7

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 meetings with state and local officials, business and trade associations, contractors, and other interested parties. These conclusions are intended to assist the State of Alabama, the State of Florida, communities, businesses, and individuals in the reconstruction process and to help reduce future damage and impact from flood and wind events similar to Hurricane Ivan. The report and recommendations also will help FEMA assess the adequacy of its flood hazard mapping and floodplain management requirements and determine whether changes are needed or additional guidance required.

7.1 Flood Hazard Conclusions

Flood levels from Hurricane Ivan exceeded the mapped BFEs throughout many bays and sounds by several feet. Flood levels along Gulf front shorelines also exceeded the mapped BFEs but to a lesser extent. As discussed in Chapters 1 and 2, HWMs were clearly higher than the stillwater levels used to develop the flood maps and were also higher than the BFEs, which include wave heights that are not accounted for in the HWMs. Due to these high flood levels, the flooding extended beyond the SFHAs in most communities investigated. Since many homes were pre-FIRM construction and/or constructed to the minimum standards in mapped A Zones and the flooding extended beyond the current SFHAs, there was severe damage of single and multi-family buildings throughout the inland bays and sounds, and along the barrier islands in Baldwin County, Alabama, and the western Florida Panhandle (see Figure 7-1).

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

1) Hurricane Ivan's storm surge was greater than the stillwater elevations of the mapped 100-year flood event. The stillwater elevations are used in the coastal flood analysis to determine the minimum elevations standards (BFEs). As noted in Chapter 1, the preliminary estimated return period for Hurricane Ivan was approximately a 150-year storm. However, the data used to develop this return period was extremely limited, and further analysis should be performed.

2) The storm surge overwashed the barrier islands, thus allowing more water to enter into the back bays and sounds, especially in those areas immediately behind the barrier islands (see Figure 7-2). This overwash effect was not accounted for in the initial storm surge modeling used to develop the stillwater elevations, which are the main input parameters in the wave height analysis to determine the BFEs and zone designations. Without the overwash effect, the flood levels in these back bays and sounds would be underestimated. In addition, the storm surge modeling was performed over 25 years ago and did not account for possible subsequent changes in the topography of the barrier islands. The barrier islands have been significantly altered over these last two decades as a result of numerous tropical storms and hurricanes, including Hurricane Opal, which drastically altered and destroyed many of the dunes on the barrier islands. When these dunes stood higher than 15-25 feet, as they did when the initial surge model was developed, they prevented the floodwaters from overwashing the barriers; the only way the storm surge entered the bays and sounds was through the inlets. Now that the barriers islands have been impacted and altered by Hurricane Ivan, the contribution of the overwash into the back bays and sounds will continue to be a factor for future events.

Figure 7-1.
Newly constructed house in Zone AE, which was damaged due to high flood levels and impacts from waves and floodborne debris. The effective FIRM shows the BFE as 9 feet, but the flood levels exceeded this by 3-5 feet. (Big Lagoon)

Figure 7-2.
Barrier island on Santa Rosa Island, east of Pensacola Beach, which was completely overwashed by storm surge. The storm surge then inundated the Santa Rosa Sound.

Floodborne debris and wave damage (characteristic of V-Zone damage) in A Zones was extensive, especially along bay and sound shorelines. The storm surge and wave impacts destroyed buildings, enclosures, stairs, utilities, and docks and piers, which all became floodborne debris. Structures that were not elevated higher than the storm surge were not only damaged by floodwaters and wave action, but also impacted by the floodborne debris.

Erosion was severe along the barrier islands of Alabama and Florida. Areas that had wide beaches before Ivan were less impacted than those with smaller, narrower beaches. Erosion along bay and sound shorelines was generally minimal, and structural damage there was predominantly due to storm surge, waves, and floodborne debris. The erosion undermined shallow foundations and piers with shallow embedment. Many areas were susceptible and impacted by past coastal storm events, which led to further erosion and impact from Ivan. The methodology used to develop the FIRMs takes into account the erosion that would likely occur during the 100-year event. However, this analysis accounts for only one event and not multiple events that change or alter the barrier islands and dunes. Based on the eroded conditions from this one 100-year event, a wave height analysis is performed to determine the BFEs and the zone designations. Buildings are constructed to the standards developed and mapped on the FIRMs. These standards remain in-place for years and/or decades until a significant event results in severe damage or the methodology has been modified. After Hurricane Opal, which impacted much of the same area as Hurricane Ivan, the FIRMs were revised due to the severe damage, the observed HWMs, and new coastal methodologies that had been developed. Although smaller events had affected the coastal topography on the barrier islands and the new methodologies had been in place for over five years, it took a severe event like Hurricane Opal to instigate a map change.

7.1.1 Lowest Floor Elevations

One of the critical factors for this event was that the amount of damage to the building was in direct correlation with the elevation of the lowest floor (see Figure 7-3). Generally, the lowest floor elevation was a function of the type of foundation chosen for the building. Pile foundations had the advantage of getting the lowest floor up a full story, which usually placed it several feet above BFE. Other foundation types often resulted in buildings that were at BFE or only slightly higher. For Hurricane Ivan, this difference in elevation made a great difference in flood and debris damages.

