windborne-debris-resistant. Install power-operated shutters, laminated glass, or engineered film system to the glazing and frame on upper-level floors.	D, C, CFO
General	Conduct special inspections for key building envelope components to ensure performance of critical/essential facilities. Inspect rooftop equipment twice a year. Inspect windows, doors, and wall coverings at 5-year intervals. Conduct special inspections of the entire facility (both structural and building envelope systems) after major storms.	D, CFO
Design guidance	Develop a comprehensive design guide to complement FEMA 424 for mitigating existing facilities.	D, G

* All recommendations are detailed in the FEMA 549 MAT report unless otherwise noted.
** Action required by: Designer (D), Contractor (C), Government Official (G), Critical Facilities Operator (CFO).
*** See applicable items under New Construction

Table 4-9. Flood and Wind Hazard - Public Outreach Recommendations

Education Topic	Outreach Method
Flood Hazard	
Building Owners and Homeowners	
Mapping flood hazards: ongoing restudies and interim Katrina Flood Recovery Maps Design and construction guidance as to how to resist future hurricanes. Include consideration of storm impacts above design conditions. The costs, benefits, and consequences of employing (or not employing) best practices for design and construction Provide training to local engineers, builders, and code enforcement officials on *Recommended Residential Construction for the Gulf Coast: Building Strong and Safe Foundations* (FEMA 550, publication available May 2006) Provide training to local engineers, builders, and code enforcement officials on requirements of the latest adopted codes.	✓ Conduct public meetings to educate building owners on Katrina Flood Recovery Maps and rebuilding information. ✓ Provide outreach, via local newspapers and pamphlets, to describe advisory elevations and what they mean to building owners ✓ Provide the FEMA web site address where the Katrina Flood Recovery Maps can be viewed ✓ Provide information to public and building owners regarding reconstruction guidance and best practices
Wind Hazard	
Building Owners and Homeowners	
Plan and budget construction projects that incorporate natural hazard mitigation measures. Select design and construction teams knowledgeable in effective construction methods in hurricane-prone areas. Prepare and protect building prior to hurricane landfall. Educate building owners on what to do after hurricane passes (inspecting for building damage, performing emergency repairs, and drying out building interiors). Rebuild damaged structure in manner that protects against future damage. Inspect exterior connections and fasteners for wear, corrosion, and other deterioration. Educate building owners on how wind-driven rainwater enters buildings, the resulting implications (loss of electricity, mold), and prevention methods.	✓ Tailor informational pamphlets to homeowners and building owners. ✓ Develop strategy to distribute information (e.g., standardized information sheets during sale of building). ✓ Enlist assistance of real-estate companies and organizations such as the Building Owners and Managers Association. ✓ Provide public service notices at start of each hurricane season. ✓ Develop informational materials on how wind-driven rainwater enters buildings, the resulting damage, and prevention methods.

Table 4-9. Flood and Wind Hazard - Public Outreach Recommendations

Wind Hazard	
Education Topic	**Outreach Method**
Architects, Engineers, Consultants	
Improve the technical proficiency of building envelope design. Provide adequate level of design details for connecting rooftop equipment, including mechanical, electrical, and lightning protection. Share post-disaster building performance information to maximize the value of lessons learned.	✓ Prepare monographs for trade-wide distribution. ✓ Prepare Web-based tutorials and seminars. ✓ Encourage colleges and universities to augment existing curriculum with hurricane-resistant design instruction.
Building Officials	
Share post-disaster building performance information to maximize the value of lessons learned. Train building officials to identify structural weaknesses that may cause structural or building component failure during a hurricane (e.g., unbraced gable end walls, missing truss bracing, truss' anchorage, window/door anchorage). Implement effective enforcement techniques to maintain a high construction quality.	✓ Conduct annual seminars for building officials and plan reviewers in coastal areas to share lessons learned. ✓ Implement hurricane disaster building inspection training program and "train the trainer" program.
Contractors	
Educate contractors who construct building envelopes and install rooftop equipment on hurricane-resistant fastening and anchoring systems. Educate contractors on how wind-driven water enters buildings, the resulting implications (loss of electricity, mold), and prevention methods.	✓ Develop and distribute visual tools such as instructional videos or DVDs. ✓ Conduct on-the-job training to highlight failures that occur when simple anchoring techniques are not applied. ✓ Encourage trade schools in hurricane-prone areas to augment their curriculum with courses on state-of-the-art, hurricane-resistant construction.

