5

Building Envelope Performance

Good structural system performance is critical to avoiding injury to occupants and minimizing damage to a building and its contents. It does not, however, ensure occupant or building protection. Good performance of the building envelope is also necessary. The building envelope includes:

- Sheathing on the underside of bottom-floor joists of elevated buildings,
- Exterior doors,
- Non-load-bearing walls, wall coverings, and soffits,
- Roof coverings,
- Windows, shutters, skylights, and
- Exterior-mounted mechanical and electrical equipment.

Historically, poor building envelope performance is the leading cause of damage to buildings and their contents in weak- to moderate-intensity hurricanes. Building structural capacities have improved because of stronger building codes and better enforcement, resulting in less structural damage overall from hurricanes such as Hurricane Ivan. As a result, the performance of the building envelope is becoming increasingly important. The following sections describe envelope performance during Hurricane Ivan as observed for residential, commercial, and critical and essential facilities.

5.1 Sheathing on the Underside of Elevated Buildings

Sheathing was typically installed on the underside of bottom-floor joists on elevated buildings. Besides protecting batt insulation that is placed between joists, sheathing can also protect electrical and plumbing lines from floodborne debris. A variety of sheathing materials were observed. Vinyl siding and plywood were the most common, but gypsum board was observed on three buildings, and corrugated metal was observed on one building. The majority of the buildings with vinyl experienced sheathing loss (Figure 5-1). For further discussion of vinyl siding, see Section 5.3.2.

Figure 5-1. Loss of vinyl siding panels from the underside of an elevated residence in Gulf Shores (Laguna Key)

All of the buildings with gypsum board experienced sheathing loss (Figure 5-2). One of these buildings was a large apartment or condominium – essentially all of the gypsum board was torn away (the gypsum board typically pulled over the nail heads).

Figure 5-2.
Loss of gypsum board from the underside of an elevated residence in Gulf Shores (Laguna Key)

The plywood panels typically performed well, but some losses were experienced (Figure 5-3). Nails were typically used to attach the sheathing. Fastener corrosion was common and some of the nail heads were totally corroded away. Fastener spacing along the joists was often about 12 inches on center. Although the long edge of the sheathing typically occurred over blocking, fastener spacing along the long edge was often only about 16 inches on center.

Figure 5-3.
Loss of plywood from the underside of an elevated residence in Gulf Shores (West Beach)

Fast-moving floodwater and peaking waves likely caused some of the sheathing loss, including complete loss of gypsum board at one building. Gouging of sheathing (including penetration of plywood) by floodborne debris was also observed. However, the majority of the sheathing loss appeared to be caused by wind accelerating as it passed beneath the elevated building. ASCE 7, FBC, and IBC do not provide guidance on determining design wind loads on sheathing on the underside of elevated buildings. Hence, professional judgment in specifying attachment is needed.

5.2 Doors

Failure of an exterior door has two important effects. First, failure can cause a rapid increase in internal pressure, which may lead to exterior wall, roof, interior partition, ceiling, or structural failure. Second, wind can drive rainwater through the opening, causing damage to interior contents and finishes, and lead to the development of mold. The essential elements of good high-wind door performance include product testing to ensure sufficient factored strength to resist design wind loads (both static and cyclic loading); suitable anchoring of the door frame to the building; proper flashing, sealants, tracks, and drainage to minimize water intrusion into wall cavities or into occupied space; and, for glazed openings, the use of laminated glass or shutters to protect against windborne debris damage, as discussed in Section 5.5.

5.2.1 Personnel Door Damage

Personnel door damage was observed on a limited number of buildings. Observed damage included broken window panes (caused by windborne debris) and door frames that disengaged from the building (likely caused by inadequate fastening to the building), as illustrated by Figures 5-4, and 5-5. The sliding glass door frame in Figure 5-5 had recently been installed in an existing building. The door assembly was rated for a load of +/- 50 pounds per square feet (psf). The applied loads were well below 50 psf. The frame was attached with nails spaced at 4 3/8 inches on center through a vinyl nailing flange. Although the edge distance was limited, the typical failure mode was nail pull-out.

