3

Basic Assessment and Characterization of Damage

The MAT's observations of the type and extent of damage caused by Hurricane Charley's high winds and flooding are broadly presented in this chapter and discussed in detail in Chapters 4, 5, and 6. The majority of building damage observed was due to the effects of wind and windborne debris.

Damage to the structural systems of buildings, including full and partial collapses of buildings, was observed in both residential (site-built and manufactured housing) and commercial (non-residential) buildings. Buildings with severe structural damage were located in the area impacted by a narrow band of wind that tracked the eye of the hurricane from Charlotte Harbor up into De Soto County and were typically older structures; the buildings located along this narrow band experienced wind gusts estimated to be at or above the design wind speeds noted in the current Florida Building Code (2001 FBC). However, most of the observed damage was to the exterior portions of buildings, such as roof coverings, wall coverings, soffits, windows, and doors (elements that are commonly referred to as the building envelope). Additional observed damage was associated with wind-driven rain that entered and damaged building interiors through openings in the building's exterior caused by the failure of an element of the building envelope or attachment.

The MAT also observed damage to elements attached to the buildings, including rooftop equipment, carports, pool screen enclosures, etc. This type of damage was widespread across the impacted area and was observed in both residential and non-residential buildings. Failure of the attached structures and screen enclosures generated significant amounts of debris in areas not considered to be debris-prone regions (i.e., areas in the 2001 FBC where design wind speeds are 120 mph or greater). Damage to the building envelope and attachments also occurred across the area impacted by wind speeds estimated to be at or below the design wind speeds currently identified in the 2001 FBC. This type of damage can be extensive and is often under reported.

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Wind speeds are measured and recorded as sustained and gust wind speeds. For consistency, this report defines **sustained wind speeds** as 1-minute average wind speeds and **gust wind speeds** as 3-second peak gust wind speeds.

Flood-induced damage to buildings was observed primarily along the barrier islands west of Charlotte Harbor and in a few instances along tributary rivers. Post-FIRM buildings received minor damage from floodwaters passing below elevated first floors. Pre-FIRM buildings experienced inundation and standing water in areas subjected to storm surge. The MAT observed this type of damage to buildings on the barrier islands of Fort Myers Beach, Sanibel and Captiva Islands, and North Captiva Island.

3.1 Wind Effects

The measured wind data, combined with wind field modeling, along with the observed damage in the field, suggest that Hurricane Charley made landfall as a strong Category 3 or borderline Category 4 hurricane in the Port Charlotte and Punta Gorda area. As the storm moved across Florida, winds decreased, but there was still a continuous narrow wind field containing winds at or above hurricane force (and with higher gusts) that continued across the state until the storm left the coast. Figure 3-1 illustrates the correlation of the estimated wind speed from Hurricane Charley (Figure 1-4) adjusted to 3-second peak gust values with the design wind speed requirements of the 2001 FBC (Figure 2-1) by overlaying the maps. The shaded area in Figure 3-1 represents the impacted areas that likely experienced a code-level event; the requirements of the 2001 FBC for the buildings in this area are shown. Although not all buildings were built to

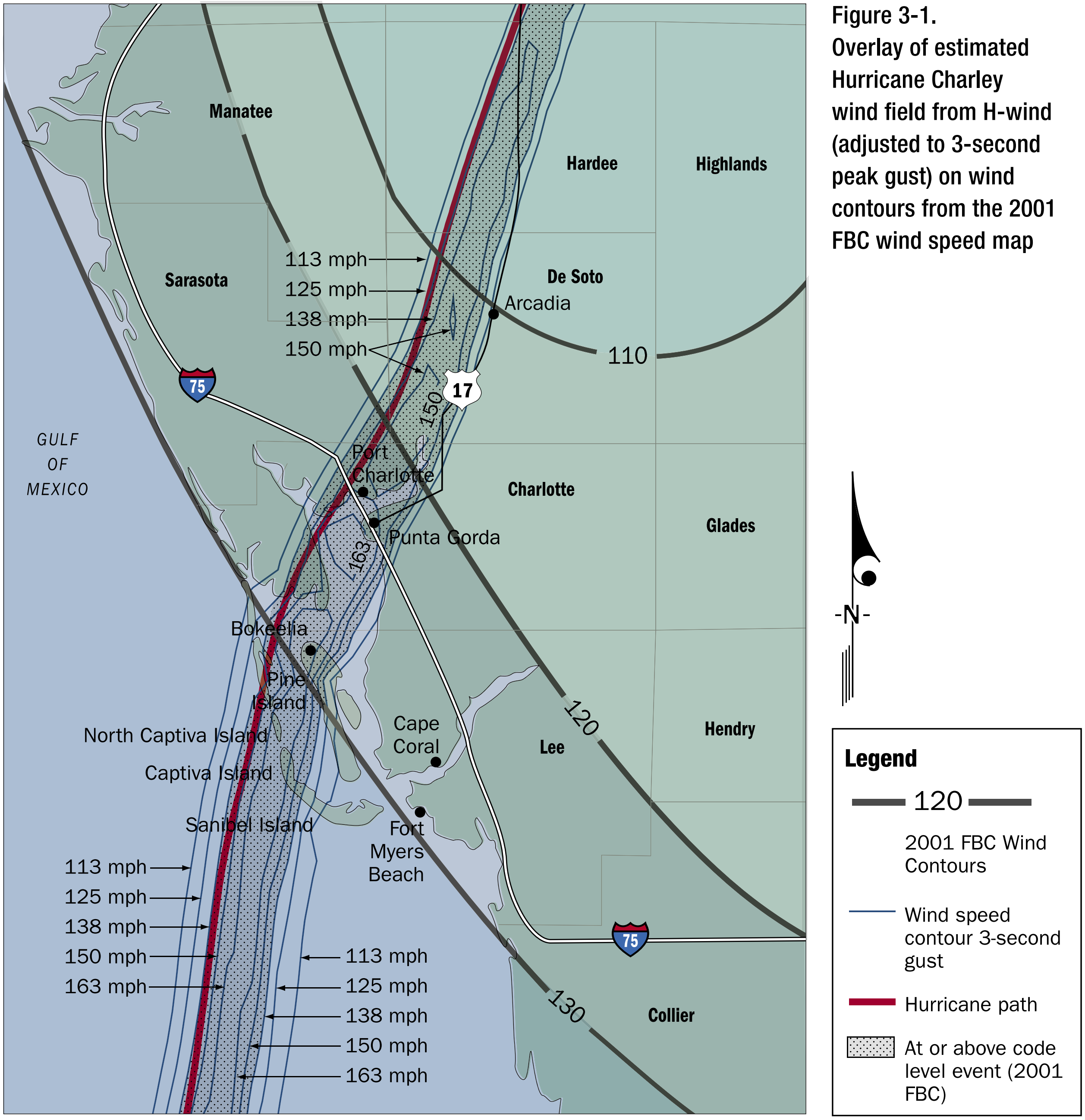

Figure 3-1. Overlay of estimated Hurricane Charley wind field from H-wind (adjusted to 3-second peak gust) on wind contours from the 2001 FBC wind speed map

the 2001 FBC, Figure 3-1 will assist in relating damage from the wind event to the expected performance of both new and old buildings.

