HURRICANE IKE IN TEXAS & LOUISIANA

6 Conclusions

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

The conclusions presented in Sections 6.1 (residential), 6.2 (critical facilities), and 6.3 (Houston's Central Business District) relate to recommendations made in Section 7 to ensure that designers, contractors, building officials, and coastal populations understand what is necessary for disaster-resistant construction in hurricane-prone regions.

6.1 Residential

6.1.1 Flood

Flood-related damage was severe and widespread, especially along the Texas shoreline east of the entrance to Galveston Bay. High storm surge levels, waves, scour and erosion, and floodborne debris contributed to the damage.

On Bolivar Peninsula, wave damage to floor systems of surviving homes revealed that wave crest elevations probably reached 2 to 5 feet above the BFE. Along western Galveston Island and along Follets Island, wave crest elevations appear to have been below the BFE. Flood levels in some communities adjacent to Galveston Bay or Sabine River were several feet above the BFE. In southwest Louisiana and in the Sabine Pass region of Texas, flood levels were above Hurricane Rita elevations in many places, below in others, but were generally above BFEs shown on FIRMs.

The MAT observed a much greater incidence and severity of scour around Gulf-front building foundations during Hurricane Ike than during other recent Gulf coast hurricanes (e.g., Opal, Ivan, and Katrina). The reason for the prevalence and magnitude of foundation scour during Ike is not known at this time.

Most structural failures observed by the MAT and associated with flooding appeared to be the result of one or more of the following: inadequate elevation of the building, inadequate pile embedment, unanticipated levels of scour and erosion around the foundation, improper load path connections from the elevated building to the foundation to the ground, or inadequate foundation resistance to flood loads.

Building Elevation Relative to Flood Level. Flood damage to buildings was generally consistent with expectations, given the observed flood levels. Flood damage to commercial facilities was generally similar to flood damage at nearby residential structures.

1. In areas where flood levels exceeded the BFE, newer construction elevated several feet above the BFE on strong foundations generally survived with little flood damage, except in instances where unanticipated scour or floodborne debris led to foundation failures. Nearby newer construction elevated only to the BFE was heavily damaged or destroyed. Older, lower construction was often damaged or destroyed as well.
2. In areas where flood levels were below the BFE, flood damage to NFIP-compliant buildings was generally minimal, with a few exceptions where scour and erosion or foundation-related deficiencies led to damage.

3. In areas subject to Coastal A Zone conditions during Ike, apparently compliant Zone A construction was sometimes damaged by waves and velocity flow. The NFIP practice of allowing construction of floor systems below the BFE leads to building damage.
4. Buildings behind the Galveston seawall were subject to flooding from Galveston Bay and to Gulf-side flooding due to wave overtopping, but were not exposed to direct wave attack.

Buildings that were built according to minimum standards and code, with the lowest floor elevation at the BFE, sustained significant damage or destruction when the flood level exceeded the BFE.

Many houses were elevated to the BFE and survived Ike—they were not subject to base flood or design wind conditions during the storm. However, some of these houses will fail if they are ever subject to base flood conditions or design winds. The MAT observed houses that were not attached to their foundations or were elevated on foundations that lacked load path continuity to the ground. This problem was also noted in cases where the MAT observed houses in Louisiana that were elevated with Federal funds, including HMGP grants and flood policy Increased Cost of Compliance payments.

Several houses visited by the MAT in Galveston County were advertised as, or known to be, enhanced code construction (refer to Section 2.4 for discussion of enhanced code construction). While it is true that these houses were elevated above the BFE and incorporated certain wind-resistive features that exceeded code requirements, some of these houses sustained flood damage. The flood damage observed by the MAT was typically a result of scour and erosion exceeding the ability of the pile/column foundation to remain vertical, or lateral loads and bending moments exceeding the material properties of the foundation piles/columns.

