NIST Technical Note 1476

Performance of Physical Structures in Hurricane Katrina and Hurricane Rita: A Reconnaissance Report

National Institute of Standards and Technology
Technology Administration, U.S. Department of Commerce

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National Institute of Standards and Technology
Gaithersburg, MD 20899

June 2006

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Acknowledgement

The National Institute of Standards and Technology (NIST) would like to gratefully acknowledge the contributions of a number of individuals whose efforts contributed to the success of the reconnaissance effort and to this final report.

First, we would like to thank the external peer reviewers whose insights and technical expertise contributed greatly to the final report. Those reviewers are:

Robert Bea Ph.D., NAE
University of California, Berkeley

Gregory Baecher Ph.D., NAE
University of Maryland

William Coulbourne, P.E.
URS Corporation

Robert Hanson, Ph.D., NAE

James R. Harris, Ph.D., P.E., NAE
J. R. Harris and Company

Timothy Reinhold, Ph.D.
Institute for Building and Home Safety

NIST would also like to thank the Federal Emergency Management Agency, U.S. Army Corps of Engineers, Federal Highway Administration, and the Department of Housing and Urban Development, who reviewed and provided comments on the draft final report.

NIST would also like to thank the National Oceanic and Atmospheric Administration for providing data and valuable technical input on modeling of storm surge and for their comments on the draft final report.

NIST would also like to acknowledge Mr. John Ingargiola of the Federal Emergency Management Agency's Mititgation Assessment Team, and Dr. Paul Mlakar of the U.S. Army Corps of Engineers, with whom NIST technical experts coordinated their deployments to the Mississippi Gulf Coast and New Orleans during the week of September 26, 2005. NIST also would like to acknowledge the Roofing Industry Committee on Weathering Issues who organized a reconnaissance of roofing damage during the week of September 6, 2005 that included a NIST technical expert. Both of these deployments provided opportunities to share observations of damage and provided valuable firsthand information to guide the planning of the NIST-led reconnaissance.

Finally, we would like to acknowledge the NIST staff who worked diligently to help make the NIST-led reconnaissance successful. We would like to thank Michael Szwed, Joan Smith, and Joseph Widdup of the NIST Acquisition Management Division whose efforts enabled NIST to quickly contract with the Applied Technology Council and deploy teams to the affected areas; Frank Davis, Kellie Beall, Darren Lowe, and Stan Morehouse of the Building and Fire Research Laboratory for their support in the preparation of the field deployment and this report. We would also like to thank Matthew Heyman, NIST Chief of Staff; Michael Rubin and Melissa Lieberman, NIST Office of General Counsel; Sharon Shaffer and Michael Newman, NIST Office of Public and Business Affairs; and Kevin Kimball, NIST Office of Congressional and Legislative Affairs, for their valuable contributions.

Executive Summary

Introduction

This report documents the findings and recommendations resulting from a multi-organizational reconnaissance of the performance and damage to physical structures due to Hurricanes Katrina and Rita in 2005. The reconnaissance was organized and led by the U.S. Commerce Department's National Institute of Standards and Technology's (NIST)[1].

The NIST-led reconnaissance was a cooperative effort from its very launch. NIST and other participating federal agencies and private sector organizations have openly shared data and information from the beginning to plan for and conduct the reconnaissance, and to develop the findings and recommendations. NIST technical experts have participated on other Katrina-Rita studies (e.g., Federal Emergency Management Agency's Mitigation Assessment Team, the U.S. Army Corps of Engineers' Interagency Performance Evaluation Task Force, and the Roofing Industry Committee on Weathering Issues). Similarly, the NIST-led reconnaissance that is the subject of this report has benefited from the participation of technical experts from other federal agencies and the private sector. While the findings and recommendations are NIST's, the report and its recommendations have been reviewed by the participating organizations. The interagency cooperation is continuing as agencies plan and carry out follow-up actions in response to the recommendations of this report.

This work complements other completed and ongoing studies of the performance of structures in the Gulf region during the hurricanes. It is the only study to take a broad look at damage to physical structures and its implications for the Gulf Coast and other hurricane-prone regions.

Disasters such as Hurricane Katrina and Hurricane Rita provide an unfortunate but important opportunity to learn from the performance of structures exposed to catastrophic events and to derive lessons that can lead to improvements in standards, codes, and practice that will reduce losses in future events. NIST chose to undertake a broad-based reconnaissance effort rather than a detailed investigation since much already has been learned from past hurricanes. The reconnaissance was intended to identify new technical issues that need to be addressed in the rebuilding effort, in the improvement of building standards and model codes, or in future research studies. In the process, the team identified opportunities for improvement in standards, codes, and practices that require no additional study.