The most severe structural damage and the largest concentrations of building envelope damage were typically observed within 10 to 15 miles of the path of the eye of the storm. Structural damage to older buildings and manufactured homes was common. The most severe structural damage observed was loss of roof structure and some exterior wall failures and collapses. Failures of roof coverings and the detachment of rooftop equipment were observed throughout the areas visited, including, surprisingly, areas that did not experience hurricane-force winds. Soffit failures, which led to water damage, were also observed throughout the entire wind field of the storm. Tree blow-down, including the uprooting of large trees and the fracturing of pine trees, was observed throughout the entire wind swath, including areas experiencing only tropical storm-force winds.

3.1.1 Variability in Hurricane Winds

It is important to note that the actual wind field generated by a hurricane contains variability that is frequently associated with areas of significant convective activity, where stronger winds aloft are brought down toward the surface. Model-based assessments, such as the H-wind and HAZUS-MH models, do not capture that variability. Nevertheless, model-based assessments provide the best estimate of wind speeds in the path of a hurricane because wind instruments are typically spread some distance apart and, as a result, there are relatively little hard data indicating the magnitudes of these variables.

In situations where a large number of wind speed measurement instruments are present, the relative uniformity of measured wind speeds generally matches typical wind field models; this suggests that local variability may not be all that great. However, tree blow-downs and other tracers frequently suggest at least some level of local variation, particularly toward the edges of the storm and in areas where the strongest wind activity is contained within rain bands or convective cells. Thus, there are typically instances of severe damage to buildings outside of high-wind areas that are likely the result of either higher-than-estimated winds (due to variability) or the age and construction type of the buildings. These issues are addressed in this chapter and Chapters 4, 5, and 6.

In addition to actual wind speed measurements taken from permanent and mobile wind recording devices, there are often other opportunities to record wind speed and the effects on buildings and structures. FEMA, the National Institute of Standards and Technology (NIST), and other Federal, state, and industry organizations sponsor building monitoring programs in which residential buildings are supplied with instruments that record wind and air pressure. The intent is to capture full-scale wind/building interaction data to help study and improve the wind design criteria used in building codes. Although a number of instrumented houses were impacted during Hurricanes Frances, Ivan, and Jeanne, none were impacted by Hurricane Charley. As a result, characterizations of damage for this report were made with the best available data on the wind field (Chapter 1), wind pressure data computed after field investigations, and building data obtained during field investigations.

3.1.2 Building Structural Damage Due to Wind Effects

Across the impacted area, older buildings were typically affected more than new buildings. The poor performance of the older buildings was likely the result of a number of factors. The most significant factor is that older buildings were built to building codes less rigorous about building structural issues than the 2001 FBC. As a result, these buildings typically experienced more damage than buildings constructed since the adoption of the 2001 FBC. Another factor that contributed to the observed damage was that older buildings may have suffered from degradation of strength due to corrosion, termites, poor maintenance, or a variety of other factors. Also, design and construction methods and materials used at the time an older building was built may be now considered insufficient for a high-wind area. Finally, where flood damage occurred, the building may have been built at a time when the need for elevation to avoid flooding in that area was not well understood or, if it was understood, was not being enforced or required.

Some examples of the above factors include:

- Design wind loads used were too low, resulting in members and connections too weak for the winds encountered and roof and framing damage occurred as a result
- Fasteners for roof sheathing were too small or were spaced too far apart and led to loss of panels
- Small or missing strapping to anchor the roof structure to the walls led to roof framing damage
- Unreinforced masonry walls lacked a continuous load path and led to wall damage and failure
- Lack of a continuous load path at the connection between the walls to the foundations often resulted in wall and roof collapse
- Structural design that did not account for unprotected glazing, leading to structural failures due to increased internal pressures
- Unprotected glazing, leading to interior damage from wind and wind-driven rain

- Corrosion of ties or fasteners used to attach siding to the wall structure led to loss of wall cladding and water intrusion
- Corrosion of anchors or connectors that attach the building to the foundations or tie structural elements together led to structural collapse in some instances
- Improper elevation of habitable space and utilities relative to flood risks resulted in structural and contents damage
- Degradation of building elements and connections due to material deterioration, insect infestation, or lack of proper preventive maintenance resulted in premature building and envelope system failure

The MAT observed many cases where buildings constructed within the past few years survived the storm relatively unscathed (however, exceptions were noted), while older buildings next door or directly across the street sustained significant damage either due to roof covering loss or rain water intrusion through damaged roof coverings, damaged soffits, and/or broken windows and doors. A return visit to the area 2 months after Hurricane Charley struck Florida reinforced the stark contrast of successes and failures. During this visit, many families were observed living in the lightly damaged or undamaged homes and working from businesses that were lightly damaged or undamaged, while many of their neighbors' homes and businesses were still vacant.

The discussion below presents an overview and categorization of the structural damage observed. A more detailed discussion follows in Chapter 4.

3.1.2.1 Residential Buildings (One- and Two-Family Dwellings, Wood-Frame Multi-Family Buildings, and Manufactured Housing)

The effect of internal pressures from broken doors and windows on the windward side of buildings was an important factor in the structural damage to several homes and multi-family residences, although it was not the cause of all damage observed across the storm path. When a building is not designed for internal pressures or if a window or door is broken (breached) such that wind is allowed to enter the building, the building experiences an increase in loads it was probably not designed to handle.

Figure 3-2 shows a masonry home with a wood roof structure. Failure of the window in the front wall of the house likely led to pressurization of the house and contributed to the dramatic failure of the roof structure.