Figure 5-4.
Tempered glass door broken by debris from a mortar-set tile roof (Pensacola)

Figure 5-5.
Sliding glass door frame blown from the wall

5.2.2 Garage Door Damage

Many damaged garage doors were observed in coastal areas. The majority of the doors were damaged by floodwater. Wind-induced damage was minimal. (For observations and discussion of garage door wind damage caused by Hurricane Charley, see FEMA 488, *Mitigation Assessment Team Report, Hurricane Charley in Florida.*) Figure 5-6 shows a combined garage door and wall covering failure. Where breakaway walls are installed, collapse of the garage doors is intended.

Figure 5-6. Floodwater collapsed the garage door at the left end of this residence. (Laguna Key)

5.2.3 Rolling and Sectional Door Damage

A limited amount of wind damage to rolling and sectional doors (e.g., service garage doors and loading dock doors) was observed, including damage to sectional doors at a fire station. (For observations and discussion of rolling and sectional door damage caused by Hurricane Charley, see FEMA 488, *Mitigation Assessment Team Report, Hurricane Charley in Florida*.)

5.3 Non-Load-Bearing Walls, Wall Coverings, and Soffits

Hurricane Ivan caused damage to several non-load-bearing walls, wall coverings, and soffits. Non-load-bearing walls included exterior insulation finish systems (EIFS) and stucco. Wall coverings included brick, metal panels, vinyl, and wood. Vinyl was typically used for soffits. The following factors are essential to good high-wind non-load-bearing wall, wall covering, and soffit performance: product testing to ensure sufficient factored strength to resist design wind loads; suitable anchoring of the wall, wall coverings, and soffits to the building; use of moisture barriers (e.g., asphalt saturated felt or housewrap) where appropriate; and proper flashing, sealants, and drainage to minimize water intrusion into wall cavities or into occupied space.

Note: For observations and discussion of breakaway walls, see Subsection 4.1.3.3.

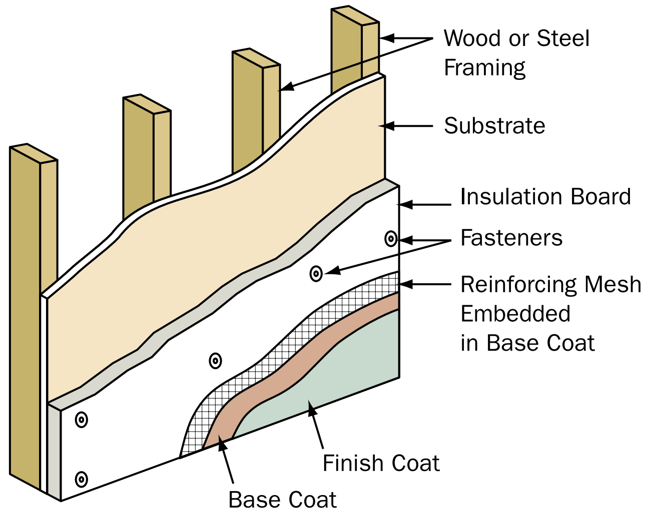
5.3.1 Non-Load-Bearing Walls

Non-load-bearing walls that were investigated included EIFS over studs and stucco over studs. EIFS and stucco wall coverings over bearing walls were also investigated and are included in this section. A large number of EIFS failures and several stucco failures were observed. With loss of the EIFS or stucco coverings, wind-driven rain was often able to enter the wall cavity or the building itself and initiate mold growth. EIFS and stucco coverings that became windborne debris were capable of breaking unprotected windows. Figures 5-7 and 5-8 show typical EIFS and Stucco assemblies.