The reconnaissance identified three key areas where detailed technical studies are essential: (1) to evaluate the performance of the New Orleans flood protection system and provide credible scientific and engineering information for guiding the immediate repair and future upgrade of the system; (2) to develop risk-based storm surge maps for use in flood-resistant design of structures, and (3) to evaluate and, if necessary, modify the Saffir-Simpson hurricane scale's treatment of storm surge effects due to hurricanes.

The findings of the reconnaissance highlight the critical importance of state and local entities adopting and then rigorously enforcing building standards, model codes, and practices.

[1] The National Institute of Standards and Technology (NIST) is a non-regulatory agency of the Department of Commerce. NIST's Building and Fire Research Laboratory (BFRL) supports U.S. industry and public safety by providing critical tools – metrics, models, and knowledge – and the technical basis for standards, codes, and practices.

First, at the time of the hurricanes, there was no statewide building code in Louisiana, Mississippi, Alabama, or Texas[2], although some local jurisdictions within those states had adopted model building codes. The City of New Orleans had adopted the 2000 edition of the model building and residential codes issued by the International Code Council in January 2004. Second, the team observed significant damage in many instances where the winds were lower than those levels cited in codes and standards—suggesting that the structures did not perform as required. Third, older structures—only required to meet building codes in effect when they were built—were particularly vulnerable to wind damage. Current model building codes and standards contain provisions for the design of structures subject to high wind, flood, and storm surge; adoption and enforcement of such codes and standards in hurricane prone regions can greatly improve the performance of structures.

Federal agencies, state and local governments, and the private sector already have taken actions consistent with NIST's recommendations to facilitate rebuilding and mitigate the potential for damage in future storms—in many cases even as the findings were being analyzed and recommendations were being formulated. The U.S. Army Corps of Engineers (USACE) promptly took action to repair damage to the flood protection system in New Orleans as well as to determine the factors that contributed to the failures and make improvements. The Federal Emergency Management Agency (FEMA), in conjunction with USACE, is providing updated base flood information to guide rebuilding. The Federal Highway Administration (FHWA) is developing a plan of action for studies and research for coastal bridges.

NIST Response and Scope of Reconnaissance

On August 29, 2005, Hurricane Katrina first made landfall near Buras, Louisiana[3]. Less than one month later, Hurricane Rita made landfall near the Texas-Louisiana border. NIST began preparation for conducting reconnaissance in the hurricane affected areas on August 29, 2005. NIST coordinated with FEMA, USACE, and other agencies to begin planning for an initial deployment to the region. NIST technical experts deployed to the field twice during September 2005: first during the week of September 6th as part of a team assembled by the Roofing Industry Committee on Weathering Issues (RICOWI), and again, during the week of September 26th in cooperation the FEMA Mitigation Assessment Team (MAT). Two NIST team members also inspected damage to the levees and floodwalls in New Orleans during this deployment. These initial deployments provided valuable input to NIST in planning a comprehensive reconnaissance effort.

NIST, working with the Applied Technology Council (ATC) under a contract, assembled a team of 26 experts to conduct reconnaissance in the areas affected by Hurricane Katrina and Hurricane Rita. The team consisted of a diverse and balanced group of private sector, academic, and government experts from 16 organizations, including NIST, FHWA, and USACE. Based upon the earlier reconnaissance efforts and other available data, the team was deployed to the Mississippi Gulf Coast, New Orleans, and Southeast Texas-Southwest Louisiana areas to conduct reconnaissance and collect perishable data.

The scope of the reconnaissance was broad-based in light of the breadth and scope of damage from the hurricanes and it included major buildings[4], physical infrastructure[5], and residential structures. In

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[2] The Texas Department of Insurance put into effect the 2000 International Building Code and International Residential Code with Texas revisions on February 1, 2003 for the 14 counties located on the Gulf Coast. The 2003 editions of these codes were put into effect on January 1, 2005 for these counties. To be eligible for windstorm insurance, homeowners were required to comply with the Windstorm Code (which is based on these model codes) published by the Texas Department of Insurance.

[3] Cities in southern Florida were hit by Hurricane Katrina on August 25, more than three days before it made landfall in Louisiana on August 29, 2005.