Most of the damaged buildings occurred in areas mapped as A Zone on the current FIRM, although many of the buildings were pre-FIRM construction and built on slab foundations. The elevation of the buildings varied throughout the impacted area as well as among houses in the same neighborhood and along the same street. Generally, buildings near or on the bays or sounds, constructed to the BFEs or below for the pre-FIRM buildings, experienced significant flood levels and damaging waves and floodborne debris. FIRM revisions over the past two decades have resulted in changes in flood hazard zone designations and BFEs. This has led to varied construction practices and different lowest floor elevations throughout the coastal areas. These map changes may explain some of the variations in structural damages observed. However, many newer structures that were constructed to the minimum NFIP standards were severely damaged by the high storm surge elevations, while many buildings that were constructed several feet higher than the minimum standards were much less damaged. Figure 7-1 is also an example of a building built to the current minimum standards that sustained severe damage.

Some of the variations in building elevations were based on:

- Changes in the BFE on the FIRMs
- Higher building elevation requirements such as SRIA
- Homeowners voluntarily chose to elevate higher than the BFE on pile foundations for various reasons: for a better view, to create additional parking or storage areas, as a cautionary measure because of the proximity to a large bay or sound and the potential flood hazard, and/or because other adjacent buildings were elevated several feet above the BFE
- Recommendations by contractors, engineers, architects, state and local building and floodplain management officials

Figure 7-3.
Lowest floor elevation was one of the most important factors in determining building damage during Ivan (Gulf Shores, Little Lagoon)

7.1.2 Foundations and Structures

On the barrier island, relatively few pile failures were observed during field inspections of newer, post-Hurricane Opal homes. However, preliminary review of pre- and post-Ivan aerial photography indicates many pile-supported homes along the beachfront may have been destroyed due to some combination of erosion, flood, and wind effects. Poor structure-to-beam connections likely resulted in intact piles and beams with structures missing from atop the foundations. Had these structure-to-foundation connections been adequate, these structures would have been damaged but probably would have remained in place.

In areas subjected to coastal erosion and scour, shallow foundation damage was extensive and the structural failures dramatic. Shallow foundations are not appropriate for supporting structures in high risk coastal areas.

In the bays and sounds, there was generally very little scour or erosion that affected the foundations, although some was observed behind bulkheads. Overall, since scour and erosion was not a factor, newer stem wall and pile foundations performed well; however, once the flood levels and wave heights exceeded the lowest floor, severe damage resulted to the building. Many older pier and pile foundations failed as the result of flood and wave loads that were above the lowest floor and exerted pressure on the buildings. The failures occurred due to lack of connections, tie-downs, and reinforced concrete. Figure 7-1 is also an example of a building constructed on a stem wall foundation, which was not impacted by erosion or scour, but due to the elevation of the building, the high flood levels and wave and debris impacts totally destroyed the building.

7.1.3 Piers and Docks

The construction of pier and docks, which extend several hundred feet in the bays and sounds, was prevalent throughout the impacted coastal areas. Damage to these systems was extensive, and dock materials and pilings provided a significant source of damaging debris. Piles and dock sections were found in the lower areas of buildings, which contributed to the destruction of many homes.

Figure 7-4.
Docks along back bays contributed to flood debris causing extensive damage.

7.1.4 Construction Features beneath Elevated Buildings

The newer buildings built to V-Zone standards with adequate pile embedment, generally performed well. Breakaway walls functioned as intended with the exception of those situations where a clear breakaway joint separation was not achieved, which led to siding and building component damage above the breakaway wall. Utility damages were observed when utility connections were attached to or passed through breakaway walls. Enclosed areas and stairways were destroyed or severely damaged, as would be expected.

NFIP minimum standards require that buildings constructed in V Zones be elevated on piles or columns so that the bottom of the lowest horizontal structural member of the building is above the BFE. The area below the lowest horizontal member must be left free of obstructions or enclosed with non-structural breakaway walls, insect screening, or latticework, and the area's use be restricted to parking, building access, or storage. The standards were developed with the understanding that the area below the lowest horizontal member would be sacrificial and would be totally destroyed during a major flood event.

During Hurricane Ivan, these construction features (e.g., access stairs and enclosures) beneath elevated buildings were often destroyed. Not only were the enclosed areas, stairs, utilities, and other systems severely damaged, but they also become a significant source of floodborne debris. Many enclosed areas below the lowest floor were fully enclosed and, in some cases, finished as additional living space. These features are becoming more substantial and are a significant source of floodborne debris. Once dislodged by storm surge, wave action, or wind, these features can act as obstructions and create unanticipated loads on the foundations and increase the potential for structural failure for many buildings.

Stairs and building access features are becoming more elaborate and expensive, increasing the total dollar damages resulting from the event. Most of the damage below the lowest floor is preventable by limiting the construction of these enclosures and other systems beneath the elevated building.

Figure 7-5. Access stairs and enclosures that were constructed below the lowest floor were severely damaged.

7.1.5 Pools and Bulkheads

Pools and bulkheads suffered extensive damage and should be viewed as sacrificial features during a major hurricane.