A. Acronyms and Abbreviations

A

AFBE Advisory Base Flood Elevations

ANSI American National Standards Institute

ARA Applied Research Associates

ARC American Red Cross

ASCE American Society of Civil Engineers

ASOS Automated Surface Observing Systems

AWRP Aviation Weather Research Program

B

BFE base flood elevation

C

CDT Central Daylight Time

CFR Code of Federal Regulations

cfu/cm^2 colony-forming units per square centimeter

CMU concrete masonry unit

D

DDT dichloro-diphenyl-trichloroethane

DRO Diesel Range Organics

E

EDT Eastern Daylight Time

EIFS exterior insulation and finish systems

EIMA EIFS Industry Members Association

EOC Emergency Operations Center

EPA U.S. Environmental Protection Agency

F

FEMA Federal Emergency Management Agency

FIRM Flood Insurance Rate Map

H

HAZUS-MH Hazards U.S. – Multi-Hazard

HRD Hurricane Research Division

HVAC heating, ventilation, and air conditioning

I

IBC International Building Code

ICC International Code Council

IEBC International Existing Building Code

IRC International Residential Code

M

µg/kg micrograms per kilogram

MAT Mitigation Assessment Team

mb millibars

mph miles per hour

MWFRS main wind force resisting system

N

NAHB National Association of Home Builders

NAVD North America Vertical Datum 1988

NCDC National Climatic Data Center

NFIP National Flood Insurance Program

NFPA National Fire Protection Association

NGVD National Geodetic Vertical Datum 1929

NHC National Hurricane Center

NIBS National Institute of Building Sciences

NOAA National Oceanic and Atmospheric Administration

NWS National Weather Service

P

PCBs polychlorinated biphenyls

PEMB pre-engineered metal building

R

RECAP Risk Evaluation/Corrective Action Program

S

SBC Standard Building Code

SFHA Special Flood Hazard Area

T

TAS Testing Application Standard

U

USACE U.S. Army Corps of Engineers

B. 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 ASCE, *Minimum Design Loads for Buildings and Other Structures*, which gives current requirements for dead, live, soil, flood, wind, snow, rain, ice, and earthquake loads, and their combinations, suitable for inclusion in building codes and other documents.

ASCE 24 – National design standard issued by the ASCE, *Flood Resistant Design and Construction*, which outlines the requirements for flood resistant design and construction of structures in flood hazard areas.

Base flood elevation (BFE) – Elevation of the 1-percent annual flood. This elevation is the basis of the insurance and floodplain management requirements of the National Flood Insurance Program.

Building envelope – The entire exterior surface of a building, including walls, windows, and doors, which encloses or envelops the space within.

Capillary action – Water has good adhesion properties. Water molecules adhere to surfaces and to each other. Capillary action, commonly referred to as "wicking," 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 flooded, 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 – 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 speed – The wind speed used to calculate design wind loads when designing structures.

Eave – The horizontal lower edge of a slope roof.

Erosion – Process by which floodwaters lower the ground surface in an area by removing upper layers of soil.

Floodborne debris impact – Floodwater moving at a moderate or high velocity can carry floodborne debris such as tree limbs, fuel tanks, or vehicles, which can impact the building and damage building walls and foundations.

Floodwall – A long, narrow concrete or masonry embankment built to protect land from flooding.

Freeboard – The additional height of a levee or floodwall above design high water level to prevent overflow. The increased elevation of a building above the minimum design flood level to provide additional protection for flood levels higher than the 1-percent chance flood level and to compensate for 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.

Hurricane – An intense tropical weather system with a well-defined circulation and sustained winds of 74 mph or higher.

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.

Purlin – A horizontal structural member that supports roof covering and carries loads to the primary framing members.

Rake – The inclined edge of a slope roof over a wall (the edge above the gutter).