Figure 5-7.
Typical EIFS assembly

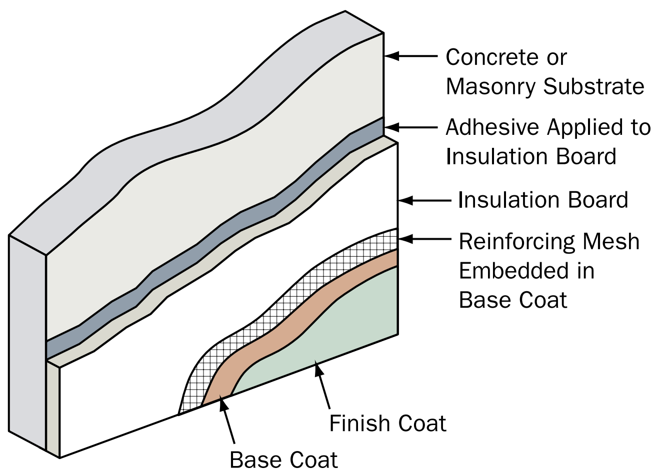
Option A

Steel or Wood Framing
EIFS may be attached by mechanical fasteners (as shown) or by adhesive (as shown below)



Option B

Concrete and Masonry
EIFS attached to concrete or masonry using adhesive. Mechanical fasteners may also be used.