[4] Major buildings are defined herein as buildings that are a result of engineering design or have special occupancy classifications. See Chapter 3 for further detail.

addition to collecting perishable data in the field, the team analyzed environmental data (e.g., wind speeds and storm surge heights) and analyzed observations made by other teams working in the affected areas. The findings contained in this report are consistent with a broad-based field reconnaissance effort covering a large geographic region, rather than an in-depth scientific investigation of a limited set of technical issues. Further, the findings are based on physical evidence that was not completely destroyed by the hurricane.

The Hazard Context

Hurricane Katrina struck the Gulf Coast region as a Category 3 hurricane on the Saffir-Simpson hurricane scale. However, due to the large horizontal size of the hurricane, the accompanying storm surge was observed to be as high as 28 ft at some locations along the Mississippi Gulf Coast. Hurricane Katrina reached Category 5 intensity while in the Gulf of Mexico, with maximum sustained winds of 150 kt (approximately 175 mph). The storm began weakening about 18 hours before making landfall as a Category 3 hurricane with maximum sustained winds of 110 kt (approximately 125 mph).

Hurricane Rita made landfall near the Texas-Louisiana border as a Category 3 hurricane and generated storm surge as high as 15 ft (Cameron, Louisiana). Although the National Hurricane Center (NHC) has officially classified Hurricane Rita as a Category 3 hurricane, Category 3 intensity winds were confined to a small area on the coast in extreme Southwest Louisiana. Most of the affected areas experienced wind speeds consistent with Category 1 or 2 hurricane intensity. Like Hurricane Katrina, Hurricane Rita reached Category 5 intensity over the Gulf of Mexico, with maximum sustained winds of 155 kt (180 mph. Hurricane Rita began weakening 48 hours before landfall.

Principal Findings

Based upon data collected in the field during the reconnaissance, analysis of observations made by other teams, analysis of environmental data, and engineering judgment[6], NIST has identified key findings described below.

In coastal areas and in New Orleans, storm surge was the dominant cause of damage. Storm surge heights, in general, exceeded the levels defined by existing flood hazard maps as well as historical records. While design provisions exist to address storm surge and flooding, existing flood hazard maps – which provide the basis for design of structures – are outdated and not consistent with the risks posed by storm surge in these coastal areas. Better definition of the storm surge hazard is required to appropriately apply existing design provisions and elevation levels to mitigate the effects of storm surge on buildings and residences.

The Saffir-Simpson hurricane scale—which is used in part by emergency managers for evacuation planning and making evacuation decisions—specifies hurricane wind speeds and indicates storm surge heights associated with each hurricane category. Wind speed is the determining factor in the scale, as storm surge values are highly dependent on the slope of the continental shelf and the shape of the coastline, in the landfall region. Hurricane Katrina and Hurricane Rita showed that it is possible for storm surge heights to substantially exceed heights associated with a specified category on the Saffir-Simpson hurricane scale. The National Oceanic and Atmospheric Administration (NOAA) does not rely on the storm surge ranges associated with the Saffir-Simpson hurricane scale in its hurricane advisories. Instead, NOAA includes in its advisories storm surge forecasts based upon use of storm surge simulation models.

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[5] Physical infrastructure includes: levees and floodwalls, bridges and roadways, seaport structures, utilities (e.g., electric power, water and wastewater, communications, gas distribution), and industrial facilities such as petrochemical plants.
[6] Analytical, numerical, and statistical calculations were outside the scope of this reconnaissance study.

NOAA, in their advisories prior to landfall of Hurricane Katrina, predicted "coastal storm surge flooding of 18 to 22 ft above normal tide levels…locally as high as 28 ft along with large and dangerous battering waves…can be expected near and to the east of where the center makes landfall", and "storm surge flooding of 10 to 15 ft near the tops of the levees is possible in the greater New Orleans area." These storm-surge related advisories were consistent with observed high water marks along the Mississippi coast where the hurricane made landfall and the greater New Orleans area.

Storm surge and associated wave action led to breaches in the flood protection system in New Orleans, resulting in significant structural damage to residences in the immediate vicinity of breaches due to high-velocity water and flooding in approximately 75 percent of the city. The NIST-led team observed failures of the levees and floodwalls in New Orleans by three different mechanisms: rotational failure of the floodwall-sheet pile system triggered by soil erosion due to overtopping; massive erosion and scour of the earthen levee at the levee/floodwall junction (with water overtopping); and sliding instability of the floodwall-levee system due to foundation failure (without water overtopping). The foundation failures due to sliding instability at the above breaches could have been possibly caused either by underseepage erosion and piping or by shear failure within the clay in the foundation beneath the levee and the floodwall.

