Reconnaissance of Damage to Physical Structures in the Gulf States from Hurricanes Katrina and Rita

by

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ABSTRACT

The National Institute of Standards and Technology (NIST) led reconnaissance to assess the performance of physical structures during Hurricane Katrina and Hurricane Rita. This paper summarizes 1) the major findings of the NIST-led reconnaissance team, 2) analysis of environmental actions (wind speed, storm surge, and flooding) that were present during the hurricanes in regions that were affected by the hurricanes, and 3) the team's observations of damage to major buildings, infrastructure, and residential structures resulting from wind and wind-borne debris, storm surge and surge-borne debris, and flooding. Storm surge and flooding caused the most extensive damage, completely devastating most physical structures in their paths. Damage due to wind and wind borne debris was also prevalent in most areas of the reconnaissance.

KEYWORDS: building codes and standards; building practices; flooding; hurricane; major buildings; physical infrastructure; residential structures; storm surge; surge-borne debris; wind; wind-borne debris.

1.0 BACKGROUND

On August 29, 2005, Hurricane Katrina made landfall along the Mississippi-Louisiana border. During its movement through the Gulf of Mexico, Hurricane Katrina reached a Category 5 intensity on the Saffir-Simpson Hurricane Intensity Scale, with maximum sustained winds of 77.3 m/s (173 mph). The storm began to weaken about 18 hours before landfall, and was a Category 3 hurricane with maximum sustained winds of 56.3 m/s (126 mph) when it made landfall. However, the storm generated a significant storm surge, particularly along the Mississippi Gulf Coast, where in some locations the storm surge reached heights of 28 ft. The storm surge caused extensive damage to buildings, residential structures, and physical infrastructure along the Mississippi Gulf Coast. Damage from wind and storm surge extended east into Alabama's coastal areas. To the west, the storm surge caused breaches in the levees and floodwalls surrounding New Orleans, Louisiana, in several locations. These breaches caused flooding of approximately 75 % of the city and led to extensive damage to buildings, infrastructure and residential structures. In areas beyond the storm surge debris line, wind and wind-borne debris damage was extensive. Hurricane Katrina is the costliest hurricane to strike the United States.

Less than one month later, Hurricane Rita made landfall near the Texas-Louisiana border as a Category 3 hurricane with maximum sustained winds of 44.7 m/s (100 mph). During Hurricane Rita's path through the Gulf of Mexico but prior to landfall, the storm reached Category 5 intensity with maximum sustained winds of 78.2 m/s (175 mph). Hurricane Rita began weakening 36 hours before landfall. While Hurricane Rita did not generate the same level of storm surge as Hurricane Katrina, storm surge did cause significant damage in some developed coastal

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areas. Wind and wind-borne debris were the dominant causes of damage in the affected area.

The National Institute of Standards and Technology (NIST) is a non-regulatory agency of the Department of Commerce. NIST supports U.S. industry and public safety by providing critical tools – metrics, models, and knowledge – and the technical basis for standards and codes, and practices. Disasters such as Hurricane Katrina and Hurricane Rita provide an opportunity to learn from the performance of structures exposed to extreme loads and to derive lessons that can lead to improvements in standards, codes, and practice that will reduce losses in future events.

NIST began preparation for conducting reconnaissance in the hurricane affected areas on August 29, 2005. NIST coordinated with the Federal Emergency Management Agency (FEMA), and other agencies to begin planning for an initial deployment to the region. During the week of September 6, 2005, a NIST roofing expert deployed as part of a team assembled by the Roofing Industry Committee on Weathering Issues (RICOWI). This team conducted reconnaissance of damage to commercial and residential roofing systems in the Alabama and Mississippi coastal areas. During the week of September 26, 2005, four NIST structural engineers deployed in cooperation the FEMA Mitigation Assessment Team to conduct reconnaissance of damage in the coastal areas between New Orleans and the Biloxi-Gulfport, Mississippi, area. Two of the NIST team members went to New Orleans during the last two days of this deployment to document damage to the levees and floodwalls in New Orleans. These initial deployments provided valuable input to NIST in planning a more comprehensive reconnaissance effort.