The Federal Communications Commission studied communications related to response activities following Hurricane Katrina; this study included a consideration of emergency power requirements for cell towers. The MAT noted and benefited from the elevation of cell phone tower equipment and powering by emergency generators on Bolivar Peninsula (Figure 6-1). When the MAT was in the field 5 days after Hurricane Ike, it had cell phone coverage and was able to access maps and other information from the Internet, despite the fact that much of the commercial and residential development on the Peninsula lay damaged or in ruins.

Foundation Design. Based on the failures observed by the MAT, foundation design does not receive adequate attention from design professionals. Specifically, the MAT observed:

1. Some buildings exposed to severe foundation scour collapsed, some suffered differential settlement, and some survived without damage.
2. Some buildings were elevated above the BFE and would have been expected to survive Ike's flood loads and conditions without damage. However, the MAT observed connection failures or bending failures in piles and columns that led to collapse of otherwise successful buildings.

Figure 6-1.
Two examples of elevation of equipment above grade on pile/column foundations, a good practice that ensured continuity of cell phone service on Bolivar Peninsula, TX

Parking Slab Failures. The MAT observed a wide range of parking slab performance, and a range of slab effects on foundation performance.

The MAT observed instances where parking slab failures led to timber pile failures at elevated houses. Where broken slabs remained connected to foundation piles, they transferred loads to the piles that the piles could not resist—racked foundations and broken piles resulted. Some people might argue that constructing thicker and stronger slabs would prevent this problem, but the MAT also observed instances where intact parking slabs beneath elevated houses appeared to contribute to foundation and building settlement by increasing scour around the foundation (as water flowed between the bottom of the slab and the eroded ground) and by placing additional vertical load on the foundations. Foundation success requires adequate embedment into the ground, after accounting for erosion and scour; while a slab may help to stiffen a foundation, it is not a substitute for adequate embedment.

The MAT also observed instances where unreinforced, frangible slabs had been constructed beneath elevated houses, in conformance with Galveston County requirements. These slabs collapsed, as intended, with no apparent harm to the elevated houses or their foundations.

Siting. MAT observations regarding siting effects on building damage were consistent with observations following past storms. Buildings situated the closest to the Gulf of Mexico shoreline, either by intent or because of long-term erosion effects, are at greatest risk to erosion and wave effects and sustained the greatest damage during Ike. While building elevation and foundation strength can overcome some of the risk associated with siting a building close to the shoreline, typical design practice cannot compensate for prior land planning and development decisions that result in small lots close to an eroding shoreline.

Breakaway Wall Performance. Generally, solid breakaway walls performed as expected—they broke free when subjected to lateral flood loads. However, below-BFE elements constructed of lattice or louvers may be preferred over solid breakaway wall panels. While the latter tended to break away (as designed) when exposed to flood depths of a few feet and small waves, the louver and lattice wall panels, subjected to the same flood conditions, allowed water to flow through the panel without damage to the panel or building, thereby reducing repair costs for the owner.

As homes are elevated to higher and higher elevations above the BFE (which FEMA encourages), one unintended consequence is that breakaway wall panels are becoming taller and taller, resulting in larger and larger floodborne debris elements.

Manufactured Homes. Manufactured homes generally performed in a manner consistent with their performance in prior storms. Those that were elevated on strong foundations and tied down to resist wind effects survived intact as long as flood levels remained below the chassis frame and wind speeds were low. Those not installed and restrained on adequate foundations were damaged or destroyed once flood levels reached the floor system. Those homes not properly tied down often shifted due to lateral wind loading.

In some locations in Louisiana, manufactured housing installed after Hurricane Rita was not elevated at or above the BFE. This may have occurred in existing manufactured housing parks where an NFIP exception allows homes to be elevated 3 feet above grade, even where this is lower than the BFE, or it may have occurred through incorrect application of the 3-foot exception. Whether this was allowed by the NFIP exception or not, the result was the same—manufactured housing installed below the BFE after Hurricane Rita was completely destroyed by Hurricane Ike.

6.1.2 Wind

The observed and modeled wind speeds of Hurricane Ike were less than the design wind speeds required by ASCE 7-05 for the areas of Texas and Louisiana affected by the storm. Damage to buildings and other structures was therefore generally associated with wall cladding and roofing materials.