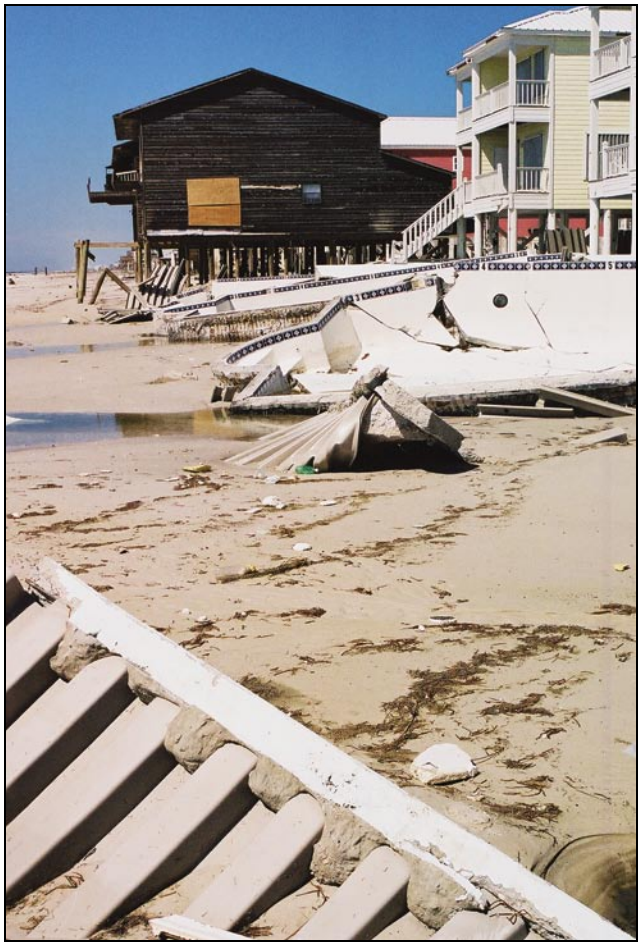

Figure 7-6.
Typical failure of swimming pools and bulkheads (Gulf Shores)

7.1.6 Utilities

Exterior utilities suffered extensive flood damage when not elevated or sited properly. The lack of design and installation attention resulted in destruction of building service utility lines, systems, and equipment, and led to the loss of function of the occupied space. Compliance with current FEMA publications and codes is essential to the future prevention of damages of this type. Figure 7-7 shows an inappropriately mounted condenser that was carried off its platform by high floodwaters.

Figure 7-7. Inappropriately mounted condensers for a coastal residential site that should have been mounted at a higher elevation and securely anchored to their platform

7.2 Wind Hazard Conclusions

While Hurricane Ivan is categorized as a Category 3 "major hurricane" by the NHC in its Tropical Cyclone Report with estimated 1-minute sustained wind speeds (over open water) of 121 mph, the actual wind speeds gathered on land (presented in Chapters 1 and 2) suggest Ivan was more typical of a Category 1 to 2 hurricane. Flood-related hazards such as storm surge, floodborne debris, inundation, and wave action were the primary cause of damage. The categorization of the storm by a single hurricane classification has limited use in the post storm assessment and may lead people in the impacted areas to draw incorrect conclusions about the event they actually experienced at their site and the strength of their building. The development of wind field estimates and resulting wind speed swath maps are critical to the proper assessment of an event and its implications for building construction and code development. The response of buildings to the high winds varied in relationship to their location in the wind field, building code in effect at the time of construction, and mitigation efforts implemented on the building.

Although structural system failures tend to be perceived by the public and the building industry as the dominant issue of concern, it is clear that for buildings built in accordance with the 2001 FBC or the 2000/2003 IBC, structural issues have, in general, been resolved. Now, the arena in which improvements can and must be made are those related to water intrusion and protection of the building envelope (refer to Chapter 5). Protection of the building envelope is important to minimizing losses and damages to building contents, but also because of the importance of the building envelope with respect to internal pressurization of a building or structure. In addition, failure in the building envelope often leads to progressive failures in structural systems.

Widespread building envelope damage was observed throughout the area visited by the MAT. Performance of building envelope elements such as roof coverings, roof mounted equipment, unprotected glazing, doors, soffits, and siding was generally poor and led to widespread damage to the interiors of residences, businesses, and critical/essential facilities.

Windborne debris damage was observed, but was not widespread across the entire path of the hurricane. Wind and structural engineering experts predict that significant windborne debris damage will begin in the 120-mph range in inland areas and in the 110-mph range when buildings are within one mile of the coast. In response to this, ASCE 7 requires that openings in the geographic areas described above be protected to resist windborne debris impact. Since Ivan's estimated gust speeds were generally below that level, it is expected that glazing damage during Ivan would be less common than in other more powerful storms, such as Hurricane Charley. Given that the actual wind speeds were below current code level wind speeds but at or near the older code level wind speeds, the occasional damage to the structural elements and the widespread damage to building envelopes can be characterized as wind-related damage caused by inadequate design, old construction methods, outdated codes, building age, lack of maintenance, and/or poor construction/code enforcement. Wind damage to the contents of residential and commercial buildings, and critical/essential facilities due to these failures is clearly preventable.

This report's conclusions and recommendations relate only to what was observed by the MAT in Hurricane Ivan. The conclusions and recommendations of the Hurricane Charley MAT report (FEMA 488) with regard to wind hazards are also relevant to design and construction in the areas impacted by Hurricane Ivan because similarities in damage observations exist. Hurricane Charley was a code level wind event along much of the hurricane's path, and readers are encouraged to obtain a copy of this report. In addition, a summary report for all four hurricanes that impacted Florida in 2004 is available (FEMA 490, *Summary Report on Building Performance 2004 Hurricane Season*, March 2005). This report is available online at http://www.fema.gov/fima/mat/fema490.shtm.