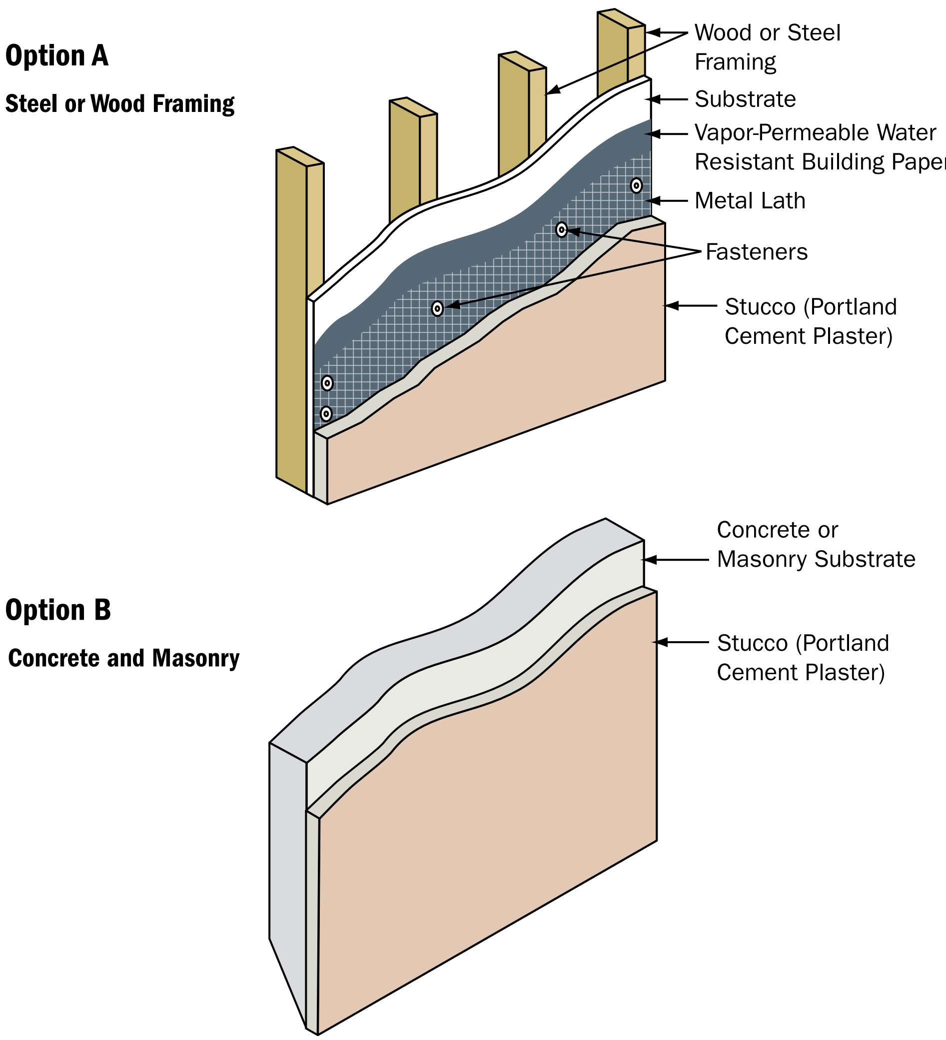


Figure 5-8.
Typical stucco assembly

EIFS

Fast-moving floodwater initiated damage at the residence shown in Figure 5-6, but a projecting wall band limited progressive peeling of the EIFS in the vertical direction. The synthetic stucco was applied over a cementitious board that was installed over housewrap. Floodwater broke away the wall and initiated progressive peeling of the synthetic stucco and cementitious board. However, the presence of the white band that projected about 2 inches out from the face of the wall inhibited vertical peeling.

At the residence shown in Figure 5-9, there was no projecting band, reveal, or other detailing to limit vertical peeling. The synthetic stucco was applied over polyisocyanurate insulation that was installed over asphalt saturated felt. Floodwater broke away the wall and initiated progressive peeling of the synthetic stucco and a portion of the polyisocyanurate. The facer on the polyisocyanurate peeled off with the synthetic stucco. The polyisocyanurate was attached with mechanical fasteners. The fasteners were poorly applied. There were fewer fasteners near the bottom edge than there were in the field rows. The fasteners were placed too close to the long edge of the board. At the end of the boards, fasteners were installed through the board joint, so that one fastener would hold the edge of two boards (see red circle in Figure 5-9). Rather than placing fasteners at the joints, fasteners should have been inward of the joint. If the fasteners had been properly located, several more fasteners would have been required.

Figure 5-9.
Vertical peeling on a home in Gulf Shores due to lack of a projecting band or reveal after the breakaway wall failed (Laguna Key)

Figures 5-10 through 5-12 show dry rotted studs and sheathing, indicating long-term moisture intrusion behind the molded expanded polystyrene (MEPS) insulation. Both of these buildings used a barrier EIFS design, rather than the newer drainable EIFS design. (No drainable EIFS designs were observed.) At the condominium in Figure 5-10, the synthetic stucco was installed over MEPS over gypsum board over wood studs. Essentially all of the gypsum board blew off (the boards typically pulled over the fasteners). Some of the gypsum board on the interior side of the studs was also blown off. Note the missing studs on the second level at the left. Stud failure may have initiated the EIFS blow-off. Note the metal diagonal stud bracing straps. Two of the windows were broken by debris.

Figure 5-10.
All gypsum board blown off and two windows broken by debris. Note the missing studs. (Pensacola Beach)

Figure 5-11 is another view of the condominium complex shown in Figure 5-10. The studs were severely rotted and the metal connectors were very corroded.

Figure 5-11.
Severely deteriorated studs and corroded metal connectors

Figure 5-12. Blown off EIFS revealed severely rotted oriented strand board (OSB) due to water infiltration at windows and wall penetrations. Roof decking blown off of a building with a 5-V crimp metal panel roof.

Figure 5-13 shows common planes of failure of EIFS installed over wood and metal studs. Typically, separation of the synthetic stucco from the MEPS is likely a secondary failure plane. Initial failure is likely caused by detachment of the MEPS from the gypsum board, or detachment of the gypsum board from the studs. When the MEPS detaches from the gypsum board, the gypsum board can suffer strength reduction due to wetting from the wind-driven rain, and it, too, will often then blow off during a hurricane.