Figures 3-3 and 3-4 illustrate that installing shutters on a building to protect windows and doors can ensure the envelope is not breached and thus prevents the increase in internal pressure. The condominiums in these photos were located within a few hundred feet of each other at the north end of Captiva Island. The top unit in the building in Figure 3-3 was not protected with shutters, and most of the upper floor framing likely failed due to an increase in wind pressure when windows (and doors) were breached. Conversely, the same type of building constructed two buildings away had shutters to protect the building (Figure 3-4). The shutters protected windows and doors, keeping the building "enclosed," and ensured that the building performed without failure.

Figure 3-2.
Failure of roof structure from pressurization of a pre-2001 FBC house when the window failed on windward face (Punta Gorda)

Figure 3-3.
Loss of roof structure in a wood-frame building likely due to internal pressurization resulting from unprotected windows and doors (Captiva Island)

Figure 3-4.
Nearby undamaged wood-frame building similar to that shown in Figure 3-3 protected with shutters (Captiva Island)

In addition to structural framing damage due to internal pressures, some wood buildings experienced failures due to a lack of continuous load path. Figure 3-5 is an example of a wood-frame structure that experienced a partial wall failure due to a lack of continuous load path. These types of damages were typically limited to areas along the path of the eye and were not typical of damage in areas with estimated wind speeds less than 100 mph (3-second peak gust).

Figure 3-5.
Wall failure on older multi-family wood-frame building due to lack of continuous load path. Internal pressurization may have also contributed to this failure (Fort Myers Beach).

Most one- and two-family homes and multi-family dwellings observed as part of this study were constructed of either reinforced concrete or from concrete masonry units (CMUs). The primary roof structure on these concrete buildings was wood framing or trusses. For these CMU and wood-frame buildings, the most common damage observed was a roof sheathing failure due to inadequate connections to the underlying roof framing. This type of damage was typically observed on older buildings. Other structural failures to wood-frame buildings included a failure of the roof structures (trusses or rafters) at the connections to the top of walls and the collapse of gable end walls. Loss of roof sheathing (decking) was observed where large, improperly secured overhangs were present (Figure 3-6). Other damages to multi-family housing units commonly included damage to wall sheathing at gable ends; this damage occurred near the center of the hurricane's track.

Figure 3-6.
Damage to older multi-family building roof deck with inadequately supported and braced overhang (Captiva Island)

Structural failures to manufactured housing were also observed. Structural damages observed near the path of the eye could be classified as foundation damage, including shifting of the units on the foundations resulting in out of plumb foundations (piers) or complete collapse of the foundation. Figure 3-7 shows a pre-1976 manufactured housing unit completely displaced from its foundation piers. The homeowner of this unit indicated that his unit was retrofitted in the late 1990s during a park-wide mitigation project that installed additional tie-downs such that spacing would not exceed 4 feet. Improper installation of the additional tie-downs and saturated soil likely led to the failures observed. Other structural damages observed to manufactured housing were failures due to wind effects (not related to an attached structure or enclosure). Although these failures were not representative of the performance of all manufactured housing, the post-1994 unit in

Figure 3-7.
Pre-1976 manufactured home unit displaced from its foundation, damaging the structure itself (Pine Island)

Figure 3-8 experienced extensive structural damage from 3-second peak gust winds in excess of the range of 110 to 130 mph.

Figure 3-8. Post-1994 manufactured home with major roof and wall failure (east of Port Charlotte)

3.1.2.2 Commercial and Mixed-Use Buildings

Most buildings observed in this category were either load-bearing wall or frame. Buildings constructed from heavy steel and concrete frames were not observed to have experienced structural failures, although light metal-frame buildings experienced structural damage and failure. Buildings with load-bearing wall construction were typically constructed of either reinforced concrete or CMU wall systems supporting wood or steel frame roof structures. The CMU buildings had walls both with and without reinforcing. Concrete and CMU buildings were the primary type of commercial building observed throughout the damage path, although some wood-frame commercial buildings were also observed.

Concrete and CMU buildings. Damage to concrete and CMU buildings typically included a loss of roof sheathing that was inadequately attached to the roof deck supports or failure of roof framing elements at their connection to the walls. Figure 3-9 illustrates the partial collapse of a wood truss roof system due to loss of roof sheathing and lack of gable bracing. Figure 3-10 also shows wood-frame roof damage and loss of roof sheathing on a masonry structure in addition to damage to an inadequately reinforced masonry gable end wall. In Figure 3-11, the metal roof deck supported on steel joists failed. Field observations of the building shown in Figure 3-11 noted failed welds at the plate connectors used to secure the steel joists to the wall systems. The MAT observed that this type of roof damage to masonry buildings often led to partial or total collapse of walls that were left unsupported when roof systems failed. Unreinforced masonry (URM) construction, insufficient steel reinforcement, or improper grouting in the walls, particularly along the tops of walls and at gable ends, may have also contributed to the damages observed. These types of damages were observed primarily around the Port Charlotte and Punta Gorda areas of Charlotte County with isolated incidences observed along the path of the eye into De Soto, Hardee, and Polk Counties.

Figure 3-9. Example of wood truss roof failure due to sheathing loss and lack of bracing at gable end on a pre-2001 FBC unreinforced masonry building (north of Arcadia)

Figure 3-10.
Roof sheathing and partial failure of wood roof structure on a masonry building. Note damage to inadequately reinforced masonry parapet at gable end wall (Wauchula).

Figure 3-11.
Damage to a pre-2001 FBC masonry building with steel joist roof framing and metal deck (Port Charlotte)

Pre-engineered metal and light-metal frame buildings. Pre-engineered metal and light-metal frame buildings were also observed during the assessment. Most were rectangular buildings with gable ends. The walls of pre-engineered metal and light-metal frame buildings were constructed using steel columns. Lateral bracing was provided by CMU infill walls (with and without reinforcing), by purlins or tension rods, or by the exterior metal panels that clad the exterior of the building.

Structural damage to pre-engineered metal and light-metal frame buildings included the collapses of structural frames (partial and complete) as shown in Figures 3-12 and 3-13. Other damages to pre-engineered metal and light-metal frame buildings observed by the MAT included a partial or complete collapse of gable end walls. Common traits of the observed failures were partial or inadequate lateral bracing of the structural frame, loss of roof and wall panels, and failure of large rolling and sectional doors (e.g., service garage doors and loading dock doors). Panel loss and failure of doors may have contributed to the failures by allowing an increase in internal pressures. Another factor related to the failures of these buildings was the poor condition (i.e., corrosion) of structural members and connections on older buildings.