7.2.1 Building Performance and Compliance with the Building Codes, Statutes, and Regulatory Requirements of the States of Alabama and Florida

Most building damage and failures observed by the MAT appeared to be the result of inadequate design and construction methods commonly used before the 2000/2003 IBC and the 2001 FBC. Some observed damage and failures might be explained by lack of maintenance or poor condition of the building. Code changes implemented in response to Hurricane Andrew in 1992, such as improvements to the SBC and the adoption of the 2001 FBC, can be credited with improving the wind resistance of buildings that have been designed and constructed over the past 12 years. In addition, the improvements in ASCE 7, including the addition of windborne debris protection requirements and the elimination of the 1/3 stress increase factor, are further refining the loads that new buildings must resist, thus ensuring better performance in wind events.

A summary of the historical code prescribed wind pressures over the last 25 years at two locations within the Hurricane Ivan damage zone is presented in Table 7-1. Typical single family residences in Gulf Shores, Alabama, and Perdido Key, Florida, as well as a small essential facility in the city of Pensacola, Florida, were selected for comparison. The table shows that the design wind pressures have been changing, and sometimes increasing, with each new code; therefore, it would be expected that failures of older buildings would be common if this were a code level wind event. For example, the required pressure for corner zones of roofs has increased more than 3 fold over that period. Corner zone pressures did not even exist in the 1979 SBC. These increases are a reflection of the findings of both wind tunnel research and post-storm investigations. The pressures have increased most dramatically on the parts of buildings that have suffered worst in wind storms.

To properly evaluate the compliance with past building codes, an analysis of the actual pressures experienced by the buildings in Hurricane Ivan was necessary. In addition to the design pressures for the current and two preceding codes, Table 7-1 also contains the estimated actual pressures thought to have been experienced at these locations. These pressures are based on the maximum recorded 3-second gust wind speeds at each location, using the latest code method of wind pressure determination in effect at each location. The resultant pressures range from 5 percent to 40 percent below the current design pressures, confirming that this was not a code level wind event with respect to the 2001 FBC or 2000/2003 IBC. However, it is important to note that in most cases, the actual pressures are in the same range as the 1997 SBC design pressures. These wind provisions were first introduced in the 1982 edition of the SBC and were largely unchanged through the 1999 SBC. Therefore, it is reasonable to expect that a significant number of buildings in the damage zone should have been built to withstand design pressures in the range of what was experienced in Hurricane Ivan. Considering the amount of wind damage observed by the MAT, it is evident that under-prediction of the design wind loads by past building codes for critical building areas such as roof and wall corners led to significant building envelope damage and may have led to some of the structural damage observed. However, investigation of the damage observed suggests compliance of the construction with the building codes was a much bigger factor.

Some elements of buildings constructed under older codes were vulnerable to damage because of the lack of specific provisions for those elements. Building envelope components such as roof coverings have much more stringent requirements in the current codes. Rooftop equipment and protection of glazing, for example, were largely ignored in older codes. Other failures were the result of installed materials and systems that are known to lack the ability to perform under high-wind loads (i.e., the use of unsecured soffit panels). These components either do not meet the new criteria or there is a lack of clear evidence that the product will work under high-wind loads. Because these components are not considered "structural elements," their design and construction is often overlooked during design permitting, construction, and inspection. Therefore, improvements are needed in the design requirements of the codes themselves and in enforcement and code compliance to ensure that component and cladding (C&C) elements are being engineered and designed per the code requirements.

For the State of Florida, the 2001 FBC and the recently completed 2004 FBC (to be adopted statewide by administrative rule effective October 1, 2005) include several improvements to the structural design of buildings and attached structures, as well as improvements for the design of building envelope and equipment provisions. Based on the observations outlined in this report, design guidance provided by the code with regard to the design and construction of the building envelope and attached structures and equipment needs to be expanded and improved. Guidance for some of these issues is provided by current model codes and standards, including the IBC/IRC, NFPA 5000, and ASCE 7.

Table 7-1. Design Wind Pressures Building Code

	Equivalent Design Wind Speed (3-second gust)	Building Surface / Function			
		Exterior Walls		4 in 12 Roof Pitches	
		Main Frame	Components and Cladding	Main Frame	Components and Cladding
Single Family Residence in Gulf Shores, Alabama					
Standard Building Code 1979 Edition[1,2,3]	130 mph	+33 psf	+/- 27 psf	-25 psf	- 23 psf
Standard Building Code 1997 Edition[1,2,3]	115 mph	+32 psf	+25/-29 psf	-26 psf	+15/-52 psf
International Building Code 2003 Edition[1,2,5]	145 mph	+46 psf	+38/-51 psf	-40 psf	+22/-73 psf
Actual Maximum Recorded Wind Speed[1,2,4,6]	109 mph	+23 psf	+29/-39 psf	-31 psf	+16/-68 psf
Single Family Residence in Perdido Key, Florida					
Standard Building Code 1979 Edition[1,2,3]	125 mph	+30 psf	+/- 25 psf	-23 psf	- 21 psf
Standard Building Code 1997 Edition[1,2,3]	110 mph	+31 psf	+24/-28 psf	-25 psf	+14/-50 psf
Florida Building Code 2001 Edition[1,2,5]	135 mph	+40 psf	+33/-44 psf	-35 psf	+19/-63 psf
Actual Maximum Recorded Wind Speed[1,2,4,6]	119 mph	+31 psf	+25/-34 psf	-27 psf	+14/-49 psf

psf = pounds per square foot

1 The pressure calculations under each code for both main frame and components and cladding were calculated using building design coefficients in wind zones that provide the maximum wind pressure for any area on that building surface.

2 Positive value pressures indicate pressures acting inward toward building surfaces. Negative value pressures indicate pressures acting outward from building surfaces.