Reinforced concrete – Concrete with steel mesh or bars embedded in it to increase its tensile strength.

Saffir-Simpson Scale – Measures a hurricane's present intensity on a 1-5 scale to give an estimate of the potential property damage and flooding expected along the coast from a hurricane landfall. Wind speed is the determining factor in the scale. A Category 1 hurricane is the weakest, with winds from 74-95 mph, and a Category 5 hurricane is the strongest, with winds over 155 mph.

Slab-on-grade foundation – Type of foundation in which the lowest floor of the house is formed by a concrete slab that sits directly on the ground.

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.

Storm surge – The water that is pushed toward land from the high winds of a major storm (i.e., hurricane).

Tropical storm – A tropical weather system with a defined circulation and sustained winds of 39 to 73 mph.

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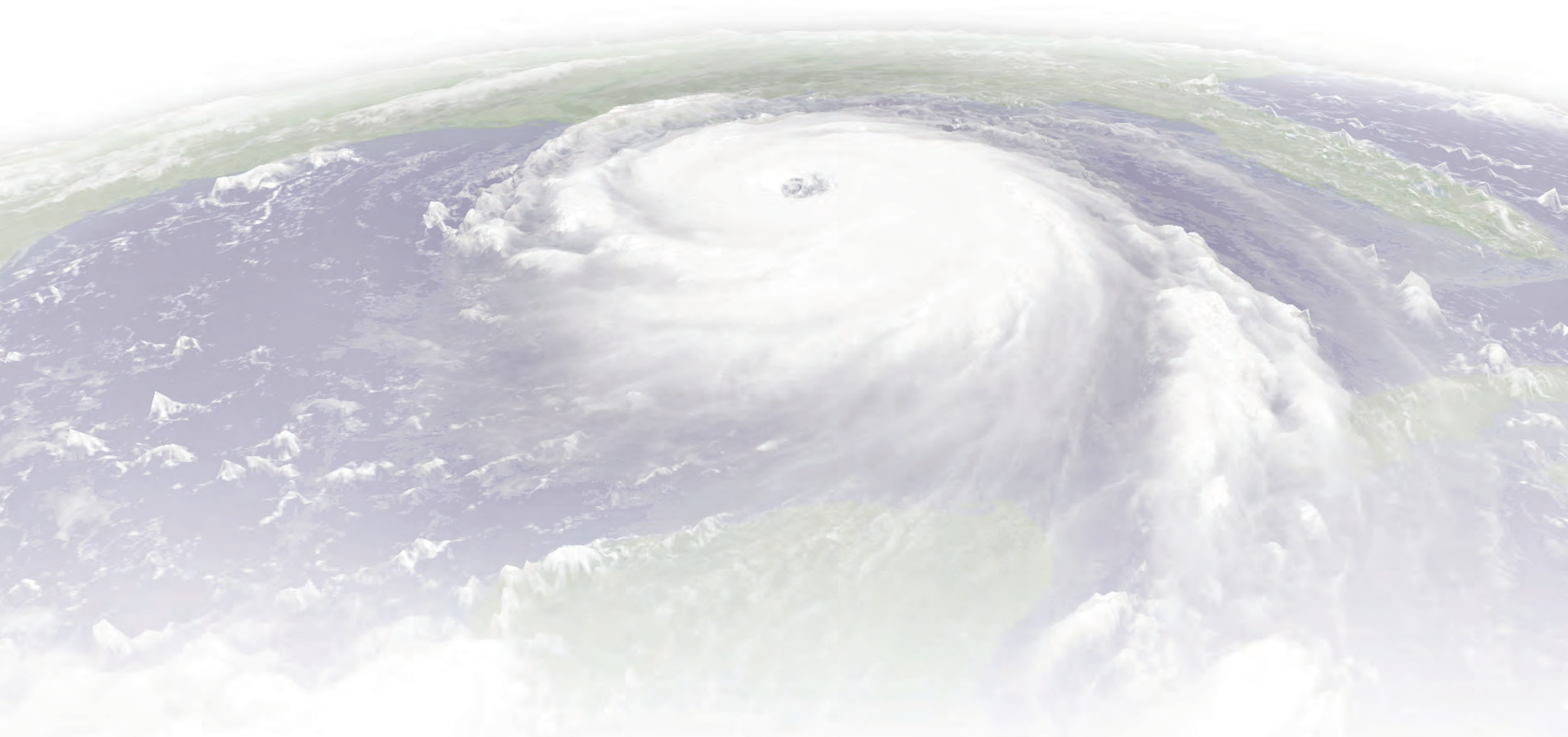