NIST, working with the Applied Technology Council (ATC) under a contract, assembled a team of twenty-six experts to conduct reconnaissance in the areas affected by Hurricane Katrina and Hurricane Rita. The team consisted of experts from NIST, Federal Highway Administration (FHWA), U.S. Army Corps of Engineers (USACE), as well as a diverse and balanced group of experts from the private sector and academia. The team deployed during the weeks of October 10, 2005 and October 17, 2005. Based upon the earlier reconnaissance efforts and other available data, the team selected the Mississippi Gulf Coast, New Orleans, and Southeast Texas-Southwest Louisiana area for conducting reconnaissance and collecting perishable data. The scope of the reconnaissance included major buildings, physical infrastructure, and residential structures. The team subdivided into three smaller teams, each of which deployed to one of the selected areas to conduct reconnaissance. In addition to collecting perishable data in the field, the team analyzed environmental data (e.g., wind speeds, storm surge, and flooding), and analyzed observations made by other teams working in the affected areas.

2.0 MAJOR FINDINGS

In coastal areas and in New Orleans, storm surge was the dominant cause of damage. Storm surge heights, in general, exceeded historical records. Storm surge led to breeches in three major canals in New Orleans resulting in significant structural damage to residences in the immediate vicinity of breeches due to high-velocity water and flooding in approximately 75 % of the city. In coastal Mississippi, storm surge and surge-borne debris caused extensive structural damage to buildings and residences in the surge zone, damage to casino barges that either sank in place or broke free of moorings and floated inland. Storm surge also caused significant damage to bridges in the coastal areas of Mississippi and Louisiana. Currently, storm surge is not considered as a design load for buildings, residences, and transportation structures in coastal areas.

Away from the immediate coastal areas, wind and wind-borne debris were the dominant causes of damage to buildings, residences, and infrastructure. Major buildings suffered damage to glazing (windows) as a result of aggregate surfacing on nearby roofs, debris from damaged equipment screens, and debris from damaged buildings. Wind also caused damage to roofing and rooftop equipment providing paths for water ingress into buildings. Wind-driven rain through wall and around intact windows was also responsible for water damage to the interiors of buildings.

It was also observed that both Hurricane Katrina and Rita generated storm surges that were higher than would be expected for hurricanes of their intensity at landfall. While wind speeds diminished rapidly as the hurricanes approached landfall, the storm surge did not dissipate as rapidly and led to significant damage to structures located in the areas of greatest storm surge height.

Based upon its data collection in the field during the reconnaissance, analysis of observation made by other teams, and analysis of environmental data, NIST has identified a number of key findings related to environmental actions, major buildings, infrastructure and residential structures.

3.0 ENVIRONMENTAL ACTIONS

3.1 Wind Speeds

In general, for all locations studied in this reconnaissance report, the observed and modeled/estimated wind speeds for both hurricanes were less than the design wind speeds prescribed in the ASCE 7-02 (2005) Standard.

Hurricane Katrina. Wind speed estimates taken from the National Oceanic and Atmospheric Administration (NOAA) and Applied Research Associates (ARA) indicate that the maximum sustained wind speed at landfall along the Mississippi coast was estimated between 49.2 m/s (110 mph) and 53.6 m/s (120 mph) (2005). In New Orleans, the ARA maps suggest that wind speeds reached 40.2 m/s (90 mph), while the NOAA maps indicate that winds were 35.8 m/s (80 mph) or less. Furthermore, according to a recent National Hurricane Center (NHC) report (2005), the maximum sustained wind speed produced by Katrina was approximately 56.3 m/s (126 mph). Based on wind speed information from these data sources, Hurricane Katrina was a Category 3 event on the Saffir-Simpson (SS) scale.

Hurricane Rita. At landfall, Hurricane Rita's sustained winds had diminished to a SS Category 2 intensity, with the exception of a small area on the coast of extreme Southwestern Louisiana that was to the east of the eyewall, where wind speeds were a Category 3 intensity. However, most of the affected area in Southwest Louisiana and Southeast Texas was exposed to wind speeds of SS Category 1 or 2 intensity. The highest 3 s peak gust observed for Hurricane Rita was 51.9 m/s (116 mph) at Port Arthur, Texas. Based on an assessment of maximum sustained wind speeds (NOAA wind speed map), the highest level estimated was less than 49.2 m/s (110 mph). Hurricane Rita was officially classified as a Category 3 hurricane. However, most of the effected area in southwest Louisiana and southeast Texas was exposed to hurricane wind speeds of Category 1 or 2 intensity.