Due to Ike's lower wind speeds, most of the homes were spared the devastating high wind pressures that cave in walls and doors, and remove large sections of roofs. The observed damage from Ike related to debris impacts and wind pressures appeared to be the result of the use of building products not intended for hurricane-prone regions, poor installation practices, and poor code enforcement, all of which are correctable. In Texas, where specific independent review and inspection practices were provided by TDI, the required construction practices were well understood and complied with by the builders. However, questionable building practices of new construction in unincorporated areas that fall within the purview of the TRCC was observed.

Roof Systems. In the areas observed by the MAT, roof covering damage was common and quite variable, which is consistent with what was observed by the Hurricanes Charley, Ivan, and Katrina MATs (see FEMA 488, 489, and 549).

- Very little sheathing damage was observed. However, the damage observed was related to unsupported large overhangs and poor construction practices.
- Roofing damage to older homes appeared to be a function of the age of the roof, whereas roofing damage to newer homes was a function of poor installation and failure to follow guidelines for installations in high-wind zones.
- Several houses visited by the MAT in Galveston County were advertised as or known to be enhanced code construction. While it is true that these houses were elevated above the BFE and incorporated certain wind-resistive features that exceeded code requirements, some of these houses sustained wind damage. The wind damage observed by the MAT was typically roof covering loss, roof sheathing loss, or water penetration through soffits and vents or around windows and doors.

Non-Load-Bearing Walls and Wall Coverings. An extensive amount of wall covering was damaged by Hurricane Ike. The majority of this damage was to vinyl siding and fiber cement siding. In most cases, the failures were related to installation of products not rated for the high-wind zones and installers not utilizing industry recommendations for high-wind zone installations. It was further observed that some cladding failures associated with attics were related to the use of sheathing that was not attached in accordance to high-wind zone procedures. These attachment failures made the sheathing/cladding system incapable of independently withstanding design wind pressures behind the system, which led to failures.

Doors, Windows, and Shutters. Few impact-resistant glazed window units were observed by the MAT. Most houses observed by the MAT had some form of shutter to provide debris impact protection. The shutter type varied from simple plywood to expensive roll-down shutters. The MAT observed numerous instances where plywood shutters were not properly anchored to the building structure, but rather to window frames and wall cladding. Though few debris impacts were observed, it appeared that most shuttering was effective in this less-than-design wind event. It was further observed that some homeowners chose not to shutter all windows (Figure 6-2). In some instances, shutters were only placed on the seaward facing windows, and the unshuttered north facing windows left vulnerable to Ike's backside winds.

Figure 6-2.
The upper windows on this Seabrook, TX, residence were not shuttered and were vulnerable to windborne damage

Roof Soffits, Fascias, and Gable Vents. The MAT observed many instances where vinyl soffits and aluminum fascia covers failed, thereby allowing water infiltration into the homes, resulting in damage. At least one gable end vent was observed to have blown from its mounting. All of these failures appeared to be installation issues.

Exterior-Mounted Equipment. All observed HVAC units mounted on the outside of the homes were elevated, per the guidelines contained in FEMA 55.

6.2 Critical Facilities

6.2.1 Flood

Critical facilities generally performed as expected. Those that were elevated higher than the minimum permitted elevation and on stronger foundations sustained less damage to structural and non-structural components. Those that were constructed in a manner similar to nearby, minimally compliant residential and commercial structures sustained more damage.

Building Elevation Relative to Flood Level. At least one critical facility, a hospital destroyed by Hurricane Rita and rebuilt prior to Ike, does not appear to have sufficient elevation and will likely be flooded again. The facility was rebuilt with the top of its lowest floor 1 foot above the BFE. While Ike flooding did not enter the building (the flood level was reported to be just a few inches below the floor's walking surface), below-floor utilities were damaged by Ike and facility function was lost for a period of time. Critical facilities such as this should be elevated such that the floor system and all below-floor utilities are several feet above the BFE to reduce the likelihood of future flood damage and loss of facility use.