Houses in New Orleans were constructed at grade level or slightly elevated on the presumption that the flood protection system would remain intact and that flooding in low lying areas would be the result of precipitation only. Many houses located in the immediate vicinity of levee breaches were severely damaged or destroyed as a result of high velocity water flow and flooding. It is important for building codes and standards to better define the hazards and design requirements in coastal flood prone regions in a risk-consistent manner.

Many bridges in the coastal areas were damaged due to the uplift and lateral loads imparted by storm surge and associated wave action. A number of simple span bridges lost spans or had spans displaced as a result of these actions. Some bridges, both highway and railway, exposed to these actions remained in place due to design features that prevented displacement of decks. Swing span bridges exposed to storm surge were in many cases rendered inoperable due to inundation of mechanical and electrical equipment. Failures of precast parking-garage structures were similar to those of simple span bridges, where uplift and wave forces dislodged first floor decks from their connections to columns.

In coastal Mississippi, storm surge, wave action, and surge-borne debris caused extensive damage to casino barges that either sank in place or broke free of moorings and floated inland. Mooring requirements, based on wind speeds of 155 mph and 15 ft storm surge heights were inadequate for the storm surge heights generated by Hurricane Katrina. There are no national standards for the design of mooring systems used to secure permanently moored facilities such as casino barges.

Many industrial facilities, such as seaports, petrochemical facilities, and utilities sustained damage due to storm surge and flooding. One of the major ports in the region sustained significant structural damage to piers and warehouses due to storm surge and wave loading. Inundation due to storm surge and waves caused damage to electrical and mechanical equipment on the port's cargo crane, rendering the crane inoperable. Also, the hurricane tie-down for this crane was damaged.

Current model codes and standards contain provisions for design of structures and location of equipment to account for flooding and storm surge. However, several buildings were rendered inoperable because critical equipment, such as backup electrical generators, electrical equipment, and chiller plants were located at or below grade and damaged due to inundation by floodwaters. In addition, some utilities such as electrical generation plants and substations, and water and wastewater treatment plants, became inoperable because they sustained damage to electrical and mechanical equipment.

Away from the immediate coastal areas, wind and wind-borne debris were the dominant causes of damage to structures. In general, wind speeds were below levels required by codes and standards. Wind also caused damage to roofing and rooftop equipment, providing paths for water ingress into buildings. Wind-driven rain through walls and around intact windows also was responsible for water damage to the interiors of buildings.

Major buildings suffered wind-induced damage to glazing (window glass) as a result of debris impact from aggregate surface roofs on adjacent buildings, debris from damaged equipment screens on top of buildings, and debris from the damaged façade or structure of adjacent buildings. In many cases, buildings that suffered structural damage due to wind were built before current model building codes were available. Design wind speeds in current codes and standards provide a sufficient level of safety if provisions are properly implemented and enforced.

Roofing failures on buildings and residential structures were observed throughout the region. Typical damage to building roofs included failure of roof coverings and finishing details, loss of the roof deck, and in some cases the supporting structure. Failure of shingles on residential structures was observed throughout the region, and the team documented many cases of improper installation of shingles[7].

Industrial facilities outside the surge and flood zones also sustained damage due to wind loads. In another major port in the region, failures of hurricane tie-downs due to wind loads caused significant damage to three large cranes. As many as one million timber electric power distribution poles were lost in the two hurricanes, as well as a number of high voltage transmission towers. Petrochemical plants in the region experienced damage that was generally limited to cooling tower shrouds, and insulation on oil storage tanks and flare towers, due to wind. Some structural failures of oil storage tanks were observed at plants near Hurricane Katrina's landfall.

Recommendations

As a part of its reconnaissance, NIST is making 23 recommendations for specific improvements in the way that buildings, physical infrastructure, and residential structures are designed, constructed, maintained, and operated in hurricane prone regions. It is important to note that these recommendations may apply to other hurricane-prone regions of the country. These recommendations are grouped as follows:

Group 1: Immediate impact on practice for rebuilding: These recommendations (1 through 5) have immediate implications for the repair and reconstruction of buildings, physical structures, and associated equipment damaged or destroyed by Hurricanes Katrina and Rita.