Figure 3-12. Pre-engineered metal building with progressive failure and severe panel loss (Arcadia)

Figure 3-13. Roof framing failure and gable end wall collapse due to insufficient supports of pre-engineered metal building. Note corroded base plate with failed bolts for gable end wall column (Wauchula).

3.1.3 Building Components and Cladding (C&C) Damage Due to Wind Effects

The building envelope is composed of the systems that clad the exterior of a building, including roof coverings, wall coverings, walls, windows, and doors. Designers refer to these systems, along with exterior building mechanical systems and attachments, as C&C. These building envelope systems or C&C were observed to be the areas of buildings that experienced the most damage from Hurricane Charley.

Over the past 20 to 30 years, research has demonstrated that localized pressures affecting the skin of the building can be much larger than originally anticipated. The use of electronic pressure sensors and data acquisition systems that allowed the rapid measurement of wind pressures on scale models in boundary layer wind tunnels have been responsible for much of the dramatic changes in code-based wind load provisions. Better understanding and improved modeling of the gust structure of extra-tropical winds also led to the development of new design coefficients that produce higher required C&C element loads along edges and in the corners of roofs and walls. As a result, the design guidance for C&C loads affecting the design of the building envelope and the design of attachments to buildings has resulted in a significant increase in the design loads for these building components. Questions persist concerning whether these simulations adequately model the gust characteristics of hurricane winds. Nevertheless, the wind load provisions used to design C&C and the attachment of these elements to buildings have changed, and the loads have increased significantly over the past 20 years. These provisions and design requirements were incorporated into later editions of the SBC and ASCE 7, and have always been in the 2001 FBC.

The discussion below presents an overview and categorization of the damage observed to the building envelope. A more detailed discussion follows in Chapter 5.

3.1.3.1 Residential Buildings (One- and Two-Family Dwellings)

The most widespread damage to one- and two-family housing units occurred at or above the roof line and included loss of asphalt shingles or tile roof coverings (Figures 3-14, 3-15, and 3-16). This type of damage was observed across the wind field on both the barrier islands and on the mainland (including inland areas). By contrast, one- and two-family homes with metal roof coverings suffered only minor, if any, damage (Figure 3-17). The metal roof systems most frequently noted to be damaged were those with concealed clips integrated into the seaming process; however, such fastening is not readily visible.

Figure 3-14. Asphalt shingle roof covering damage on a new one-story house. In some areas, the underlayment was also blown away (Deep Creek).

Figure 3-15. Typical asphalt shingle roof covering loss on elevated, two-story house (Captiva Island)

Figure 3-16.
Foam set tile roof covering failure (Punta Gorda)

Figure 3-17.
Typical pile-elevated residence with undamaged metal panel roof (coastal flood zone on Pine Island)

Other damages to one- and two-family housing units included loss of roof sheathing and the consequent partial or total collapse of gable end roof sections (Figures 3-18 and 3-19). The loss of roof sheathing was observed in the areas with the highest winds. This type of damage was not common.

Figure 3-18. Example of roof decking loss on one-story house (Punta Gorda)

Other observed types of damage to residential buildings were to large roof overhangs, double-entry doors, garage doors, and soffits that were not properly reinforced to resist high-wind pressures. Homeowners repeatedly reported the failure of double-entry doors. These failures typically resulted in the blowout of sliding glass doors and the movement of furniture as wind and rain blew through the home. Figure 3-20 shows a double-entry door that failed; insets show the cracking of the door and the top of the door frame where the latches on the fixed door failed.

Figure 3-19 Partial gable end wall failure with loss of roof shingles (Deep Creek)

Figure 3-20. Double-entry door that failed under wind pressure. Upper inset shows close-up of crack in door frame at top latch. Lower inset shows crack in door emanating from bottom latch (Punta Gorda).

In addition, widespread loss of vinyl and aluminum soffit panels was also observed. These panels were either pulled out by negative wind pressures (suction) or pushed up by positive pressures (Figure 3-21). The damage was not limited to the loss of the windows or doors or loss of the exterior soffit cladding system. Damages to these building envelope components led to wind-driven rain entering the homes and wetting the building interior and the internal wall cavities, and saturating attic insulation and ceilings that sometimes collapsed (Figure 3-22).

Figure 3-21. Typical elevated wood-frame house with extensive soffit damage (North Captiva Island)

Figure 3-22.
The drywall ceiling in the home shown in Figure 3-21 collapsed after becoming waterlogged and weakened by wind-driven rain that entered through the exterior soffit space. Plywood covers the opening of a window broken by windborne debris after the plastic shutters blew off (North Captiva Island).

3.1.3.2 Commercial and Mixed-Use Buildings (Including Multi-Family)

As with one- and two-family dwellings, the most common type of damage to multi-family housing units occurred at or above the roof line and included the loss of asphalt shingles and tiles, and metal roof coverings and roof decking. Roof covering, underlayment, and deck loss was mostly observed on older structures, but there were notable exceptions, which are discussed in Chapter 5. This type of damage was also observed in other areas affected by the highest winds, such as Captiva Island (Figure 3-23), but was observed less in areas farther inland. Other types of damage to multi-family housing units commonly included damage to wall sheathing at gable ends (Figure 3-24).

Figure 3-23. Roof covering loss. Note dark areas on roof are exposed underlayment (Captiva Island).

Figure 3-24. Vinyl siding wall covering on multi-family building with damage to gable end wall sheathing (Port Charlotte)

Damage to concrete and masonry buildings typically included a loss of roof sheathing that was inadequately attached to the roof or failure of roof framing elements (similar to the damage described in Section 3.1.2.2). In addition to these types of commercial buildings, steel and concrete frame buildings were observed. These robust framed buildings did not experience failure of framing systems or roof decks during Hurricane Charley, but still experienced damage. Wall cladding systems on commercial buildings were damaged across the path of the storm, with the heaviest damage observed along the path of the eye between Charlotte Harbor and De Soto County. Poor performance of wall cladding was observed where URM was used (Figure 3-25) and where exterior insulation and finish systems (EIFSs) were used (Figure 3-26).