On the building shown in Figure 5-13, wood studs were used in the center section and metal studs were used on adjacent sections. In the center area, gypsum board detached from the studs. Near the bottom of the wall and above the MEPS, the gypsum board is still attached, but the MEPS separated from the gypsum board. At the white area, the synthetic stucco separated from the MEPS. Note the attachment of the MEPS to the gypsum board. Adhesive is nearly continuous at the perimeter of the MEPS boards, and four vertical lines of adhesive occur in the field of the boards (the vertical lines are of different lengths and none of them extend all of the way to the board edges). Adhesive should have been continuously applied throughout the entire board area.

Figure 5-13.
Loss of EIFS on a commercial building

Figure 5-14 shows extensive damage to non-load-bearing EIFS walls on a multi-story building. Hurricane Ivan inflicted large areas of EIFS failure on many multi-story buildings.

Figure 5-14.
Multi-story building showing severe EIFS damage. The gypsum board typically detached from the studs. See Figure 7-11 for a close-up of the circled area.

Figure 5-15 shows extensive damage to non-load-bearing EIFS penthouse walls on a mid-rise medical office building (MOB) at a hospital. After failure of the EIFS, rainwater was able to blow into the elevator penthouse and damage the elevator controls. Loss of vertical transportation in mid- and high-rise buildings can severely interrupt functionality.

Figure 5-15.
The gypsum board detached from the studs at the penthouse. Rainwater infiltration damaged the elevator controls. (Pensacola)

Figures 5-16 through 5-19 show EIFS damage and very extensive secondary damages caused by EIFS failures at a hospital complex. Because of rapid emergency response by construction crews, the hospital remained functional. However, the damage was very costly and created hardships on hospital staff.

EIFS debris from the hospital shown in Figure 5-16 broke numerous windows in the MOB and several of the windows in the connecting walkway between the MOB and hospital. The projection from the right rear of the MOB is an elevator. The side walls of the elevator shaft were EIFS and windows were located in the front wall. Several windows were broken by EIFS debris. The EIFS (including the gypsum board substrate) blew off the metal studs in several areas. Water infiltration damaged the elevator controls. Several people were trapped in the elevator during the hurricane. Fortunately, the MOB had another bank of elevators, so vertical transportation was still possible, though handicapped by loss of this elevator.

EIFS (including the gypsum board) also blew off the MOB stair tower walls. Some of the gypsum board on the interior side of the studs collapsed into the stairway, thus trapping a maintenance worker who had gone to the mechanical penthouse during the hurricane.

Figure 5-16.
EIFS blew off the hospital building in the background (see red circle and Figures 5-18 and 6-2). EIFS debris broke numerous windows in the MOB in the foreground. (Pensacola)

Glass shards punctured the one-story roof (Figure 5-17) at the right of the MOB (red arrow in Figure 5-16), which housed the urgent care facility and regional dialysis unit. However, by quickly performing emergency roof repairs and cleaning up the interior, the dialysis unit was non-operational for only one day. The roof over the dialysis unit was a ballasted ethylene propylene diene monomer (EPDM) membrane roof. The roof deck was a concrete or lightweight insulating concrete topping over metal decking. The deck was effective in minimizing water infiltration into the facility. (Note: At the time the photo in Figure 5-17 was taken, the ballast had been repositioned into rows in preparation for removal.)