3 Pressures calculated from the 1979 and 1997 SBC were calculated using their appropriate fastest-mile wind speed and design methods in the code that was in effect at the time. The 3-second gust wind speed is shown for comparative purposes only and was not used in the calculation of the design wind pressures.

4 Assumed Exposure Category C.

5 Assumed Exposure Category B.

6 Actual maximum recorded wind speeds were measured in 3-second gust speeds. Pressures were calculated under the current code for that location (IBC or FBC).

7.2.2 Performance of Structural Systems (Residential and Commercial Construction)

Buildings designed and constructed to resist wind loads prescribed in the 2001 FBC and to the requirements of ASCE 7 performed well and showed how improvements to the building codes have been successful in Florida. Adoption of the IBC in Alabama communities was so recent that few buildings had been constructed under those provisions; however, the same results as those in Florida are expected. Throughout the Hurricane Ivan damage zone, structural wind damage was common in certain construction types, at wind pressures 5 to 40 percent below design level in the code. The most prevalent construction type experiencing structural damage was residential wood roof framing. Inadequate nailing of roof sheathing panels, gable end wall failures, and lack of properly installed wood framing connectors were the major factors in these structural failures. Pre-engineered metal building structures suffered significant damage, particularly to older buildings.

7.2.2.1 Internal Pressures

Breach of the building envelope through broken windows, failed doors, or loss of sheathing led to significant changes of the internal pressures in buildings, which sometimes resulted in structural damage. Research suggests that internal pressures are affected by openings as small as 1 percent of the wall area and that the internal pressure generally becomes equal to the external pressure at the opening when the area of the opening reaches or exceeds 5 percent of the wall area. Consequently, the loss of a large window, a sliding glass door, a double-entry door, or a garage door can expose the interior of a building to the full effect of the external wind pressure. When openings are breached on the windward face of the building by direct pressure-related failure or by impact from windborne debris, the internal pressure in the building rises toward and tends to follow the fluctuations in positive pressure that would have occurred on that window, door, or panel had it not failed. Because air is essentially incompressible at the wind speeds encountered in even the most severe wind storms, the pressure builds without the need for much wind flow through the opening. However, if other openings in the building are present, including panels covering ceiling access holes in attics, air pressure can escape from the building, but does so as rapidly moving air that whips through the building. Failures of windows and doors on the windward face of a building have been correlated with subsequent failures of partition walls, doors, and windows on side and leeward walls, attic access panels, roof sheathing, and even whole roof structures (refer to Chapter 4 for details of these types of failures).

The MAT observed window failures that resulted in interior partition failure and failure of exterior walls, as seen in Figures 7-8 and 7-9 (this failure is fully described in Subsection 5.5.1. The MAT saw other examples where wall materials or framing in the gable end walls failed, causing the attic space to become pressurized. In some cases, the pressurized attic pushed off the roof sheathing. In other cases, the pressurized attics failed the ceilings below them, pressurizing the interior spaces, and caused failures in the building envelope from the inside.

Figure 7-8.
Window damage caused exterior wall failure (Gulf Shores)

Figure 7-9.
Partition walls destroyed by interior pressurization due to window damage (Gulf Shores)

7.2.2.2 Wind Mitigation for Existing Buildings

To minimize damage or prevent failure of older buildings (residential, commercial, and critical/essential facilities), mitigation to create a continuous load path from the roof to the foundation must be implemented. This type of mitigation can be expensive because it often requires partial demolition and replacement of interior building finishes, and may require displacement of occupants while the mitigation is performed. Justifying the cost may also be difficult because the building code or local ordinance may not require that the building be upgraded to current code requirements.

For homeowners, opportunities to perform mitigation retrofits that improve the building's continuous load path would be during renovation work or during roof replacement projects, when significant invasive work is already being performed and the cost to install extra clips, screws, or nails to secure decking to rafters/trusses would be minimized. Access to the roof structure/top of wall connection is often made accessible during these projects, and clips and straps may be installed to help with the creation of a continuous load path. Additional anchorage of the bottom of the walls may still be required to develop a complete load path. Mitigation projects stated above would address much of the roof decking and roof structure failures observed after Hurricane Ivan.

In commercial, government, and critical/essential facility buildings, mitigation retrofit costs may be minimized if these types of projects are performed during tenant fit-out projects or during major capital improvement projects. Prioritization can be given to mitigating space used for critical and essential functions. Public schools are examples of places where these types of mitigation projects have occurred. As part of their efforts to increase safe public shelter space, FL DCA has evaluated schools, and sponsored structural and non-structural mitigation projects to strengthen buildings and provide debris impact protection to mitigate existing buildings that were once vulnerable to damage from wind and windborne debris.

7.2.3 Performance of Building Envelope, Mechanical and Electrical Equipment

Although structural system failures tend to be perceived by the public and the building industry as the dominant issue of concern, the greatly improved houses built in accordance with the FBC 2001 and other model codes have, in general, resolved most structural issues. Now, the arena in which improvements can and must be made are those related to water intrusion and protection of the building envelope (refer to Chapter 5). Protection of the building envelope is important in minimizing losses and damages to building contents, but also because of the importance of the building envelope with respect to internal pressurization of a building.