Another critical facility—a relatively new jail and criminal justice complex—was flooded during Hurricane Rita and was flooded again during Ike (18 to 24 inches of flooding was reported during Ike). The electronic equipment and controls for the jail security and communications systems were damaged during both Rita and Ike, and prisoners had to be transferred temporarily to a State facility. The 1985 FIRM (the most recent FIRM at the time of construction) showed the site in Zone C (outside the 500-year floodplain). This example points out that flood hazard evaluations for proposed critical facilities should involve more than reading an old FIRM; designs for proposed critical facilities should involve a careful assessment of potential damage and operational interruptions in the event that flooding exceeds the flood level shown on the FIRM. Self-audit guidelines have been published for existing correctional facilities and could also be used to help inform siting and design decisions for proposed facilities.

Given the nature of critical facilities, a higher level of flood protection is needed. Loss of facility function due to flood damage can have far-reaching consequences for community response, recovery, and reconstruction. ASCE 7-05 and ASCE 24-05 designate jails and detention facilities as Category III facilities, which require additional design consideration beyond building code requirements for typical commercial and residential construction. Correctional facilities should be located outside the floodplain or elevated to the 500-year flood elevation. If 500-year flood elevations are not available, elevate above the BFE with sufficient freeboard to prevent damage and loss of use. Some States have mandated special permit requirements and freeboard for correctional facilities located in or near flood hazard areas (e.g., Commonwealth of Pennsylvania, 2001). Federal agencies with involvement in funding, permitting, and constructing critical facilities are required to adhere to the requirements of Executive Order 11988, Floodplain Management (refer to Section 4.0 for additional information).

Equipment and Utilities. Critical facilities with equipment and utilities in basements, at ground level, or above ground but below the flood level, sustained flood damage to these support systems that either prohibited post-Ike resumption of operations, or delayed or reduced operational capabilities.

Mitigation Project Performance. The MAT observed critical facilities that had received Federal mitigation grant funds to address previous damage or known vulnerabilities. However, the mitigated facilities were still vulnerable, either to the hazard against which they had presumably been mitigated, or against other hazards.

6.2.2 Wind

All of the critical facilities exposed to Hurricane Ike were subjected to wind speeds that were less than the design wind speeds given in ASCE 7-05. Hence, while most of the critical facilities observed by the MAT experienced relatively little or no wind damage, had Hurricane Ike delivered current design wind speeds, poor wind performance would have been likely at many of the facilities.

Many critical facilities in the area impacted by Hurricane Ike (as well as in other hurricane-prone regions of the United States and its Territories) have significant wind vulnerabilities and are therefore in need of mitigation. This is particularly the case with those facilities older than 10 to 15 years, when codes, standards, design, and construction practices did not adequately address wind, windborne debris, and wind-driven rain issues. Older buildings with significant vulnerabilities were observed by the Ike MAT.

The recommendations in FEMA 424, *Design Guide for Improving School Safety in Earthquakes, Floods, and High Winds* (January 2004), FEMA 543, and FEMA 577 were largely based on field observation research. The research was conducted on numerous critical facilities that were struck by nine hurricanes dating back to 1989. The buildings were exposed to wind speeds ranging from around 100 to 160 mph (peak gust, Exposure C at 33 feet). The majority of that research was conducted by FEMA teams. None of the Hurricane Ike MAT observations refuted the recommendations in FEMA 543 or 577. Hence, it is still believed that the recommendations in these design guides are valid. (Note: The wind recommendations in FEMA 424 are out of date—refer to the wind chapter in FEMA 543 for more current guidance on schools.)

The Hurricane Ike MAT observations revealed issues that led to new recommendations in Section 7.3 regarding roof drainage, flexible ductwork connectors, and emergency generators.

> In addition to providing redundancy for the emergency generator, another advantage to a back-up generator is that it can be sized to carry electrical loads that are truly needed for long-term functioning of a facility. For example, at the hospital discussed in Section 4.2.2, the emergency generator only carried the minimum loads required by code—the generator did not power the HVAC system.

Emergency Generators. Maintaining adequate power during and after a hurricane is vital to the functioning of many critical facilities. The Ike MAT observed several notable deficiencies.