Group 2: Standards, codes, and practices: These recommendations (6 through 14) address the need for development or modification of codes, standards, and practices with a view toward improving the performance of buildings, physical structures, and associated equipment in future hurricanes based upon the observed damage due to Hurricanes Katrina and Rita.

[7] A statistically-based analysis of roofing performance, damage, and installation practices was beyond the scope of this reconnaissance study.

Group 3: Further study of specific structures or research and development: These recommendations (15 through 23) identify the need for detailed performance assessments of structures or classes of structures to determine the factors that influenced their performance during the hurricanes or the need for research and development on specific technical issues.

The recommendations call for action by specific entities regarding standards, codes, and regulations, as well as their adoption and enforcement; professional practice, education and training; and research and development.

The recommendations do not prescribe specific systems, materials, or technologies. Instead, NIST encourages competition among alternatives that can meet performance requirements. The recommendations also do not prescribe threshold levels; NIST believes that this responsibility properly falls within the purview of the public policy setting process, in which the standards and codes development process plays a key role.

NIST believes that the recommendations are realistic, appropriate, and achievable within a reasonable period of time.

Most of the recommendations deal with adopting and enforcing current requirements or with making improvements to existing requirements and practice. Some of the recommendations address developing a risk-consistent basis for consideration of storm surge as a design load for coastal buildings and structures.

NIST strongly urges state and local agencies to adopt and enforce building codes and standards since such enforcement is critical to ensure the expected level of safety. In many cases, the reconnaissance clearly found that building codes, standards, and practice are adequate to mitigate the types of damage that resulted from the hurricanes. *Following good building practices also is critical to better performance of structures during extreme events like hurricanes.* Relatively straightforward changes to practice could have reduced the damage that occurred. The best codes and standards cannot protect occupants or buildings unless they are strictly followed. Examples include:

- Masonry wall failures observed during the reconnaissance may have been prevented had they been properly anchored and reinforced as required by the model codes.

- Many roofing shingle failures resulted from installers using an inadequate number of fasteners or installing fasteners in the wrong locations. NIST is recommending that states and localities consider licensing roofing contractors, providing continuing education for contractors, and putting in place field inspection programs to monitor roofs being constructed. A licensing program instituted by the state of Florida for roofing contractors may serve as a model for other states to implement licensing programs.

- Wind-borne gravel from building rooftops caused a great deal of damage to nearby structures. Model building codes do not permit aggregate surface roofs in high wind zones to ensure that the aggregate does not become wind-borne debris and cause damage to windows on nearby buildings.

- In many instances backup electrical generators, electrical equipment, chillers, and other critical equipment were not placed above the expected flood levels. Model code provisions address the location of critical building equipment to avoid this kind of damage due to flooding. This would not have protected all buildings that lost equipment due to the high storm surge, but it would have made a large difference for many critical structures.

Federal agencies, state and local governments, and the private sector already have taken actions that are consistent with NIST's recommendations—in many cases even as the findings were being analyzed and recommendations were being formulated. NIST encourages other organizations with responsibility for implementation to take similar actions. Some of the actions that are already underway include:

<u>Levees and Floodwalls:</u>

- USACE immediately began a major project (Project Guardian) to rebuild the levees and floodwalls where breaches occurred before the start of the hurricane season on June 1, 2006.

- USACE initiated the Interagency Performance Evaluation Task Force (IPET) to assess the performance of the New Orleans flood protection system, understand the factors that contributed to failures during Hurricane Katrina, and make recommendations for improvements.

<u>Building Code Adoption and Other Actions:</u>

- Louisiana has adopted the International Building Code (IBC) in the 11 parishes hardest hit by Hurricane Katrina effective immediately for reconstruction. The IBC will become effective statewide for all new construction in 2007.

- The Mississippi Legislature (House Bill 45) amended the Mississippi Code of 1972 to allow the gaming portions of Gulf Coast casinos to be built on land within 800 feet of the high water line or in some cases, as far inland as the southern boundary of the US-90 right-of-way.

- The Department of Housing and Urban Development (HUD) requires that community development block disaster recovery grants not be used for any activity in special flood hazard areas delineated in FEMA's most current flood advisory maps unless it also ensures that the action is designed or modified to minimize development-related harm to or within the flood plain.