Poor performance of building envelopes and rooftop equipment was common on residential, commercial, and critical/essential buildings. Envelope and equipment damage was more widespread and significant on older buildings, although new buildings were also damaged. Damage was noted throughout all areas observed. Ramifications of poor performance include the following:

- **Property damage.** Property damage was extensive, requiring repair and/or replacement of the damaged envelope and equipment components; repair and/or replacement of interior building components; and mold remediation and furniture and equipment replacement as a result of rainwater and/or wind damage in the interior of the building. Even when damage to the building envelope or equipment was limited, such as blow-off of a portion of the roof covering or broken glazing, substantial rainwater damage frequently resulted because of the heavy rains accompanying the hurricane and rains occurring in the following days and weeks. Rainwater entered the buildings through the breaches in the building envelope.

- **Loss of function.** Depending upon the magnitude of the wind and rainwater damage, repairs can take days or months. As a result, residents may not be able to return home, businesses may not be able to reopen, and critical/essential facilities may be incapable of providing their vital services. In addition to the costs associated with repairing the damage and/or replacing the damaged property, other financial ramifications related to interrupted use of the building can include rental costs of temporary facilities or lost revenue due to business interruption. These additional costs can be quite substantial.

Building Envelope

Poor performance was a function of both inadequate wind resistance and damage from windborne debris impact. Inadequate resistance to high-wind pressures on building envelopes and rooftop equipment was responsible for much of the damage caused by Hurricane Ivan. In addition, windborne debris caused significant envelope damage (and virtually all of the glazing damage) that the MAT observed. Damaged and fallen trees, and failed building envelope components and rooftop equipment (such as roof coverings, gutters, HVAC equipment, and wall coverings) also became windborne debris that damaged the buildings they blew off of, as well as other buildings in the vicinity.

The importance of the building envelope is illustrated by Figure 7-10. Although the structural frame performed well, poor performance of the building envelope resulted in significant damage. Balcony railings, stucco wall covering, and entire portions of the non-load-bearing walls were blown away. Glazing damage was extensive, although as shown in Figure 7-10, shutters were successful in preventing damage to those windows and glazed doors that were protected.

Figure 7-10.
Although this was a structural success, except for the excellent shutter performance, this building was an envelope failure.

Roof Coverings, Wall Coverings, and Soffits

Observations showed that roof coverings of all types continue to fail during hurricane events. Some of these failures were due to the age of the coverings (coverings that were never considered for their ability to resist design wind loads) while other failures were due to design and construction related issues or debris impact. Specifically, these observations are as follows:

- Wind damage to roof coverings and wall cladding was widespread, even with wind speeds below design levels. Improved performance of roof and wall coverings was generally observed on the newer buildings and is likely due to improved codes and standards, product and test method improvements, a more educated designer and contractor workforce, and reduced detrimental effects of weathering (on newer buildings).

- The Brick Industry Association (BIA) sponsored research regarding windborne debris resistance of brick veneer walls versus walls with other coverings. The research demonstrated that brick veneer was quite resistant to debris impact. Based on the research BIA states that "brick provides safety for building occupants and security for property." This statement is only true if the brick veneer is not blown away. If wind-induced collapse of brick veneer does occur, as illustrated in Figures 5-26 and 5-27, the expected protection will not be present.

  As with many other building envelope elements, improved brick veneer design guidance and workmanship are needed.

- In general, EIFS performed very poorly. For many buildings, the poor performance resulted in significant rainwater infiltration damage (see Figure 7-11). Much greater attention is needed in the design and application of EIFS, and improvements are needed in design guides and testing.

Figure 7-11:
In this EIFS failure, the majority of the gypsum board detached from the studs. At some living units, the gypsum board on the interior side of the studs was also blown off, thus exposing the units directly to the hurricane.

- In general, vinyl sidings performed very poorly. The vinyl siding industry should evaluate the findings of the MAT and launch a program to more fully understand the causes of the poor performance.
- Asphalt roof shingles continued to fail below current design level winds. In general, it appeared that shingles installed within the past few years performed better than shingles installed prior to the mid-1990s. The enhanced performance is likely due to product improvements and less degradation of physical properties due to limited weathering time. In most cases, observed shingle failures were attributed to inadequate self-seal adhesive bond strength or installation that did not comply with known methods for resisting blow-off in high-wind areas (Figure 7-12).