HURRICANE *Katrina* 2005

Reconstruction Guidance

Using Hurricane Katrina Surge Inundation and Advisory Base Flood Elevations

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 Katrina. FEMA has prepared the following recovery advisories. The first advisory on using Advisory Base Flood Elevations included in this appendix:

- Reconstruction Guidance Using Hurricane Katrina Surge Inundation and Advisory Base Flood Elevations
- Initial Restoration for Flooded Buildings
- Design and Construction in Coastal A Zones
- The ABCs of Returning to Flooded Buildings
- Attachment of Brick Veneer in High-Wind Regions
- Rooftop Attachment of Lightning Protection Systems in High-Wind Regions (publication available May 2006)
- Attachment of Rooftop Equipment in High-Wind Regions (publication available May 2006)
- The Use of Fill in Coastal Flood Hazard Areas (publication available May 2006)
- Reconstruction ABFE Guidance for Louisiana (publication available May 2006)

These Advisories are available online at: www.fema.gov/fima/mat/mat_katrina.shtm

Reconstruction Guidance Using Hurricane Katrina Surge Inundation and Advisory Base Flood Elevations

FEMA

HURRICANE KATRINA RECOVERY ADVISORY

Purpose: To discuss available flood hazard information and to recommend reconstruction practices using Advisory Base Flood Elevations (ABFEs).

Key Issues

- Following Hurricane Katrina, FEMA updated its flood frequency analyses to include more recent storm surge data (including storm surge stillwater levels measured after Katrina). The results of the analysis show that the updated 1 percent annual chance stillwater levels (also known as the 100-year stillwater levels) are 3 to 8 feet above the stillwater levels previously used to produce the pre-Katrina Flood Insurance Rate Maps (FIRMs).
- For post-Katrina recovery purposes, FEMA devised a method to approximate 1 percent annual chance wave crest elevations. The results of this effort are known as Advisory Base Flood Elevations (ABFEs, sometimes referred to as Advisory Flood Elevations [AFEs]), which are shown on a series of 228 maps for Hancock, Harrison, and Jackson Counties, Mississippi. These maps are also known as "Katrina Recovery Maps" (see Figure 1).
- The ABFEs are updated estimates of the 1 percent annual chance flood elevations, and are generally 5 to 12 feet higher than the base flood elevations (BFEs) shown on the pre-Katrina FIRMs. ABFEs also extend farther inland than the Special Flood Hazard Areas (SFHAs) shown on the pre-Katrina FIRMs.