Figure 3-25. Example of unreinforced masonry wall and parapet collapse due to breaching of roof (on opposite side of building) (Wauchula)

Figure 3-26.
Example of damage to EIFS wall panels (Punta Gorda)

Damage to windows, doors, and soffits was observed in commercial applications similar to the losses and damages observed in residential construction. Figure 3-27 is a medical office building in Punta Gorda that lost roof decking, suffered damage to EIFS wall coverings, and experienced significant glass breakage.

Figure 3-27.
Structural steel frame building showing loss of roof decking and damage to EIFS wall coverings (Punta Gorda)

In commercial applications, door losses were often more dramatic when the loss was not just to personnel doors, but to large rolling and sectional doors, leading to the pressurization of buildings. As a result, the failure of these doors due to wind loading, as shown in Figure 3-28, often caused significant damage to the buildings and the building envelope itself. This type of damage was observed frequently in essential and critical facilities; further discussion on this type of damage is provided in Chapters 5 and 6. Failure modes, including door panel failure, door track failure, and the door track-to-wall (door buck) attachment failure, are also discussed in Chapters 5 and 6.

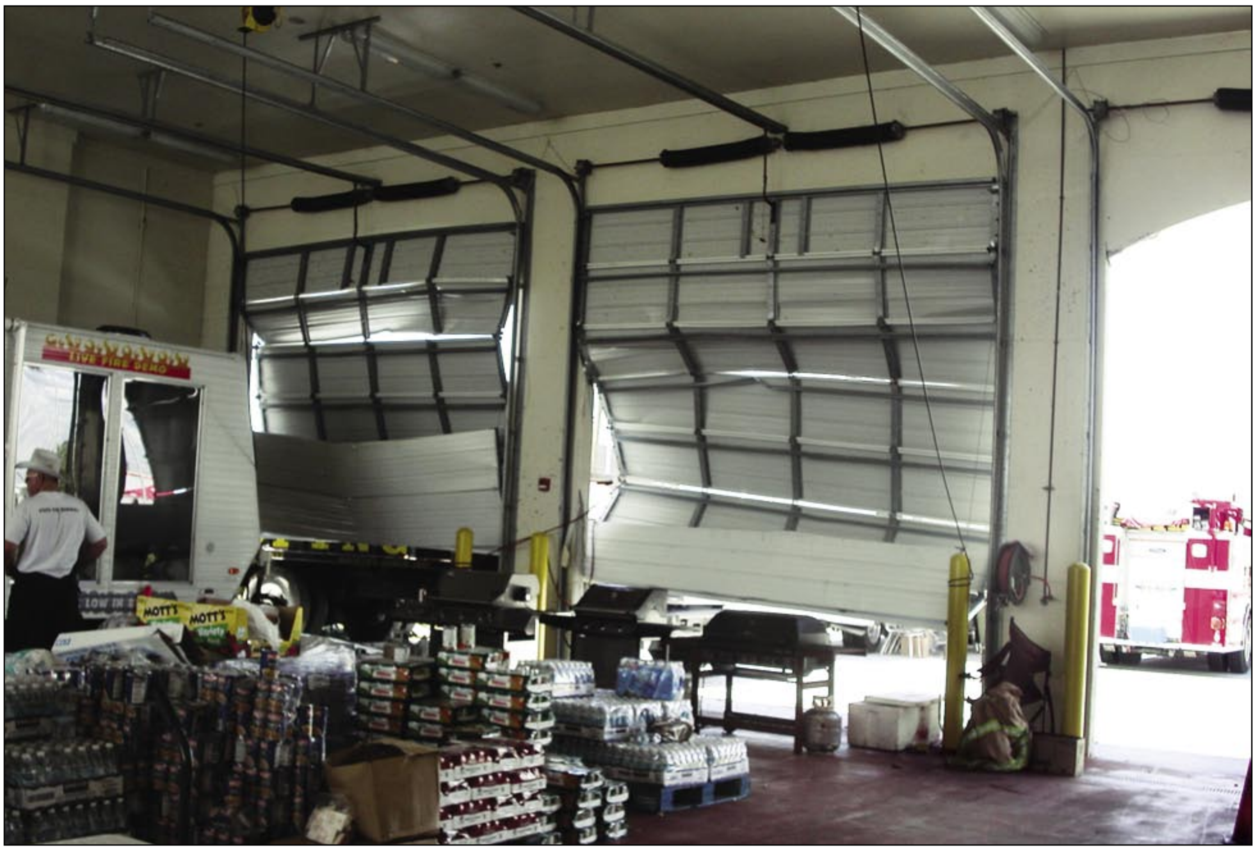

Figure 3-28. Damage to large rolling and sectional doors at Fire Station No. 1 (Punta Gorda)

Other types of damages to commercial buildings observed by the MAT included loss of large awnings and HVAC equipment due to the lack of proper connections (Figure 3-29). This type of damage was observed across the damage path of the storm.

Figure 3-29. Dislocation of rooftop equipment (Pine Island)

3.1.4 Building Damage Due to Windborne Debris

In addition to damage caused by the wind itself, windborne debris (e.g., missiles) from failed building components and other sources caused damage to surrounding buildings. During a hurricane, the severity of the windborne debris problem and the resulting damage depends on:

- wind speeds
- debris source and elevation of the source
- proximity of the debris source
- weight and rigidity of the debris
- resistance of the debris to release into the wind field
- angle of debris impact

The MAT's observations clearly demonstrated that there were significantly larger numbers of debris missiles and greater windborne debris damage in the areas that experienced the highest wind speeds (e.g., 120 mph or higher, 3-second peak gust). In the Punta Gorda and Port Charlotte areas, where wind speeds were estimated to be between 125 and 130 mph 3-second peak gust, fully one-third of the homes that were not outfitted with shutters experienced at least one broken window (reported by damage assessment teams from the University of Florida and the IBHS) and only one of the houses surveyed that had shutters experienced a broken window. This suggests that, when an area experiences wind speeds at or above 120 mph 3-second peak gust, the damage of unprotected glazings can be significant and that using appropriate laminated glass or shutter systems will be an effective deterrent to such damage. In contrast, very few broken windows were observed in areas where the gust wind speeds were estimated to be less than about 100 mph 3-second peak gust. The 2001 FBC (and ASCE 7 since the 1995 edition) requirements for protection of glazed openings on buildings located in windborne debris regions are:

- where the basic design wind speed is greater than 120 mph 3-second peak gust, or
- within 1 mile of the coast where the design wind speed is greater than 110 mph 3-second peak gust.