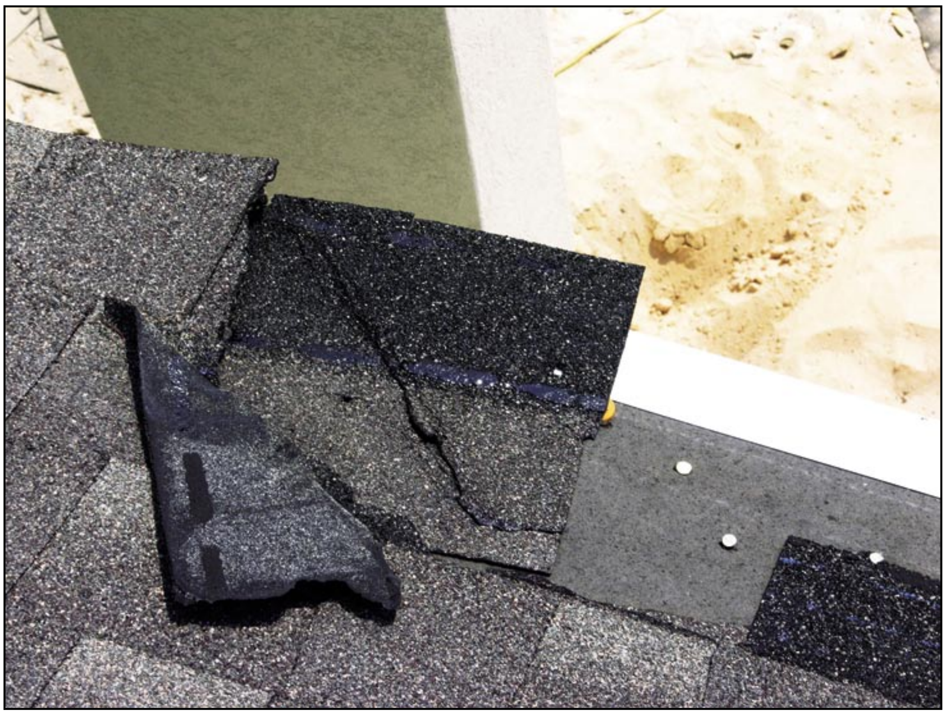

Figure 7-12.
Rather than cutting off the tabs, the starter course on this new roof was turned 180 degrees. Hence, the tabs of the first row were free to lift because they were not adhered in the self-seal adhesive on the starter.

- Tile roof systems experienced varied levels of performance from complete resistance to wind to substantial loss of tiles. Variation in performance was primarily related to installation and attachment methods with mortar-set tile system failure most frequently observed. Tile failures on roofs with foam-adhesive were observed, in most cases, to not comply with manufacturers' installation recommendations. All types of tile (concrete and clay) are vulnerable to breakage from debris impact, regardless of installation methods used. Tiles lifted by wind or broken from windborne debris often lead to cascading failures (Figure 7-13). Tiles on hips, ridges, and edges of the roof were a frequent point of failure. Hip and ridge tiles rarely were attached using mechanical anchors.

Figure 7-13.
These batten-attached tiles were damaged by windborne debris. Much of the damage was caused by tile impacting other tiles. A tile was blown 140 feet from this building.

- Aggregate roof surfacing continued to cause debris damage when aggregate was displaced by high winds, becoming windborne missiles.
- For all roof systems, inadequate attention was typically given to edge flashing, coping, and gutter/downspout design and installation despite being located in the roof areas subject to the highest wind pressures. Failure of these roofing components often initiated roof membrane lifting and peeling.
- Wall cladding appeared to have typically received minimal attention during design and construction, and continues to be an initiation point for progressive failures leading to interior contents damage or pressurization of the building interior.
- In numerous buildings, rain was driven into attic spaces because of soffit failures. Widespread loss of soffits was observed in residential construction. In many of these instances, water intrusion occurred from wind-driven rain through areas where soffits were displaced or lost.

Windows, Doors, and Shutters

Windows and glazed doors can be protected in all wind regions using shutter systems, laminated glazing systems, and other means of opening protection. The required protection of these openings in areas within the ASCE 7 windborne-debris region appeared justified from the amount of observed debris. (However, the lack of a FBC windborne debris region in the Florida Panhandle does not appear to be justified.) Using glazing protection to prevent full internal pressurization and to protect interior contents from being damaged is an effective means of damage reduction for all hurricane-prone regions. Specifically:

- Many homes and businesses that experienced only contents damage could have prevented these losses if their openings were protected. Success in designing the structural frame to resist wind loads and internal pressures was partially negated by significant losses to building contents (Figure 7-14).
- Most shutters observed on buildings during Hurricane Ivan performed well.
- In the ASCE 7 windborne-debris regions, unprotected glazing located with the first few floors above grade is typically more susceptible to breakage than glazing located several stories above grade. This is due to the greater quantity of windborne debris at lower elevations. However, as illustrated by Figure 7-15, glazing in tall buildings can also be broken. Breakage at upper levels can be caused by dislodged roof coverings, rooftop equipment, balcony railings or wall coverings from the building or an adjacent building. However, as discussed in the ASCE 7 C6.59 Commentary, the greatest threat to upper-level glazing is the presence of aggregate roof surfacing on the building or other buildings within 1,500 feet.

  If aggregate roof surfaces do not occur within the parameters given in ASCE 7, then for most buildings, glazing protection above 60 feet above grade is generally not needed (although isolated damage may occur as shown in Figure 7-15). On some critical or essential facilities, as a very conservative measure, protecting glazing above 60 feet may be prudent. For these buildings, a special evaluation, including consideration of the basic wind speed, characteristics and proximity of other buildings, and characteristics of the building being considered should be conducted to determine if glazing protection above 60 feet is appropriate.

Figure 7-14.
Glazing at the top two window units broken by debris, while the entire middle window unit was blown away. The shuttered window unit was not damaged.

Figure 7-15.
A few of the upper level windows were broken.

Attached Equipment (Rooftop and Ground Level)

Much like the building envelope systems already discussed, rooftop and ground level equipment is not typically receiving the design, installation, or code attention needed. Design guidance in ASCE 7 provides basic information to calculate wind loads on these elements to determine connection and support anchoring systems, but detailed guidance is needed. The lack of design and installation attention resulted in displacement or damage to these units across the wind field of the hurricane. This not only resulted in the loss of function associated with the damaged units, but in many cases led to the loss of function of the occupied space due to rainwater infiltration at the displaced equipment.