Location and Protection. In general, the MAT observed a lack of protection of emergency generators from wind and windborne debris at the vast majority of critical facilities that were observed. The majority of the generators were located outdoors and were susceptible to wind and windborne debris damage. For critical facilities that need to be operational during a hurricane, it is beneficial to house the generators within a building. The advantage of doing so is that if there is an equipment failure, repairs can be performed during the storm. Conversely, when generators are located outdoors, it is often unsafe to work on them during an event. Also, when housed within a building that is resistant to wind, windborne debris, and tree-fall (as recommended in FEMA 543 and 577), the generator is protected from these hazards (Figure 6-3).

Figure 6-3.
The tree shown by the red line nearly fell on the hospital's emergency generator (red arrow). The tree hit and damaged a metal roof that was over the compressed gas cylinders (blue arrow).

For critical facilities where a total loss of power for several days is tolerable (for instance, a community center that serves to house emergency workers brought in after a storm), it can be appropriate to save money and locate the generator outdoors. For facilities where loss of power is not tolerable (such as hospitals and EOCs), however, it is very unwise to place them outdoors or in enclosures that lack sufficient wind and windborne debris resistance.

Generator Capacity and Redundancy. Code requirements for emergency generators generally provide adequate capacity for life-safety equipment, essential equipment, and power required for the orderly shut-down of critical operations. However, the amount of emergency power required for a facility to provide needed services during a prolonged power outage generally exceeds that dictated by code. For critical facilities where power for some services cannot be interrupted (such as hospitals and EOCs), additional generator capacity, beyond that dictated by code, is needed. For example, most codes and standards do not require air conditioning to be powered by emergency generators. However, temperature and humidity levels can rise rapidly in critical facilities located in hurricane-prone regions if air conditioning equipment is not supplied by emergency power, thereby preventing performance of many critical functions.

For critical facilities that must remain operational during prolonged power outages, provisions should be made to supply adequate generator power for operations during and after a hurricane. Providing power from two or more generators offers benefits and should be considered for critical facilities where loss of power is not tolerable. However, for critical facilities where loss of power for several days is tolerable, it can be appropriate to save money by not installing multiple generators.

> To help ensure the reliability of emergency and back-up power, it is important that generators be well maintained and tested frequently. Also, for critical facilities that need to be functional during a hurricane, it is important to have maintenance personnel on site during the event so that if the emergency power generation system malfunctions, repairs can commence immediately. For example, on-site maintenance personnel were instrumental in the quick restoration of emergency power at the EOC discussed in Section 4.3.1.

Having multiple generators provides several advantages. When power is supplied from multiple generators, each generator is not a redundant back-up unit, but rather a power source that can be operated alone or in conjunction with other generators to provide power. In addition, having multiple generators improves reliability. During an event when municipal power is disrupted, facilities with two or more emergency generators do not have to rely on a single unit for emergency power. This is especially important during long-duration outages that can overstress generators designed for periodic short-duration operation. Having multiple emergency generators also facilitates maintenance, as individual units can be taken out of service to perform periodic maintenance without denying the facility its emergency power source.

When a facility has only one generator, the facility will be left without power if there is loss of municipal power and if the sole emergency generator fails. This scenario occurred at a hospital observed by the Ike MAT. With the failure of the single emergency generator, the entire facility had to be evacuated for 4 days until a temporary portable generator could be brought to the site. The MAT observed only a few critical facilities that had multiple generators.

Aggregate-Surfaced Roofs. The MAT observed some critical facilities (including a hospital and nursing home) that had aggregate-surfaced roofs. Even winds of about 100 mph (peak gust, Exposure C at 33 feet) are sufficient to blow aggregate from BURs with sufficient momentum to break glazing. Also, windborne aggregate can pelt people arriving at shelters or hospitals during a hurricane. Even though the potential hazard of windborne aggregate is well documented and significant, many owners of critical facilities apparently fail to understand the importance of mitigating this potential hazard.