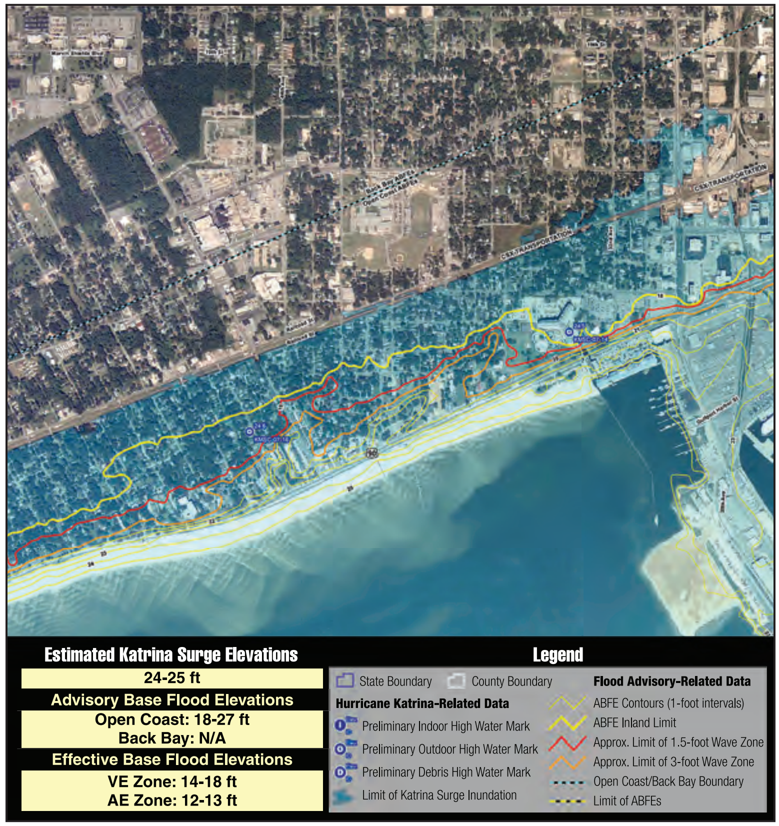


Figure 1. Sample Hurricane Katrina Surge Inundation and Advisory Base Flood Elevations. The shaded region in blue indicates the approximate inland extent of storm surge inundation experienced during Katrina; the ABFE contours are shown in yellow and the predicted inland limit of damaging wave effects during the advisory base flood is shown by the red line. Blue points indicate surveyed Katrina high water mark elevations.

- The Katrina Recovery Maps also show the approximate inland extent of storm surge inundation experienced during Hurricane Katrina. Since Katrina exceeded the BFE in most locations (based on the updated flood frequency analysis), the inland extent of Katrina storm surge penetration generally lies inland of the ABFE limit. However, where the Katrina impact was less extreme (very near the eye where the hurricane winds are small, to the left of the eye where the peak winds blow offshore rather than onshore, and far to the right of the eye where the winds weaken), the Katrina surge penetration properly lies seaward of the ABFE limit.
- FEMA and the State of Mississippi will conduct detailed studies during 2005 and 2006 to produce revised FIRMs. The revised FIRMs will result from more detailed storm surge stillwater analyses and more detailed wave analysis methods than those used to produce the Katrina Recovery (ABFE) Maps. As a result, BFEs on the revised FIRMs may differ from the ABFEs. In the interim, the ABFEs should be treated as the best available 1 percent annual chance elevation information.

- Although the information contained on the Katrina Recovery Maps is advisory in nature, communities are encouraged to use ABFEs to regulate reconstruction and new construction until the revised FIRMs are produced by FEMA.
- Until such time as the revised FIRMs are published by FEMA and adopted by communities, those communities may use the pre-Katrina FIRMs, or Katrina Recovery Maps, or other flood elevations to regulate reconstruction and new construction (as long as the other flood elevations are not lower than those shown on the pre-Katrina FIRMs).

Advisory Base Flood Elevations (ABFEs)

The pre-Katrina FIRMs for communities in Hancock, Harrison, and Jackson Counties were published between the early 1980s and 2002; the current maps underestimate today's risk. Following Hurricane Katrina, FEMA updated the stillwater flood frequency analysis for coastal Mississippi to include tide and storm surge stillwater data for the past 25 plus years. These revised stillwater elevations formed the basis for FEMA's calculation of ABFEs.

The revised 1 percent annual chance storm surge stillwater levels were published by FEMA on October 3, 2005, for Hancock, Harrison, and Jackson Counties in Mississippi (see Table 1). The procedure which makes use of these elevations to compute ABFEs is illustrated in Figure 2 and the example below.