3.2 Storm Surge

Hurricane Katrina. A number of locations experienced storm surge heights greater than 20 ft. NOAA's National Climatic Data Center estimated that the coastal surge along Mississippi exceeded 25 ft. Observations by the NIST-led reconnaissance team also suggest that in some locations between Biloxi and Long Beach, Mississippi, the surge reached as high as 30 ft. Estimates of surge heights in New Orleans ranged from 9 ft to 10 ft. This information is based on High Water Mark data collected by FEMA investigators and on other observations as well. These surge heights are consistent with a SS Category 5 hurricane.

Hurricane Rita. The National Climatic Data Center estimated surge levels of 8 ft in New Orleans and about 15 ft along the Texas/Louisiana border flooding coastal towns in the region. Surge heights observed by the NIST-led reconnaissance team are consistent with a SS Category 3 to SS Category 4 hurricane.

3.3 Flooding

The depth of flooding in New Orleans based on several independent sources (NOAA, 2005) indicates that many areas of New Orleans were covered by at least 7 ft to 9 ft of water with some areas exceeding 20 ft (as of August 31, 2005). The NIST-led reconnaissance team observed flood depths of up to 10 ft in some areas of New Orleans.

4.0 MAJOR BUILDINGS

4.1 Structural Systems

Storm surge caused partial collapse of concrete parking structures located in Biloxi. These structures were constructed of concrete columns, precast concrete girders and beams, and pretensioned, double-tee beams for decks. Decks subjected to storm surge were lifted and displaced off of their beam seats due to uplift forces (either directly or in combination with the pre-stressing forces in the beams) and poor connection details.

Unreinforced brick parapet walls were observed to have partially collapsed in New Orleans and Port Arthur. Failure of the rooftop parapets due to wind likely initiated failure of the exterior wall. There was an apparent lack of proper reinforcement within the walls or a framing system to resist lateral movement.

The collapse of masonry walls by strong winds was due to the lack of proper reinforcement within the walls or due to insecure attachment of these walls to the building frame. Instances of failure due to storm surge were also observed.

The NIST-led reconnaissance observed damage to metal buildings ranging from minimal damage to partial collapse. The roof purlins in the windward, end bay of several large, steel-framed warehouses buckled upwards due to wind pressures and the end frame collapsed inward. These failures allowed rain and winds to devastate the building's interior.

Casino barge structures along the Mississippi coast broke free of their moorings during Hurricane Katrina and caused extensive damage. Barges were observed to have 1) partially collapsed all levels to the corner bay of an otherwise structurally sound, reinforced concrete parking garage, 2) drifted inland with the storm surge, 3) collided with multi-story hotels causing partial collapse of these buildings, and 4) sank in place.

4.2 Roofing

Conventional bituminous membranes with and without gravel surfacing, and polymer-modified bituminous membranes generally with granule surfacing were the predominant roof systems on major buildings. Other systems included metal roofing, synthetic single ply roofing, and spray polyurethane foam (SPF) roofing. Damage to all types of roofing was observed but the extent of the damage varied according to the system. Examples of typical damage included: failure of flashings, puncturing of roof coverings or the total roof system, blow-off of the roof coverings often accompanied by loss of insulation, blow-off of the insulation and covering accompanied by loss of deck, failure of metal roof panels with and without damage to structural members, and combinations of these types of damage.

Where detailed observations of roofing damage were made, the failures were in many cases attributed to installation that did not comply with currently accepted practice as given in manufacturers' literature and association guidelines. Examples included lack of an adequate number of fasteners, and mis-location of fasteners, and inadequate heating of bituminous membranes.

The predominant damage to bituminous membrane roofing was blow-off of some section of the membrane. Damage was generally associated with three modes of failure that have been commonly observed in past hurricanes: (1) poor performance of perimeter metal flashing, (2) inadequate inter-laminar strength of insulation and inadequate adhesion between membranes and insulation, and (3) poor attachment of bituminous base sheets to decks and other substrates. The three are associated with selection of a membrane roofing system that does not have adequate resistance to the maximum winds expected for the given geographic location or misapplication of the roofing during installation.