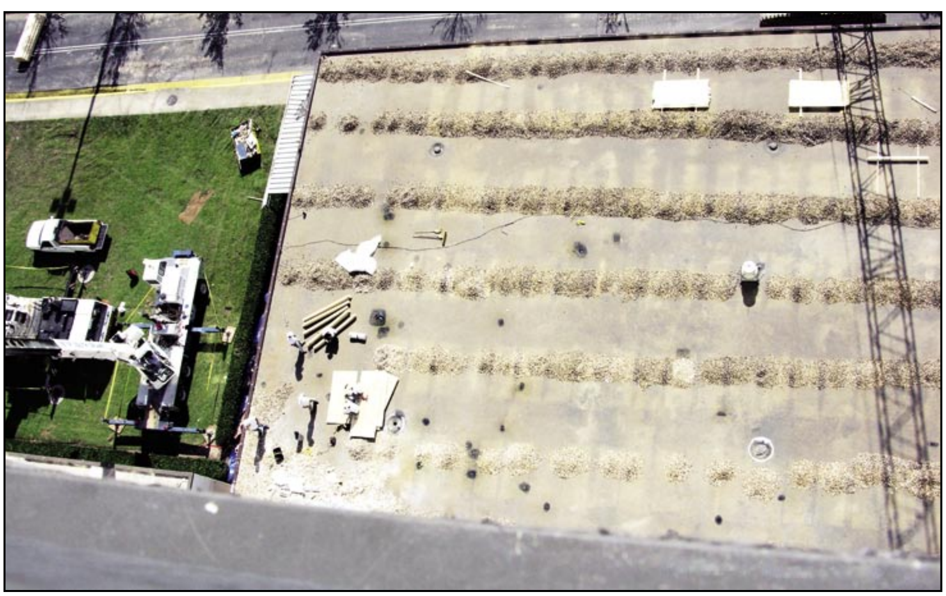


Figure 5-17.
Looking down at the one-story roof to the right of the MOB in Figure 5-16. The small dark areas are locations where emergency patches had been placed to repair punctures from falling glass shards.

The hospital's original concrete wall panels had been furred with metal hat channels and covered with EIFS (Figure 5-18). The majority of the gypsum board panels had blown off. The boards pulled over the screw heads. The screws and hat channels were moderately corroded.

Figure 5-18.
Close-up of the damaged EIFS at the hospital

Figure 5-19 shows a close-up of the EIFS spandrel damage and glazing damage at the MOB. Although the majority of the glazing damage was caused by EIFS debris, some window frames were reportedly blown out. These failures were likely due to development of high internal pressure after windows on windward surfaces were broken by debris, combined with suction pressure on the exterior surface of windows on the leeward side of the building.

Figure 5-19.
Wood studs and gypsum board had been temporarily installed after the hurricane to prevent patients from inadvertently falling out of the MOB.

Most of the EIFS damage caused by Hurricane Ivan occurred over metal or wood stud walls. However, some damaged EIFS occurred over concrete walls, as shown in Figures 5-20 and 5-21.

Figure 5-20.
Hospital with EIFS blown off a cast-in-place concrete wall. Note the damaged rooftop ductwork. (Pensacola)

Figure 5-21.
Close-up of Figure 5-20. The light colored round marks indicate where adhesive had been applied. The adhesive did not make a good bond with the concrete and it should have been continuously applied.

For many buildings, the ramification of damage to EIFS assemblies was significant. With several of these failures, the cost of repairing the EIFS was minor in comparison to the cost of damage to other building components; the cost of rainwater damage and mold remediation to building interiors, furnishings, and equipment; and the cost due to loss of use of the building while repairs where made. EIFS installed over wood or metal studs is susceptible to disproportional failure, wherein a relatively minor deficiency (such as an inadequate number of screws to attach gypsum board) results in loss of the exterior wall, as shown in Figure 5-14. Typical EIFS assemblies (i.e., studs, gypsum board, insulation, and synthetic stucco) lack redundancy to protect the building from catastrophic wind and rainwater infiltration when wind initiates failure somewhere within the assembly.

The EIFS damage was primarily related to application and/or design deficiencies. Lack of design guides likely contributed to the design problems. The test method used to determine wind resistance of EIFS assemblies may have also contributed to some of the damage. These issues are discussed below:

- **Application:** In all cases that were investigated wherein adhered insulation boards separated from the gypsum board or concrete substrate, there was significant lack of adhesive. EIFS manufacturers currently specify that the entire surface of the insulation boards is to be covered with adhesive applied with a notched trowel.