Unfortunately, damage from windborne debris will remain an issue during hurricanes even if all glazings are protected. Significant amounts of debris were generated in the areas that experienced winds less than 100 mph when poorly constructed or non-engineered enclosures, pool screens, carports, and attached structures could not withstand the hurricane winds. Adequately protecting buildings from windborne debris, as required by code, is a sound building practice. Use of the 120-mph wind contour line to require glazing protection on buildings was supported by the extensive damage to glazing systems along the eye's path. However, as discussed in Section 5.2, glazing damage was documented in areas that experienced speeds well below 120 mph. An example of shutters performing as designed is shown in Figure 3-30.

Figure 3-30. Newer house with storm shutters (Sanibel Island)

Windborne debris released from the roofs of buildings traveled farther than that released from the ground and was a more serious threat. Heavier, rigid debris, such as roof tiles, flew long distances and typically caused more damage than debris that rolled along the ground. Significant damage was frequently observed in areas where clay and concrete tiles were used as roof coverings and in neighborhoods where the building began to fail and wood structural members were released as missiles. Although a number of buildings with mortar-set tiles lost significant numbers of tile (Figure 3-31), many landed a relatively short distance from the building. These shorter transport distances are attributed to the fact that many of the tiles were so poorly attached that they blew off under moderate wind speeds. Tiles and other building elements that were better anchored, but subsequently failed during periods of higher winds, were transported greater distances and frequently attained greater velocities. Figure 3-32 shows the impact of a roof tile that punctured a Miami-Dade County-approved shutter and broke the window. Although this shutter did not perform flawlessly, it did not allow the entry of enough air to cause excessive internal pressures; however, it did expose the building to the entry of wind-driven rain, but the building was not nearly as exposed as it would have been if the glass had been unprotected.

Figure 3-31.
Extensive damage to mortar-set tile roof on this pre-2001 FBC home. Note broken windows to the right of the front door (Punta Gorda).

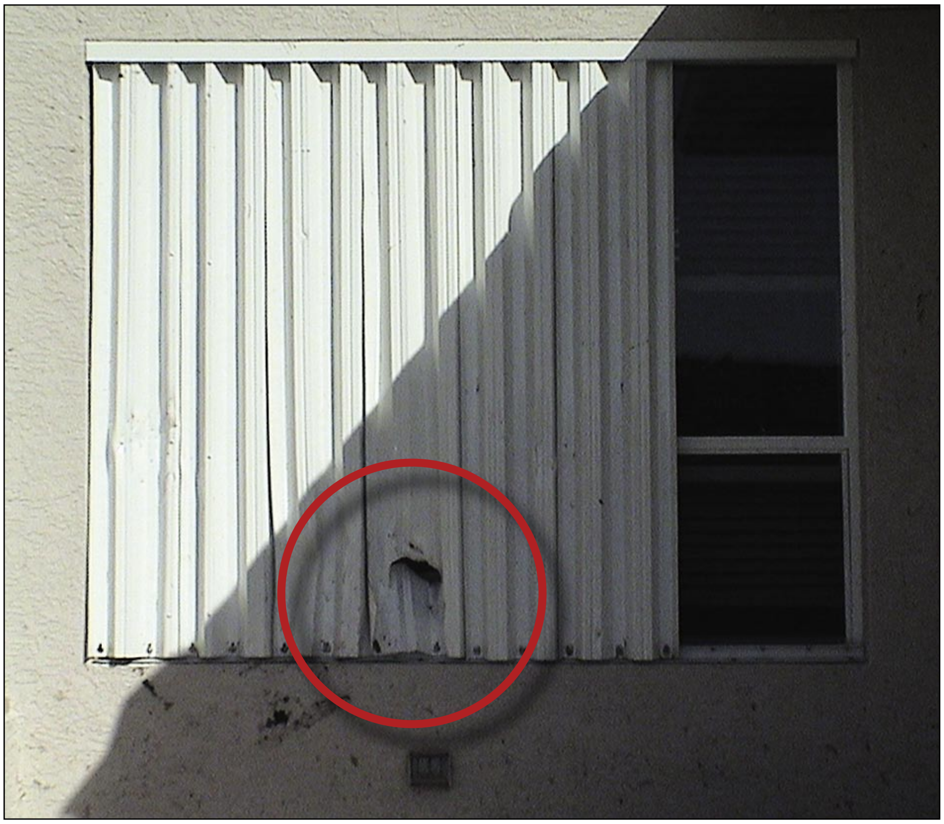

Figure 3-32.
A roof tile punctured this Miami-Dade County-approved shutter (Punta Gorda)

The importance of the height at which debris was released was also evident as far inland as the Orlando area. When a piece of debris is released into the wind field at a significant height, there is greater potential for that debris to remain aloft and be accelerated to wind speeds approaching the wind speeds of the event than for debris released or generated lower to the ground. An example of this was observed in the atrium of the hotel shown in Figure 3-33. At this hotel, the glass at the atrium was damaged by debris from the EIFS wall cladding.

Windborne debris observed by the MAT included roof coverings (tiles, shingles, metal panels, aggregate, etc.), structural and non-structural building elements, tree limbs, refuse containers, lawn furniture, and vehicles. Figures 3-34 through 3-38 show examples of windborne debris. Small debris, such as the roof shingle stuck in the side of the column in Figure 3-34, must have traveled at least a mile because this community only allowed tile roofs. As expected, larger items did not travel as far, although the section of roofing from a wood-frame building on Captiva Island traveled approximately 200 yards after being separated from the original structure.

Figure 3-33.
Damage to glass atrium of high-rise hotel. Note the loss of EIFS, which was the cause of the glass breakage (Orlando).

Figure 3-34.
Edge impact of an asphalt shingle on decorative column (Punta Gorda)

Figure 3-35.
Impact of tree branch through the stucco and metal lath wall system of a fire station. The branch was about 5 inches in diameter and protruded about 3½ feet out of the wall (Aqui Esta, east of Punta Gorda Isles).