Many metal roofs performed well, particularly standing seam metal roofs installed on commercial and industrial buildings and schools. Often where damage to such metal roofing occurred, it was limited to a small portion of the roof area whereby some panels on the structure were bent away or blown off. Where metal roofing sustained considerable damage, it often, although not exclusively, occurred at industrial-type facilities including the roofs and structural supports of all metal buildings.

A limited number of spray polyurethane foam (SPF) roofing systems was observed in the Hurricane Rita damage zone. Such roofing was found, with minor exception, to have sustained the winds well without blow-off of the SPF or damage to flashings.

Damage to rooftop equipment was observed in all study areas. In some cases, equipment and portions of rooftop mechanical screens became windborne, causing damage to the building itself, or to other buildings downwind.

4.3 Window Systems

Many buildings in areas of the NIST-led reconnaissance had roofs with aggregate surfaces. The aggregate typically became wind-borne during the hurricanes and caused damage to the windows of neighboring downwind buildings. The aggregate caused extensive damage to window systems in many high-rise buildings, particularly in New Orleans, and in many critical facilities such as schools and hospitals.

Wind-driven water penetration through exterior masonry and other undamaged cladding and glazing elements combined with water from other sources forced closure of important hospital facilities as a result of Hurricane Rita. Facilities remained partially or totally out of operation for weeks, indicating a need to review resistance of exterior cladding and glazing systems for wind-driven water.

4.4 Cladding

The NIST-led reconnaissance observed damage to exterior insulation and finish systems (EIFS) throughout the reconnaissance areas, in many cases without evidence of wind- or waterborne debris, suggesting that wind pressure caused the observed damage.

Damage to masonry veneer due to high winds was observed throughout the hurricane affected areas. Damage was associated with a lack of reinforcement to resist lateral loads and inadequate or deteriorated mechanisms that anchor the masonry cladding to the building.

4.5 Water Damage to Building Contents and Equipment

Flood damage to New Orleans hospitals, especially to critical equipment and facilities (e.g., chiller plants, backup generators, kitchen facilities) located below flood elevations in basements or at ground level, was responsible for extended closure of these facilities as a result of Hurricane Katrina.

Flooding of the basement and ground levels of buildings damaged key facilities and equipment critical to the building's operation, such as back up generators, electrical equipment, water chillers, kitchen facilities, vacuum pumps and 9-1-1 call centers.

5.0 PHYSICAL INFRASTRUCTURE

5.1 Levees and Floodwalls

Floodwall failures in New Orleans, either due to sliding or overturning instability, appeared to be the results of failure of the supporting soil. Sliding instability, likely triggered by increased outboard lateral pressure combined with loss of soil strength due to saturation by preceding rain and possibly underground water seepage, was the principal mode of floodwall failure along the 17th Street and the London Avenue Outfall Canals. Overturning instability, likely triggered by full outboard lateral pressure combined with loss of embankment material due to scour trench along the inboard toe of the floodwalls, was the principal mode of failure of floodwalls along the Inner Harbor Navigation Canal (IHNC).

The loss of embankment material due to erosion and scour trenches was widespread at breaches along the IHNC and the Intercoastal Waterway (IWW, part of the Mississippi River Gulf Outlet), where overtopping occurred. None of the sites inspected, where erosion and scour trenches occurred, was armored. Scour trenches, due to either overtopping or flow disturbance or both, were observed on both the protected and unprotected sides of the floodwall. At many breaches along the IHNC, the scour trenches were measured at more than 6 ft deep. This represented a loss of up to half of the total embedment depth of the floodwall at these locations, thus amplifying the applied moment due to full outboard pressure and making it much more vulnerable to overturning instability.

The earthen levee at the transitional junction between the levee and the floodwall, as currently designed and constructed (perpendicular transition between the concrete I-wall/ railroad closure monolith and the earthen levee), is highly susceptible to erosion due to flow disturbances. This led to complete failure of the earthen levees at the breaches on both sides of the IHNC at France Road and Jordan Road. Provisions to armor the earthen levee at this transitional junction to limit the effect of flow disturbances, with consequent erosion and scour, should be considered.

No structural failure at the connection between the concrete I-walls and steel sheet piles was observed, except for the 17th Street Outfall Canal breach where it appeared that the concrete I-walls might have been disconnected from the steel sheet piles. Where the connections between the concrete cap wall and the steel sheet piles can be inspected, the reinforcements between the concrete floodwall and the steel sheet piling appeared to be in place as shown on typical drawings. Concrete I-wall panels of the floodwalls along the 17th Street and London Avenue Outfall canals separated from adjacent panels along the vertical water stop joints at failure.