In all cases that were investigated wherein gypsum board was mechanically attached, the fasteners were too far apart. Spacings of 12 inches on center were measured. However, for the Pensacola area, the spacings typically should have been a maximum of 6 inches on center for heights up to 30 feet.[1] For taller buildings, and buildings located near or at the coast, closer spacings would be necessary. Because contract documents were not available, it is unknown whether the spacing deficiencies were due to design or workmanship errors.

- **Design:** Deficiencies included lack of provisions to prevent breakaway wall failure, beneath coastal elevated buildings, from unnecessarily propagating vertically.

- **Testing:** The EIFS industry uses American Society for Testing and Materials (ASTM) E 330 to evaluate wind resistance of EIFS assemblies. Load is applied to the specimen for 10 seconds before being released. The load is then increased and applied for another 10 seconds, then released. This process is repeated until failure occurs. While none of the investigated failures were specifically attributed to deficiencies in the test method, the test method's load duration of only 10 seconds appears to be inadequate. ASTM E 1592 (a test for metal roof and siding panels) specifies that each load increment be maintained for a minimum of 60 seconds and until the gauges indicate no further increase in deflection. The load duration and deflection criteria in E 1592 appear prudent for EIFS.

- **Design guides:** The EIFS Industry Members Association (EIMA) has a *Guide to EIFS Construction*, but the Guide is silent on wind-related issues. Manufacturers of EIFS materials have specifications, but they are typically lacking in wind-related criteria. For example, to determine fastener spacing for gypsum board (which is a very critical element in the load path), designers are referred to gypsum sheathing manufacturers. Also, ultimate load values based on ASTM E 330 typically are given, but guidance on magnitude of the safety factor is often not given to the specifier.

  An EIFS wind design guide is needed to address the various design issues associated with successful performance of EIFS. It should include criteria related to studs and their attachment to the building, criteria related to attachment of sheathing and insulation boards, safety factor selection, and key elements of field observation.

[1] Based on an ICC Evaluation Report, assuming a 16 inches on center stud spacing.

- **Codes:** Neither the FBC nor IBC have specific wind-related criteria pertaining to EIFS. The International Code Council's Evaluation Service does have the AC24 Interim Criteria for Exterior Insulation and Finish System for evaluating EIFS. AC24 uses ASTM E 330 for the wind resistance evaluation. AC24 requires at least six load increments with a 10 second load duration for each increment. AC24 also requires a minimum safety factor of 3. (Note: The Standard Building Code Congress International's Evaluation Service previously used a safety factor of two. Hence, systems designed in accordance with that criteria would be much weaker than systems designed in accordance with the ICC criteria.)

Stucco

A few buildings with traditional stucco walls were observed. Figures 3-21, 5-22 and 5-23 show significant damage to non-load-bearing stucco walls on two mid-rise condominiums. In several areas, the metal stud system failed; in other areas, the gypsum sheathing blew off the studs; and in other areas, the metal lath and stucco blew off the gypsum. It appeared that failure of the stud track connections initiated most of these failures. Figure 5-23 illustrates a serious potential risk to residents.