Figure 3-36.
Tile damage to a metal-panel garage door (Punta Gorda)

Figure 3-37.
Impact of structural wood members in the gable end from a neighboring house (Pine Island)

Figure 3-38.
Large section of roof structure transported over 200 yards from its source (Captiva Island)

In manufactured home parks, there was a significant amount of aluminum and sheet metal debris from attached structures that failed and a significant amount of glazing damage even in inland parks, as discussed in Section 5.2; however, there were some windows surprisingly intact on the windward sides of the homes. It appears that the close proximity of the homes and the deformable nature of the debris may have helped to reduce the debris impact damage; it is likely that large sheets bumped into the next home before they had traveled very far or attained much velocity (Figure 3-39). In contrast, a manufactured home park observed with homes spaced considerable distances apart appeared to have greater windborne debris damage (Figure 3-40).

Figure 3-39.
Typical metal roof panel and siding debris from failed accessory structures and manufactured homes that were stripped of siding resulting from accessory structures failure (Arcadia)

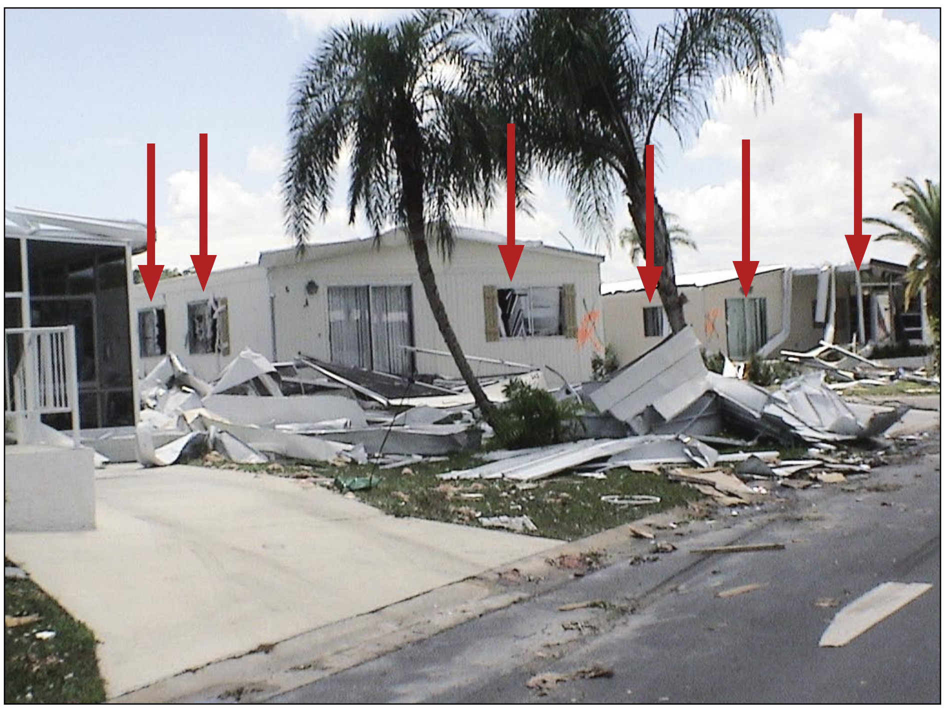

Figure 3-40.
Typical metal roof panel and siding debris caused glazing damage to units (Port Charlotte)

It was clear, through investigations at a number of hospitals and other buildings with aggregate roof surfacing, that the aggregate could, and frequently did, cause damage to windows on the building itself. The damage to windows in the intensive care unit of the hospital in Arcadia (Figure 3-41) was a prime example of this effect.

Figure 3-41.
Aggregate from the built-up roofs broke windows at the intensive care unit of a hospital where 3-second peak gust wind speeds were estimated between 110 and 120 mph (Arcadia).

In addition to windborne debris, wind forces caused larger objects to fail and create falling debris. Buildings were damaged by several types of falling objects, including trees, communications towers, rooftop equipment, and chimneys. The uprooting or fracture of large pine and hardwood trees was observed throughout the areas surveyed. On the barrier islands, the extent of tree damage resulted in severe access problems by blocking roads and driveways and creating a severe fire danger. Inland, the tree damage was more isolated, but was frequently spectacular as trees came to rest on buildings or sliced through buildings. Manufactured homes typically suffered the greatest damage from tree fall. Figure 3-42 shows a large tree that fell on a three-story house, and Figure 3-43 illustrates damage from a pine tree that sliced through a manufactured home. Figure 3-44 shows a fallen communications tower at a fire station.

Figure 3-42. Damage to three-story home from tree impact (Wauchula))

Figure 3-43. Damage to manufactured home from tree impact (Pine Island)

Figure 3-44. Fallen communications tower (Aqui Esta, east of Punta Gorda Isles)

3.1.5 Attached and Accessory Structures

Most of the damages to accessory and attached structures were observed as failures of attached structures to manufactured homes and to failures of screened enclosures on both manufactured and site-built homes (typically around swimming pools). Damages to manufactured housing units most often occurred at overhangs, carports, and awnings that were improperly attached to the units and did not have an independent support structure as required by code (Figures 3-45 and 3-46). According to the 2001 FBC, accessory structures are allowed to be directly connected to the units if a registered engineer certifies that the accessory being attached can be supported by the unit. In the failures observed, there was no evidence that the areas to which the accessory was attached were different or reinforced to support attached structures; only standard manufactured housing construction systems were observed. In general, where accessory and attached structures did not contribute to damage to the manufactured home units, the housing stock that had been constructed to post-1994 standards performed much better than the older units.

Figure 3-45.
Example of typical damage to roof covering, roof sheathing, and exterior siding of a manufactured home as a result of the failure of an attached carport structure (Port Charlotte)

Figure 3-46.
Example of damage to manufactured home roof covering, roof deck, and siding due to failure of screen enclosure attached to home (Port Charlotte)

Screen enclosures around pools are common in Florida and incurred extensive damage as a result of Hurricane Charley. Damage typically occurred on the sides of buildings that received direct windward pressures. Figure 3-47 shows an example of a screened pool enclosure that failed from wind pressures. Note the damage caused to the window by the debris from the enclosure.

Figure 3-47. Example of damage to pool screen enclosure. Note broken window in center of photo from debris (Punta Gorda Isles).

3.2 Flood Effects

Hurricane Charley did not produce large amounts of flood damage to the built environment. As documented in Section 1.3, due to the timing of the storm's landfall with respect to low tide, the compact size of the storm, and the change in course just prior to landfall, significant storm surge across Charlotte Harbor and up tributary rivers was not observed. The MAT performed assessments to identify flood-related damage in mapped flood zones (in both riverine and coastal areas) and mapped storm surge zones. Although the barrier islands west of Charlotte Harbor experienced erosion and North Captiva Island was breached by the storm, the MAT did not investigate or assess these issues.