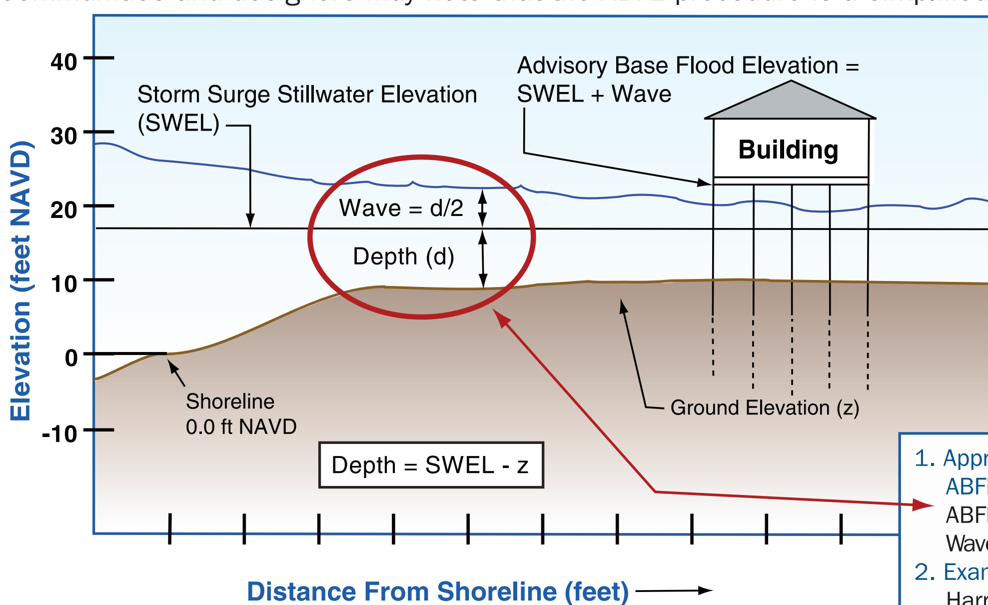
Table 1. Updated 1 Percent Annual Chance (100-Year) Stillwater Elevations for Use in Calculating ABFEs

County (Mississippi)	Updated 1 Percent Annual Chance Stillwater Elevations (SWEL), (ft NAVD*)	
	Gulf of Mexico Shoreline	Back Bay Shorelines
Jackson	14	12
Harrison	18	16
Hancock	20	18

*North American Vertical Datum of 1988

Storm Surge Stillwater Elevation (SWEL)

Communities and designers may note that the ABFE procedure is a simplified version of FEMA's Wave Height



1. Approximate Method for Calculating ABFE:
   ABFE = SWEL + Wave
   Wave = ½ depth = d/2
2. Example:
   Harrison Co Gulf SWEL = 18 ft
   Ground Elevation (z) = 10 ft
   Depth = SWEL – z = 18 ft – 10 ft = 8 ft
   Wave = ½ (8) = 4 ft

   ABFE = 18 + 4 = 22 feet NAVD

Figure 2. How to determine the Advisory Base Flood Elevation based on the site's ground elevation, applicable advisory elevation, and estimated wave height.

Analysis for Flood Insurance Studies (WHAFIS) program used to map base flood conditions on coastal FIRMs. The ABFE procedure does not account for wave attenuation due to dense stands of vegetation, buildings, or other obstructions. Nor does it account for wave growth and regeneration across flooded upland areas. Thus, BFEs on the revised FIRMs (anticipated in 2007) may differ from the ABFEs computed during this interim period. The ABFEs can be considered the best available data at this time.

Figure 3 illustrates the relationships between the stillwater flood elevation, ground elevations, associated 1 percent annual chance stillwater flood depths, ABFEs, and associated flood hazard zones.

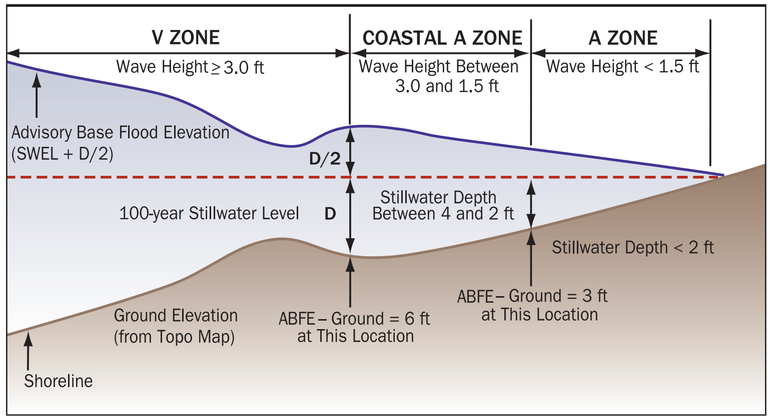


Figure 3. Cross-section showing 1 percent annual chance stillwater elevation, stillwater depth and ABFE, and inland limits of V Zone and Coastal A Zone.