<u>Flood Map Modernization and Storm Surge Mapping:</u>

- FEMA, leading the effort, in cooperation with the USACE, has undertaken a project to update the Flood Insurance Rate Maps for New Orleans and the Gulf Coast areas affected by Hurricane Katrina and Hurricane Rita. Both NOAA and FEMA already are conducting studies to document and assess the storm surge risks posed by Hurricane Katrina in the Gulf Coast region. FEMA has also published a Coastal Construction Manual which provides guidance on building standards and techniques to resist both wind and waves.

- The Federal Coordinator for Gulf Coast Rebuilding, FEMA, and USACE have issued guidelines for rebuilding in New Orleans and surrounding areas based on updated advisory base flood elevations.

- The U.S. Geological Survey (USGS) has initiated a project to map the changes in the coastline due to the effects of storm surge. The agency also plans to study the effects of natural and restored land in mitigating the effects of storm surge.

- NIST has funded a project to develop the methodology for risk-based structural design criteria for coastal structures subjected to both hurricane winds and storm surge that will consider different methods for predicting input hurricane parameters for storm surge and wave models, different storm surge models, and coupling of storm surge models with different wave models. NIST is facilitating coordination and collaboration among relevant federal agencies (e.g., FEMA, USACE, NOAA, USGS, and FHWA) and key private sector organizations in support of FEMA's overall flood map modernization program and under FEMA leadership to ensure that the needs for structural design are adequately met.

Highway Bridges:

- FHWA issued an initial guidance document on "Coastal Bridges and Design Storm Frequency." This document provides a regulatory and engineering rationale for considering both storm surge and wave forces, specifically for those coastal states affected by Hurricane Katrina.

- FHWA is developing a plan of action that will be used to coordinate with the American Association of State Highway and Transportation Officials (AASHTO) and other stakeholders in performing studies and research for coastal bridges vulnerable to scour and hydrodynamic forces.

- FHWA has issued a solicitation for a pooled funds project to develop retrofit strategies and options to mitigate damage to highway bridges subject to coastal storm hydrodynamic factors and recommend improvements for bridges in coastal environments. The objective of this project is to develop solutions that can be immediately implemented by states and bridge owners and adopted into AASHTO standards as appropriate.

Recommendation	Affected Standards/Codes/ Guidance	Primary Interested Government Entities	Interested Entities
Group 1: Immediate impact on practice for rebuilding			
<u>Recommendation 1.</u> Improve the design, construction, and performance of the New Orleans levees and floodwalls by: (1) conducting a comprehensive review and upgrade of the design hazard, criteria, and manuals for levees and floodwalls to develop a risk-based approach to design for storm surge that is similar to the current risk-based approach to design for wind; (2) performing a systematic review of the existing, as-constructed levees and floodwalls relative to design requirements in USACE design manuals; and (3) developing methodologies for levee and floodwall design, construction, and repair that allow for overtopping without subsequent failure of the floodwall or levee structures. Major steps are already underway that will fulfill this recommendation. USACE promptly took action (a) to repair damage to the New Orleans flood protection system and (b) to conduct a detailed performance evaluation that will provide credible scientific and engineering information for guiding the immediate repair and future upgrade of the system.	*USACE Engineer Manuals governing the design, construction, and maintenance of levees and floodwalls.*	USACE	Local levee districts, FEMA, ASCE-COPRI
<u>Recommendation 2.</u> Install mechanical, electrical, and plumbing components, equipment, and systems—including alternative/backup electric power supplies—required for the continued operation of existing critical facilities at a level that is above the design flood elevation by a specified minimum threshold.	*FEMA Flood Insurance Rate Maps, International Building Code, NFPA 5000*	FEMA	ICC, NFPA, BOMA, ASHRAE
<u>Recommendation 3.</u> Adopt and enforce model building codes for masonry wall construction to ensure that: (1) load-bearing masonry walls are adequately anchored and reinforced to resist lateral forces; (2) non-load-bearing masonry walls are adequately anchored to the supporting structure; and (3) exterior masonry walls are flood-proofed to the design flood elevation.	*IBC, IRC, NFPA 5000, ASCE 24, ACI 530 (also published as ASCE 5 and TMS 402), ACI 530.1 (also published as ASCE 6 and TMS 602), and ACI 318, FEMA Technical Bulletin 11-01*	FEMA	TMS, ASCE, ACI, ICC, NFPA, state and local building authorities