3.2.1 Flood Damage Observations

Hurricane Charley produced flooding in isolated riverine and coastal areas, and the storm's heavy rainfall caused riverine flooding in low-lying inland areas. Coastal storm surge resulted in inundation along coastal areas of southwest Florida.

3.2.2 Coastal Surge Damage

The most significant coastal flooding occurred in Fort Myers Beach. Some overwash occurred on Captiva Island, but resulted in minimal flood damage. Coastal areas along Charlotte Harbor, including Port Charlotte and Punta Gorda, which were along the path of the storm, had tides only a few feet higher than normal and did not result in any flood damage.

Building damage as a result of coastal surge was concentrated in structures along the coast of Fort Myers Beach. Within the first several rows of houses near the coast and along Estero Boulevard, buildings constructed at or near grade experienced the most damage. Houses set back and on properly elevated piles suffered no damage from the coastal storm surge. Figures 3-48 through 3-55 show damage on Fort Myers Beach.

Figure 3-48. Minor scour of parking lot from overwash of storm surge (Fort Myers Beach)

Figure 3-49. Minor scour around pile (Fort Myers Beach)

Figure 3-50.
Oceanfront house constructed on piles sustained only minor damage as a result of storm surge (Fort Myers Beach)

Figure 3-51.
Storm surge damage of 2 to 3 feet limited to lower floor of two-story house (Fort Myers Beach)

Figure 3-52.
Typical house with first-floor living space at grade sustained 2 to 3 feet of storm surge damage (lack of wall damage suggests low velocity flows) (Fort Myers Beach)

Figure 3-53.
Newly constructed house elevated on piles sustained no storm surge damage (Fort Myers Beach)

Figure 3-54.
Fire station elevated on fill prevented any storm surge damage (Fort Myers Beach)

Figure 3-55. Storm surge caused scouring of the road and damage to the infrastructure (i.e., water main) (Fort Myers Beach)

3.3 Critical and Essential Facilities

Critical and essential facilities were investigated by the MAT to assess the functional loss of services from these operations in response to Hurricane Charley. In addition to the buildings that would qualify under building code definitions as essential facilities, the following buildings were considered either critical or essential facilities due to their key roles in post storm recovery efforts and as day-to-day emergency response centers: fire and police stations, emergency medical facilities, non-emergency medical facilities, nursing homes, EOCs, storm shelters, schools, and other public buildings critical to the long-term recovery of a community following a major disaster. Most of the building types that serve as critical and essential facilities fit into these categories and are discussed further in Chapters 4 and 5. However, specific damages that significantly affected the ability of these facilities to function are summarized below and presented in detail in Chapter 6.

3.3.1 Fire and Police Stations and Hospitals

Most of the buildings being used for police and fire stations were older buildings that had not been enhanced or mitigated to resist wind and windborne debris to the level at which new essential facilities are required to be designed. Roof coverings, sectional doors, and roof structural systems were the most commonly damaged components of fire and police stations and hospitals. In one instance, the MAT observed cementitious wood-fiber decking that was not adequately secured to resist uplift had lifted off the supporting roof structure (Figure 3-56). On gable end and hip roofs, metal and asphalt shingle roof coverings were damaged; gable end wall collapses were also observed (Figure 3-57).

Other damages to fire and police stations included failure of large rolling and sectional doors and collapse of communications towers (previously shown in Figure 3-44). Other damages to hospitals included broken glazing from roofing aggregate and other windborne debris, and damage to awnings and other appurtenances.

Figure 3-56. Cementitious wood-fiber roof deck panels at this older fire station were not adequately secured to resist uplift (Port Charlotte).

Figure 3-57.
Gable end wall collapse and rolling and sectional door failure at fire station (Aqui Esta, east of Punta Gorda Isles). A close-up of the missile in the circle is shown in Figure 3-35.

3.3.2 Emergency Operations Centers, Storm Shelters, and Schools

The MAT observed EOCs, storm shelters, and school buildings that were impacted by Hurricane Charley. Although some of these facilities were specifically designed and retrofitted for their intended use as critical or essential facilities, many EOCs and shelters observed were older buildings not specifically designed or retrofitted for use as shelters. As was observed with the fire and police stations and hospitals, when older buildings were used for these operations, there was often little or no retrofitting or mitigating of the structure to resist high winds and debris impact.

Roof structures and coverings were the most commonly damaged elements of EOCs and storm shelters. On low-profile gable end roofs, roof damage or collapse occurred as a result of inadequate connections of roof sheathing, failure of roof framing elements, or collapse of gable end walls (Figure 3-58).

Figure 3-58.
End wall damage to long span, pre-engineered metal building designed for use as a storm shelter (Turner Agri-Civic Center, Arcadia – see Section 6.5.1.1)

Unreinforced masonry (URM) and reinforced masonry were the most commonly observed wall systems in school buildings. The amount of the steel reinforcement and grout within the reinforced masonry block walls varied based on the age and quality of construction. A few older school buildings were constructed using URM block or hollow clay tile walls. Roof framing systems for school buildings varied widely, depending on the age and condition of the structure. Many schools used low-sloped roof systems with either plywood sheathing supported by wood trusses or lightweight insulating concrete slabs on top of corrugated metal decking with steel joists. Other schools used gable end or hip roofs constructed of plywood or oriented-strand board (OSB) sheathing with wood or light-metal frame trusses. A variety of roof coverings were used; soffits were typically constructed of metal sheets or panels.

As with other critical facilities, roof coverings were the most commonly damaged components of schools (Figure 3-59). Other damage to schools included loss of soffits and large overhangs that were not adequately attached to the structure, leading to the collapse of URM parapets and walls in older schools (Figure 3-60). Glazing damage was common; windows were broken from aggregate surface roofs and other windborne debris. In the higher wind areas, typically, portable classroom units were damaged or destroyed.

Figure 3-59.
Example of roof covering damage at a school. This was a mechanically attached single-ply membrane over a previous aggregate surfaced built-up roof (Port Charlotte).

Figure 3-60.
Example of URM parapet wall collapse and broken windows at an older school (Punta Gorda)