7.2.4 The Need for High-Wind Design and Construction Guidance

Designers, contractors, and building officials need additional education and resources. Although many successes of design and construction were observed across the path of Hurricane Ivan, it was apparent that the load path concept was often not fully understood. It was also clear that many designers, contractors, and building officials do not fully understand the devastating effects that hurricanes can have on building envelopes and equipment. It was common to see fasteners spaced too far apart, fasteners that were too small, and fasteners with weak connections. Enhanced details were seldom seen. In contrast, there were numerous examples of failure to follow well established basic construction practices such as minimum edge distances for fasteners. Unless wind resistance issues are understood by designers and contractors, envelope and equipment failures will continue to occur. In part, the envelope and equipment problem is due to lack of high-wind design guides for various envelope assemblies and various types of rooftop equipment.

7.2.5 Performance of Critical and Essential Facilities (Including Shelters)

Critical and essential facilities must remain operational before, during, and after significant events, such as hurricanes, in order to serve their communities. As stated in Chapter 6, buildings that are considered critical and essential facilities include EOCs, fire and police stations, hospitals, shelters, and schools.

In general, buildings functioning as critical and essential facilities did not perform significantly better than their commercial-use counterparts. Despite codes of the past ten years that require higher design loads be used in the design of these facilities, the same flaws in construction, such as poor wall cladding, poor attachments of roof covering, and improper anchorage of rooftop mechanical equipment, were observed in critical and essential facilities. As a result, the operations and response at many essential and critical facilities discussed in Chapter 6 were hampered or shut down and taken off-line after the hurricane.

Most critical and essential facilities in the impacted area were housed in older existing buildings and most, if not all, apparently were not mitigated to resist known hurricane risks. If key areas of the buildings had been mitigated or retrofitted for wind and windborne debris design requirements that are specified in the current code, building damage and loss of function would have been reduced.

The building damage to critical and essential facilities experienced during Hurricane Ivan led to a significant, and avoidable, loss of function. Specific conclusions for critical and essential facilities based on these observations are as follows:

- When older buildings are used as critical and essential facilities, damage will likely occur to the roof covering, wall coverings, window and door systems, and rooftop equipment. This damage leads to significant loss of function at the facilities (Figure 7-16).

Figure 7-16. An older hospital that experienced blown off roof coverings, gutters, downspouts, rooftop equipment (including lighting protection system components), and broken glazing

- Some buildings designed to critical and essential facility requirements experienced damage and partial failures during the hurricane due to lack of protection from windborne debris. Lack of protection of windows was common at hospital and medical office buildings, and led to window failures and severe damage to building contents.
- Rooftop equipment loss such as loss of HVAC units and vents, antennas, communication dishes, and lightning protection systems was prevalent. In almost all cases, these failures caused damage to roof coverings that often resulted in rainwater intrusion into the facilities (Figure 7-17).

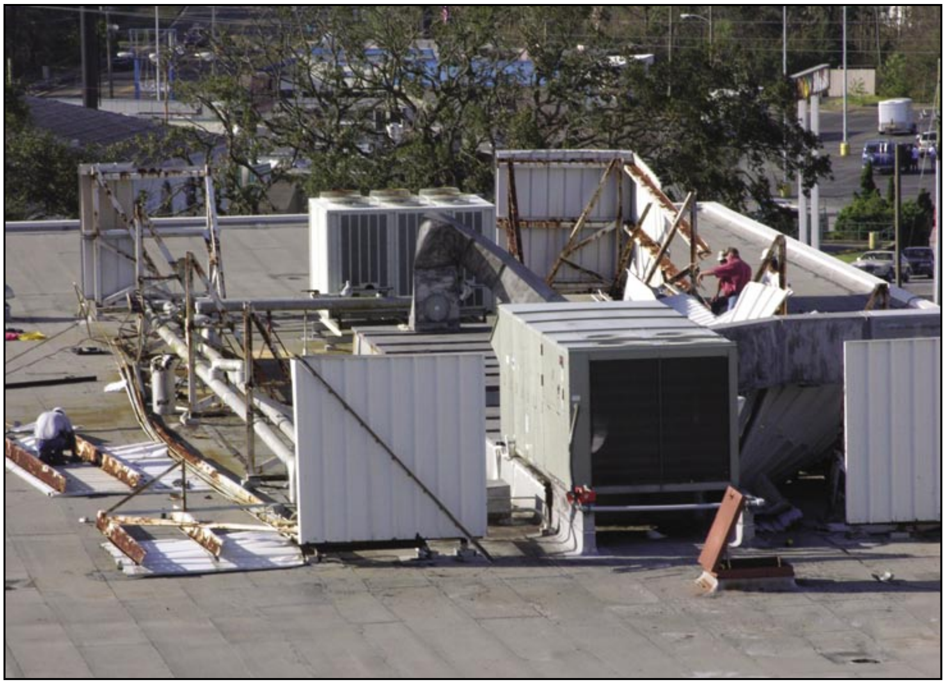

Figure 7-17.
Rooftop mechanical equipment damage at a hospital. Several of the equipment screen panels were blown away. Loose panel debris can break glazing and puncture roof membranes.

- Windborne debris could injure or kill first responders at EOCs, late arrivers at shelters, or those seeking medical attention at hospitals. Although people are not usually outdoors during hurricanes, buildings used as essential and critical facilities can be the exception. It is common for people to arrive at these facilities during a hurricane and additional efforts should be made to reduce the potential for windborne debris at these sites.
- ARC 4496 provides a baseline for a shelter's integrity and performance, but meeting this criterion does not guarantee that the building will resist wind and windborne debris associated with all hurricanes.
- Peer review of the design of critical and essential facilities would greatly improve the likelihood that a building has been adequately designed to resist extreme winds.
- Special inspections for key structural items and connections, and for installation of envelope components would help ensure the performance of critical and essential facilities