Recommendation	Affected Standards/Codes/ Guidance	Primary Interested Government Entities	Interested Entities
<u>Recommendation 4.</u> Adopt and enforce model building codes and the latest standards for roofing systems to: (1) prohibit the use of aggregate surface roofs when re-roofing existing aggregate surface roofs in hurricane-prone regions; and (2) ensure that roofing systems are designed and installed according to standards for roofing in high wind zones. This includes residential steep-sloped asphalt shingle roofs, commercial low-sloped roofs, and mechanically attached metal roofs. Model building codes should be modified to incorporate ASTM D7158, "Wind Resistance of Sealed Asphalt Shingles (Uplift Force/Resistance Method)."	*International Building Code, NFPA 5000, ASTM D 7158*	State and local building authorities (especially in Mississippi, Louisiana, Texas, and Alabama)	Roofing Industry Committee on Weathering Issues (RICOWI), Asphalt Roofing Manufacturers Association (ARMA), the National Roofing Contractors Association (NRCA), and the Roof Consultants Institute (RCI), ASTM, ICC, NFPA
<u>Recommendation 5.</u> States and local jurisdictions should consider (1) licensing of roofing contractors; (2) continuing education of roofing contractors; and (3) field inspection programs to monitor roofs under construction for proper installation, in order to ensure acceptable roofing application.		State and local building authorities	RICOWI

Recommendation	Affected Standards/Codes/ Guidance	Primary Interested Government Entities	Interested Entities
Group 2: Standards, codes, and practices			
Recommendation 6. Evaluate and upgrade mooring system design criteria for floating structures (e.g., casino barges) to be consistent with the wind and storm surge risk including dynamic wave loads.		State and local government agencies (e.g., Mississippi Gaming Commission), USACE, USCG	
Recommendation 7. Develop risk-based storm surge maps for several mean recurrence intervals, incorporating storm surge height and current velocity and the associated wave action, to provide a technical basis for the design of coastal structures in storm surge zones – including port facilities, flood protection systems, coastal highway and railroad bridges, and buildings - along the U.S. Atlantic and Gulf Coast regions. The information on storm surge heights, current velocity, and wave characteristics could be provided in separate maps at different mean recurrence intervals (e.g., 10, 50, 100, and 500-yrs)—in addition to the current flood maps which provide total inundation expected from all sources, including storm surge—for use in designing coastal structures.	*ASCE 7, ASCE 24*	FEMA, NOAA, USACE, NIST	USGS, NSF, FHWA, ASCE
Recommendation 8. Evaluate and, if necessary, modify the Saffir-Simpson hurricane scale's treatment of storm surge effects due to hurricanes. The results of the evaluation should be broadly discussed by experts before changes, if needed, are considered for implementation.		NOAA, NIST	FEMA, NSF

Recommendation	Affected Standards/Codes/ Guidance	Primary Interested Government Entities	Interested Entities
Recommendation 9. Develop design requirements for improved structural integrity of precast reinforced concrete structures subject to storm surge loadings.	*ACI 318, International Building Code, NFPA 5000*	NIST, FEMA	American Concrete Institute (ACI), Portland Cement Association (PCA), Prestressed Concrete Institute (PCI), Construction Technology Laboratories (CTL), ICC, NFPA
Recommendation 10. Establish risk-based design methodologies for: (1) coastal bridges, (2) communication systems, (3) electricity, water, and gas distribution systems, and (4) roadside signs to resist flooding, storm surge, debris impact, and wind.	*American Association of State Highway and Transportation Officials (AASHTO)'s "LRFD Bridge Design Specification" and "Standard Specifications for Structural Supports for Highway Signs, Luminaries and Traffic Signals;" ASME/ANSI B31.3; API 620 and 650; AWWA D; RUS 1742e-200 and -300; ASCE 7 and 10, Manual 72, 74, and 91, Concrete Poles; IEEE; NESC; TIA/EIA 222F and G; Bell Core.*	USACE, FHWA	FEMA, ASCE, AASHTO, EPRI, IEEE, Railroad Industry
Recommendation 11. Evaluate the adequacy of restraining systems for large cargo cranes in port facilities.		OSHA, State Port Authorities in coastal areas	American Association of Port Authorities; Port Authorities at Mobile, Pascagoula, Biloxi and New Orleans; National Maritime Satey Association (NMSA), International Longshoremen's Association (ILA)
Recommendation 12. Adopt and implement existing model code provisions for providing alternative/backup electric power supplies for all critical facilities and equipment.	*International Building Code, NFPA 5000, ASCE 24*		ICC, NFPA, APWA, AWWA, utility and telecommunication companies