5.2 Transportation Systems

The most extensive and obvious damage to bridges was caused by the uplift and lateral displacements of the superstructure spans, many of which fell into the water. The bridge construction that is most susceptible to this type of damage is the segmental bridge construction where individual superstructure spans (deck, curb rail, and girders) were prefabricated and simply supported on the bridge piers without adequate provisions for restraint against uplift or lateral transverse displacements. This is a common damage scenario that has also been observed after many earthquakes when the bridge is subjected to dynamic loading and cannot accommodate the resulting displacements. While simply-supported bridge spans are easier and less expensive to design and build, they are vulnerable to damage due to direct effects of storm surge and wave actions in coastal regions.

Bridges with continuous spans and positive connection between the superstructure and the substructure, or even single span segmental bridges with adequate provisions for restraint against lateral transverse displacements, were observed to have sustained only minor, non-structural damage even with the direct effects of surge and wave forces caused by Hurricanes Katrina and Rita.

Besides structural damage, moveable bridges are also susceptible to damage due to flooding of motors and control mechanisms when subjected to high storm surge. The loss of control mechanisms of moveable bridges severely impacted some recovery efforts.

Impacts from surge-borne debris (barges, vessels, etc.) and scour of approach pavement and embankments also led to loss of functionality of bridges. In some instances the pier fender systems did not afford protection at the elevated water levels due to storm surge or flooding.

The entire Gulf Coast region suffered extensive loss of traffic control devices such as traffic lights, road lighting, regulatory signs, and directional signs. Failure of these signs also generated debris that impacted surrounding structures. Most obvious were large advertising sign failures adjacent to U.S. Interstate 10 in Louisiana and cable-suspended traffic lights in many coastal communities.

5.3 Sea Ports

Storm surge, rather than extreme wind, was the most destructive force to port facilities in with Hurricanes Katrina and Rita; however, most structural design of these facilities focuses on wind effects. The height and force of the surge—which reportedly reached upwards of 30 ft above mean sea level—along with wave impacts and saltwater inundation of coastal areas, caused widespread damage to buildings and facilities along the Louisiana, Mississippi, and Alabama coastline. Storm surge damage affected wharfs and warehouse structures in Gulfport moored casino barges in Biloxi and Gulfport and anchorage and motor-driven equipment of container cranes in Mobile, Alabama, and Gulfport. Wind was responsible for container crane anchorage failures in New Orleans and warehouse failures in Orange and Port Arthur, Texas.

5.4 Utilities

The loss of over one million timber power distribution poles in Hurricanes Katrina and Rita through a combination of storm surge, wind, and impacts of debris and falling trees seriously affected the ability to restore power quickly. There was a significant loss of lattice and steel high voltage transmission lines that also delayed restoration of electric power. Many of these failures were in exposed locations, across rivers and marshland, which further complicated replacement of fallen structures. Cascade failures were also observed.

Underground components of the natural gas distribution system did not sustain damage. However, in buildings and houses that sustained significant damage, uncontrolled venting of natural gas often occurred as a result of damage to fixtures or appliances within these structures.

Restoration of water service was hampered by the scope of damage, difficulty in gaining access to cut-off valves due to debris, and insufficient repair part inventories to respond to an event of such magnitude. Restoration of service was further challenged by the loss of system pressure due to massive damage to distribution networks at the user level in storm surge zones, resulting in uncontrolled flow of water.

Sewage treatment plants in the Gulf Coast region became inoperable when their pumps and generators were submerged in saltwater and damaged.

Both landline and cellular telephone service was severely disrupted. Landline services were lost primarily due to damage to lines and poles from wind and debris. There were few cellular tower failures, but loss of backup power disrupted service.

The major disruption to radio and television communication services was due to loss of power.

5.5 Other Industrial Facilities

Many oil storage tanks south of New Orleans (in the vicinity of Port Sulphur) were destroyed and did not float off their supports, implying that they suffered wind-induced damage. This region experienced some of the highest land-based wind speeds during Hurricane Katrina.

In many other cases, smaller oil storage tanks had no hold-down mechanisms and floated off their foundations upon inundation of the diked area meant to contain spills.