Advisory Base Flood Elevations

The Katrina Recovery Maps (see Figure 1) include the following information:

- Pre-Katrina aerial photographs (as a base map)
- Approximate Katrina surge inundation limit (shaded area)
- ABFE contours (ft NAVD)
- Predicted inland limit of damaging wave effects during the advisory base flood (red line)
- Surveyed Katrina high water mark elevations

More background information on ABFEs and their use can be found in Flood Recovery Guidance-Frequently Asked Questions, dated October 3, 2005, and available at:

www.fema.gov/hazards/floods/recoverydata/katrina_ms_resources.shtm

Communities are encouraged to use the Katrina Recovery Maps. They may continue to enforce their adopted FIRMs and associated design and construction requirements. However, by using the ABFEs any reconstruction or new construction (following Katrina and before issuance of revised FIRMs, expected in 2007) will be at much less risk from future flood damage, and will be eligible for reduced flood insurance premiums (new and reconstructed buildings can be rated using BFEs and flood hazard zones on the effective FIRM, until revised FIRMs are adopted by the community).

Flood Protection Levels for Post-Katrina Reconstruction and New Construction

Until revised FIRMs are published by FEMA and adopted by communities, those communities are free to regulate reconstruction and new construction using several methods:

- Continue to use pre-Katrina FIRMs (understanding that this would knowingly put people and buildings at risk)
- Modify the use of pre-Katrina FIRMs (e.g., add freeboard to the pre-Katrina BFEs)
- Use the Katrina Recovery (Advisory Base Flood Elevation) Maps
- Modify the Katrina Recovery Maps (e.g., conduct a more detailed wave analysis and add to the 1 percent annual chance stillwater elevation, replacing ABFE contours shown on the maps)
- Develop other maps and methods (as long as the resulting BFEs and flood hazard zones are no less restrictive than the pre-Katrina FIRMs)

Each of these methods has advantages and disadvantages, both for implementation and for the long-term protection of buildings constructed after Hurricane Katrina. These are summarized in Table 2.

Table 2. Comparison of Various Methods for Providing Post-Katrina Flood Protection to Reconstructed Buildings and New Construction

Advantages	Disadvantages
Continue Use of Pre-Katrina FIRMs	
No change from pre-Katrina flood hazard maps	• Underestimates inland extent of flooding during base flood • Underestimates flood depths • Underestimates inland extent of the V Zone and damaging wave effects • Does not protect buildings outside the pre-Katrina SFHA against damage during the base flood • Limits eligibility for post-Katrina hazard mitigation grants and other reconstruction funds
Add Freeboard to Pre-Katrina FIRMs (where freeboard is less than that indicated by updated 1 percent annual chance flood analysis)	
• Provides increased flood protection for buildings within the pre-Katrina V Zone • Provides increased flood protection for buildings near the inland limit of the pre-Katrina A Zone • Buildings elevated to the new (freeboard) elevation will be eligible for flood insurance premium discounts (they can be rated using the pre-Katrina FIRM)	• Underestimates inland extent of flooding during base flood • Does not protect buildings outside the pre-Katrina SFHA against damage during the base flood • Does not expand the V Zone inland, and does not protect buildings in the seaward portion of the pre-Katrina A Zone against wave damage • Does not fully protect any buildings subject to the updated 1 percent annual chance flood • Limits eligibility for post-Katrina hazard mitigation grants and other reconstruction funds
Use Katrina Recovery (ABFE) Maps	
Uses the latest 1 percent annual chance flood elevation and mapping guidance to characterize the extent, depth and severity of updated base flood hazards • ABFEs near the coast may be comparable to revised BFEs expected in 2007 • Provides flood protection consistent with the latest estimate of the updated base flood • Reduces potential floor elevation and foundation differences between buildings reconstructed/constructed to ABFEs and those constructed after adoption of revised BFEs. • Buildings elevated to the ABFE will be eligible for flood insurance premium discounts (they can be rated using the pre-Katrina FIRM)	• Large differences between pre-Katrina building floor elevations and post-Katrina building floor elevations • ABFEs near the inland limit of flooding and in areas sheltered from wave effects may overstate wave hazards and wave crest elevations
Modify the Katrina Recovery (ABFE) Maps (via improved wave height analysis)	
• Same as ABFE entries above • Reduce wave height overestimates introduced by the ABFE approach	Large differences between pre-Katrina building floor elevations and post-Katrina building floor elevations
Other Methods	
Vary with method selected	Vary with method selected