Recommendation	Affected Standards/Codes/ Guidance	Primary Interested Government Entities	Interested Entities
Recommendation 13. Install isolation valves in water and gas distribution systems in areas susceptible to damage.	*ASME B31.3*	State and local governments	NFPA, APWA, utilities
Recommendation 14. Develop and implement special inspection requirements for connection and cladding attachments in pre-engineered metal buildings within model codes for hurricane prone regions.	*International Building Code, NFPA 5000*	NIST	ICC, NFPA
Group 3: Further study of specific structures or research and development			
Recommendation 15. Conduct detailed performance assessments of coastal highway and railroad bridges to fully understand and document the factors that contributed to their failure or survival and make recommendations for improvements to future designs. This work should include: (1) evaluation of design methods and connection details to improve the resistance to storm surge-induced uplift and lateral forces; (2) development of measures to prevent widespread loss of functionality of moveable bridges following a hurricane due to inundation of electrical and mechanical equipment; (3) development of means to mitigate the impacts of debris and massive objects carried by storm surge on the performance and functionality of bridges; and (4) development of methods for armoring bridge approaches against scour and erosion to avoid losing the use of a bridge.	*AASHTO LRFD Bridge Design Specification*	FHWA	AASHTO, AREMA, NSF, Railroad Industry
Recommendation 16. Conduct detailed studies to identify mechanisms for water ingress into buildings during hurricanes and to develop improved building envelope construction and cladding systems that are resistant to water ingress.	*International Building Code;IRC;; NFPA 5000*	DOE	HUD, FEMA, ASCE, ASTM, ICC, NFPA, and state and local building authorities

Recommendation	Affected Standards/Codes/ Guidance	Primary Interested Government Entities	Interested Entities
<u>Recommendation 17.</u> Conduct an evaluation of the application of seismic design methods and retrofit details to improve the resistance of existing unreinforced masonry construction to extreme wind loading.	*ACI 530 (also published as ASCE 6 and TMS 402)*	FEMA	ACI, ASCE, TMS, state and local building authorities
<u>Recommendation 18.</u> Conduct detailed performance assessments of the wharfs in the Gulf States that were exposed to uplift and lateral forces due to storm surge to fully understand and document the factors that contributed to their performance during Hurricane Katrina or Rita and make recommendations for improvements to future designs.		State and local port authorities	ASCE-COPRI
<u>Recommendation 19.</u> Conduct detailed performance assessments of the portable classrooms (manufactured houses) in Port Arthur, TX, to fully understand and document the factors that contributed to their survival and make recommendations for improvements to future designs.	*HUD Manufactured Home Construction and Safety Standards*	HUD	MHI, NAHB, state and local building authorities
<u>Recommendation 20.</u> Conduct detailed studies of the performance of metal buildings subjected to hurricane force winds to fully understand and document the factors that contributed to their performance and make recommendations for improvements to future designs.		NIST	Metal Building Manufacturers Association (MBMA)
<u>Recommendation 21.</u> Conduct detailed studies of the performance of residential asphalt shingle roofing, metal roofing on both residential and commercial buildings, and low-rise membrane roofs on commercial buildings to identify factors that affected performance and provide the technical basis for improved guidance on the use of these roofing systems in high wind zones.	*ASTM D 7158, International Building Code, International Residential Code*	HUD, DOE	Asphalt Roofing Manufacturers Association (ARMA), National Roofing Contractors Association, RICOWI, Roof Consultants Institute, Metal Construction Association, Metal Building Manufacturers Association, NAHB.

Recommendation	Affected Standards/Codes/ Guidance	Primary Interested Government Entities	Interested Entities
Recommendation 22. Conduct detailed studies to: (1) evaluate and quantify the effects of corrosion, decay, and other aging factors on the service life performance of residential buildings and components; and (2) evaluate and improve performance criteria and installation practice for anchorage systems for manufactured homes.	*International Residential Code, HUD Manufactured Home Construction and Safety Standards*	HUD	NAHB, MHI, FEMA
Recommendation 23. Evaluate the effects of shielded (e.g., wooded or wooded/suburban) exposures and their potential for reducing the wind loads on nearby residential structures and better explain the variation in observed damage.	*ASCE 7*	HUD, NIST	NAHB, ASCE, AAWE