Mitigation Project Performance. All of the HMGP work observed by the MAT failed to address all wind vulnerabilities. In seeking to reduce damage from hurricanes, building owners do not always understand or address all the vulnerabilities of the building. The MAT observed many instances where only some of the building's vulnerabilities to disaster damage had been addressed.

The MAT observed a number of buildings where mitigation projects had been accomplished that addressed one vulnerability but left other vulnerabilities unaddressed. Obviously, before implementing a mitigation project, it is important to fully evaluate vulnerabilities. While it may not be appropriate to address all of the significant vulnerabilities, if all vulnerabilities are not mitigated, that decision should be a conscious one based on deliberation and consideration of residual risks.

The MAT also observed a lack of thoroughness and robustness in mitigation efforts. For example, putting on a new roof system that lacks a secondary membrane or reroofing work that does not adequately anchor rooftop equipment. Roof membranes are frequently punctured by windborne debris. When this occurs, water will leak into the building unless a secondary membrane is incorporated into the roof assembly. Blow-off of rooftop equipment also frequently occurs and results in water leakage.

Prior to the publication of FEMA 543 and 577, there was very limited design guidance on mitigating wind vulnerabilities. Hence, those HMGP projects that were implemented before these guides were published were handicapped by lack of guidance. However, with the publication of FEMA 543 and 577, there are extensive recommendations on a variety of issues. Some of the recommendations are quite conservative, and in some cases it could be appropriate to not implement all of them. However, if a FEMA 543 or 577 recommendation is not implemented, that decision should be based on deliberation and consideration of residual risks.

6.3 Houston's Central Business District

The MAT observed various types of building envelope damage at several buildings in Houston's central business district. Although Hurricane Ike's winds were not as high as the current design wind speed, some buildings received extensive exterior envelope damage, particularly to glazing and roof coverings.

Aggregate-Surfaced BURs. Twenty-five years ago, aggregate blow-off during Hurricane Alicia caused extensive and expensive glazing damage in Houston. Therefore, it was surprising to observe that there were still aggregate-surfaced BURs in the area (see Chapter 5). Because wind speed increases as the roof height increases, the risk of aggregate blow-off also increases with roof height. It was therefore particularly surprising to observe aggregate surfacing on mid-rise buildings (such as those shown in Figure 6-4), where their presence presents enhanced opportunity for damage to surrounding buildings.

To avoid aggregate-induced glazing damage in urban areas in hurricane-prone regions, aggregate should be removed from built-up and sprayed polyurethane foam roofs.

Figure 6-4.
Aggregate-surfaced BURs on two mid-rise buildings on the periphery of Houston's central business district. The roof membrane blew off the penthouse roof, shown by the blue arrow (Figure 5-19 inset shows building locations).

Pedestrian Protection. In downtown Houston, the MAT observed remnants of unprotected broken glass several floors above grade at a few buildings (as illustrated by the inset at Figure 5-26). Those remnants had the potential to be dislodged during light winds and cause injury. At the time of the observations, many pedestrians were in the area. However, some building owners had taken quick action to mitigate the injury potential. For example, as discussed in Section 5.3.1, one building owner retained a company to install temporary film over the broken glazing as a safety precaution to avoid falling shards of glass. That appeared to be a prudent course of action. Boarding up windows can also be effective, provided it is done before people return to the downtown area.

Vegetative Roofs. As discussed in Section 5.4, the MAT observed three vegetative roofs. A decade ago, vegetative roofs were seldom installed in the United States. Although this type of roof system only captures a small percentage of the current inventory of roofs, over the past few years there has been great increase in interest, awareness, and installation of this type of system. Unfortunately, currently there are no consensus design guidelines or building code requirements pertaining to their wind performance. Although no wind-related problems related to these vegetative roofs were observed by the MAT, wind-blown tree limbs are capable of breaking glazing, and there is potential for scour of the soil media. Also, for those systems that employ trays, there may be potential for tray blow-off. The wind vulnerability of vegetative roofs needs to be better understood and dealt with via design guidelines and code criteria before large numbers of vegetative roofs are installed in hurricane-prone regions.