Using the Advisory Base Flood Elevations

Communities can make use of the Advisory Base Flood Elevations by those methods summarized in Table 2. In addition, communities can take several steps that will help to protect reconstruction and new construction:

- Define the revised inland extent of the SFHA using ground contours equal to the stillwater elevations contained in Table 1.
- Define the revised inland extent of the coastal high hazard area (V Zone) based on a 4-foot stillwater depth (the depth required to support a 3-foot wave), using whatever new 1 percent stillwater elevation the community adopts. If the community adopts the stillwater elevations in Table 1, ground elevations corresponding to the new inland V Zone limit are shown in Table 3. In most cases, the first encounter with that ground elevation (starting at the shoreline and moving inland) will be the inland V Zone limit.
- Define the inland extent of a Coastal A Zone (see Hurricane Katrina Recovery Advisory, Design and Construction in Coastal A Zones) based on a 2-foot stillwater depth (the depth required to support a 1.5-foot wave), using whatever new 1 percent stillwater elevation the community adopts. If the community adopts the stillwater elevations in Table 1, ground elevations corresponding to the inland limit of the Coastal A Zone are shown in Table 3. In most cases, the first encounter with that ground elevation (starting at the shoreline and moving inland) will be the inland limit of the Coastal A Zone.
- Implement a local ABFE revision process, to allow for special circumstances where property owners can supply better topographic data or information which will result in a more accurate delineation of flood hazards. Note: such a revision process should not allow reduction of the stillwater elevations in Table 1.
- If a community has adopted the International Building Code or the International Residential Code, define the “Design Flood Elevation” as the ABFE. Define the “Flood Hazard Area” as the inland extent of flooding using the ABFE procedure.

Table 3. Ground Elevations Corresponding to Inland Limits of V Zones and Coastal A Zones (based on 1 percent annual chance stillwater elevations published by FEMA, October 3, 2005)

County, Flood Source	1 Percent Annual Chance Stillwater Elevation (ft NAVD)	Ground Elevation Corresponding to Inland Limit of V Zone (ft NAVD)	Ground Elevation Corresponding to Inland Limit of Coastal A Zone (ft NAVD*)
Jackson, Gulf of Mexico	14	10	12
Jackson, Back Bay	12	8	10
Harrison, Gulf of Mexico	18	14	16
Harrison, Back Bay	16	12	4
Hancock, Gulf of Mexico	20	16	18
Hancock, Back Bay	18	14	16

* North American Vertical Datum of 1988

Design and Construction Practices Using ABFEs

FEMA recommends that all reconstruction and new construction within the revised flood hazard area employ a "best practices" approach, incorporating those methods known to eliminate or reduce flood damage. This will mean:

- Elevating buildings higher than before Katrina, on stronger foundations, with continuous load paths and stronger connections, and with wind- and water-resistant walls, windows, doors, and roofs.
- Elevating buildings with the bottom of the lowest horizontal structural member supporting the lowest floor above the ABFE (or whatever regulatory flood elevation a community adopts). *In A Zones, do not elevate the building only such that the lowest floor walking surface is at the ABFE (or whatever regulatory flood elevation a community adopts).*
- Using flood-damage resistant building materials above the lowest floor elevation of the building (remember, floods more severe than the base flood can, and do, occur).
- Designing and constructing buildings using methods and materials described in:
    - The latest model building codes and standards
    - FEMA 55, *Coastal Construction Manual* (revised 2000)
    - FEMA 499, *Home Builder's Guide to Coastal Construction,* Technical Fact Sheet Series (2005) (http://www.fema.gov/fima/mat/fema499.shtm)