The greatest damage observed to storage tanks was loss of insulating cladding to walls and roofs, leading to the potential to inject debris into the wind field, causing further damage downwind.

More damage was apparent on the periphery of tank farms, indicating that exposure is an important consideration in design of such structures.

Observed damage to major industrial facilities included the loss of shrouds on approximately 50 % of all cooling towers.

The NIST-led reconnaissance team was able to adequately document damage that was visible in aerial photographs and from outside the perimeter fences of the facilities.

6.0 RESIDENTIAL STRUCTURES

6.1 Structures

The types of damage observed in each broad geographic area did not vary greatly.

The predominant causes of damage to residential structures were direct storm surge impacts, surge inundation, and inland flooding. Direct surge impacts extended as much as half a mile inland; surge inundation extended up to several miles inland along the gulf coast, and inland flooding was concentrated in the New Orleans area.

Nearly all non-elevated residential structures exposed to storm surge impacts were completely destroyed. Many houses were swept off their foundations by surge and floodwaters.

For residential structures on elevated foundations, the super-structure of the single family dwellings was completely destroyed. In most cases, it appeared that the failures stemmed from inadequate connections between the building structure and the foundation piers. Concrete, timber, and steel piers exhibited very little damage, except where impacted by surge-borne debris.

Damage due to wind loading was not as severe when compared with damage caused by storm surge and flooding. Damage due to hurricane winds was observed to roofing materials, siding, windows, soffits, porches, doors, and garage doors. Wind-borne debris was not a significant contributor to overall damage.

Damage to manufactured housing was similar to that observed for site-built structures. Reconnaissance team members observed some instances where anchoring systems for manufactured homes failed, however, the team also observed cases where anchoring systems performed well (e.g., portable classrooms in Port Arthur, TX).

6.2 Roofing

The extent of damage to residential roofing in the impact zones for Hurricanes Katrina and Rita was found to be extensive with an estimated 20 % to 30 % of the dwellings observed having some level of damage. With very few exceptions, the damage was limited to the coverings with underlayment remaining on the structure.

For many homes, particularly those in the Hurricane Rita impact zone, damage to roof coverings was the only visible damage to the dwelling.

In virtually all cases where damage to individual roofs was extensive, and the observers were able to make detailed observations, roofing failures were attributed to improper installation that did not follow acceptable practice such as given in typical manufacturers' instructions and association guidelines.

The most prevalent roof covering for residential structures was asphalt shingles. Loss of those shingles was the predominant damage observed to residential roofs. Three-tab asphalt shingle roofing suffered significantly more damage than did laminated shingle systems. Reasons for the relative difference in performance of the two types of shingles were not ascertained. The reconnaissance observations clearly support a recommendation that asphalt shingles carry a wind resistance classification appropriate for the geographic area, and that they be installed according to acceptable practice and current design standards.

Relatively little metal roofing was observed on residential construction in the hurricane areas. Overall, however, observed damage to metal roofing was less than that for other types of roofing, and most residential metal roofs appeared to be undamaged. Where damage attributed to direct wind force was seen, it was relatively minor, limited to small roof areas where a panel or two were missing or bent away from the roof structure.

6.3 Cladding

Little direct wind damage to exterior cladding of residential structures was observed.

Brick veneer used an exterior cladding to residential structures sustained less damage than other cladding systems.

The effects of aging (corrosion, decay, rot) were evident in many cases where cladding system failures were observed.

7.0 SUMMARY

Hurricanes Katrina and Rita had devastating effects on the Gulf States in August and September, 2005. A NIST-led reconnaissance assessed the performance of physical structures during to these events. This paper summarized the major findings, the analysis of environmental actions (wind speed, storm surge and flooding) that were present during the hurricanes, and the team's observations of damage to major buildings, infrastructure, and residential structures. Storm surge and flooding caused the most extensive damage, completely devastating most physical structures in their paths. Damage due to wind and wind borne debris was also prevalent in most areas of the reconnaissance. NIST is preparing a written report detailing the reconnaissance and its findings. NIST plans to include recommendations in the report that focus on topics that require immediate action with respect to the reconstruction process that is currently underway in the Gulf Coast, topics that should be addressed to assess whether codes, standards or practices need to be changed or modified, and topics requiring further study or investigation.

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