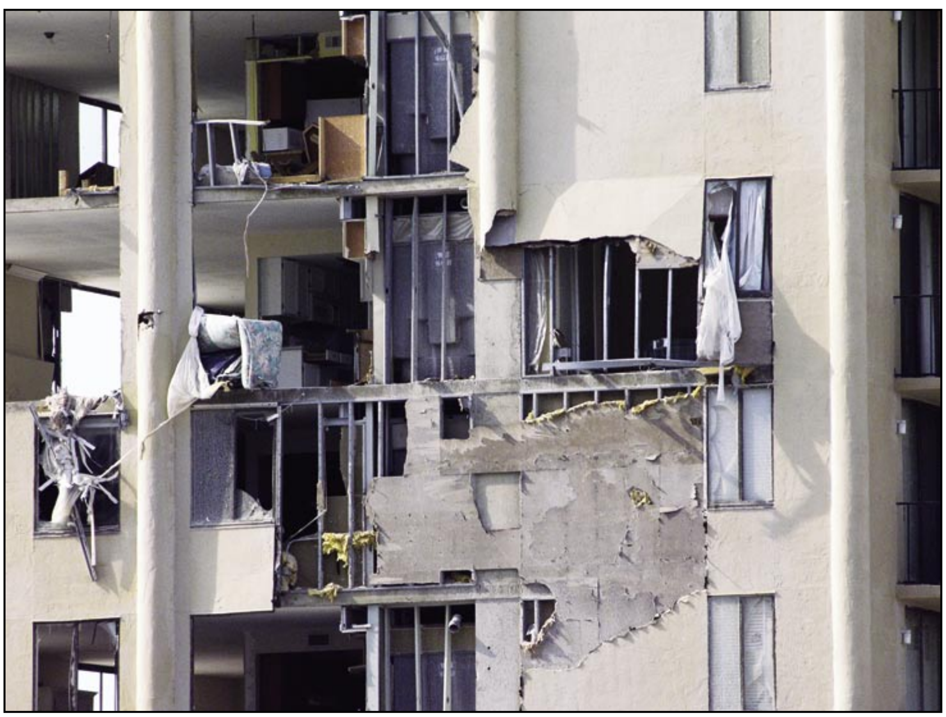


Figure 5-22.
Failure of non-load-bearing stucco wall (close-up of Figure 3-21) (Perdido Key)

Figure 5-23.
Close-up of Figure 3-21. With complete loss of the walls, the residents could have inadvertently fallen from the building. Although not shown in this photograph, several of the balcony railings had blown away. (Perdido Key)

On a few buildings, stucco was applied over plywood over wood studs. At the residence shown in Figure 5-24, the plywood was severely rotted. Figure 5-25 shows failure of stucco applied over cast-in-place concrete. Similar failures were observed in Puerto Rico following Hurricane Georges (see FEMA 339, *Hurricane Georges in Puerto Rico,* March 1999).

Figure 5-24.
Six-year old, stucco-sheathed residence with severely rotted plywood (Pensacola Beach)

Figure 5-25.
At the end wall of the center building, stucco blew off the concrete substrate. Some of the chimney walls made of stucco over gypsum board over wood studs were also blown away.

As with EIFS assemblies, attention to attachment of studs to the building, attachment of gypsum board to the studs, and attachment of the lath are critical in achieving good wind performance.

5.3.2 Wall Coverings and Soffits

Wall coverings that were investigated included brick veneer, metal panels, vinyl siding (and soffits), and wood siding. EIFS and stucco wall coverings were also observed; these were discussed in the previous section. In some instances, with loss of the coverings, wind-driven rain was able to enter the wall cavity and initiate mold growth. Some of the blown-off coverings became windborne debris that was capable of breaking unprotected glazing.

Brick

Several buildings with brick veneer were observed. Figure 5-26 shows failure on an office building. The majority of the corrugated ties remained attached to the steel studs. The ties were spaced approximately 18 inches on center vertically and 16 inches on center horizontally. According to another investigation team that had access to the building, the primary mode of failure was tension failure of the ties due to severe corrosion. Based on the Brick Industry Association's (BIA) *Technical Notes 28B – Brick Veneer/Steel Stud Walls*, "corrugated ties are not permitted when brick veneer is supported by steel stud backing." In part, this provision is based on the greater corrosion susceptibility of corrugated ties versus round ties (i.e., water is more likely to remain for a longer period of time on the flat surface of corrugated ties). The tie spacings were closer than the maximum recommended in *Technical Notes 28B*, which is 18 inches on center vertically and 32 inches on center horizontally, yet still failed due to corrosion.

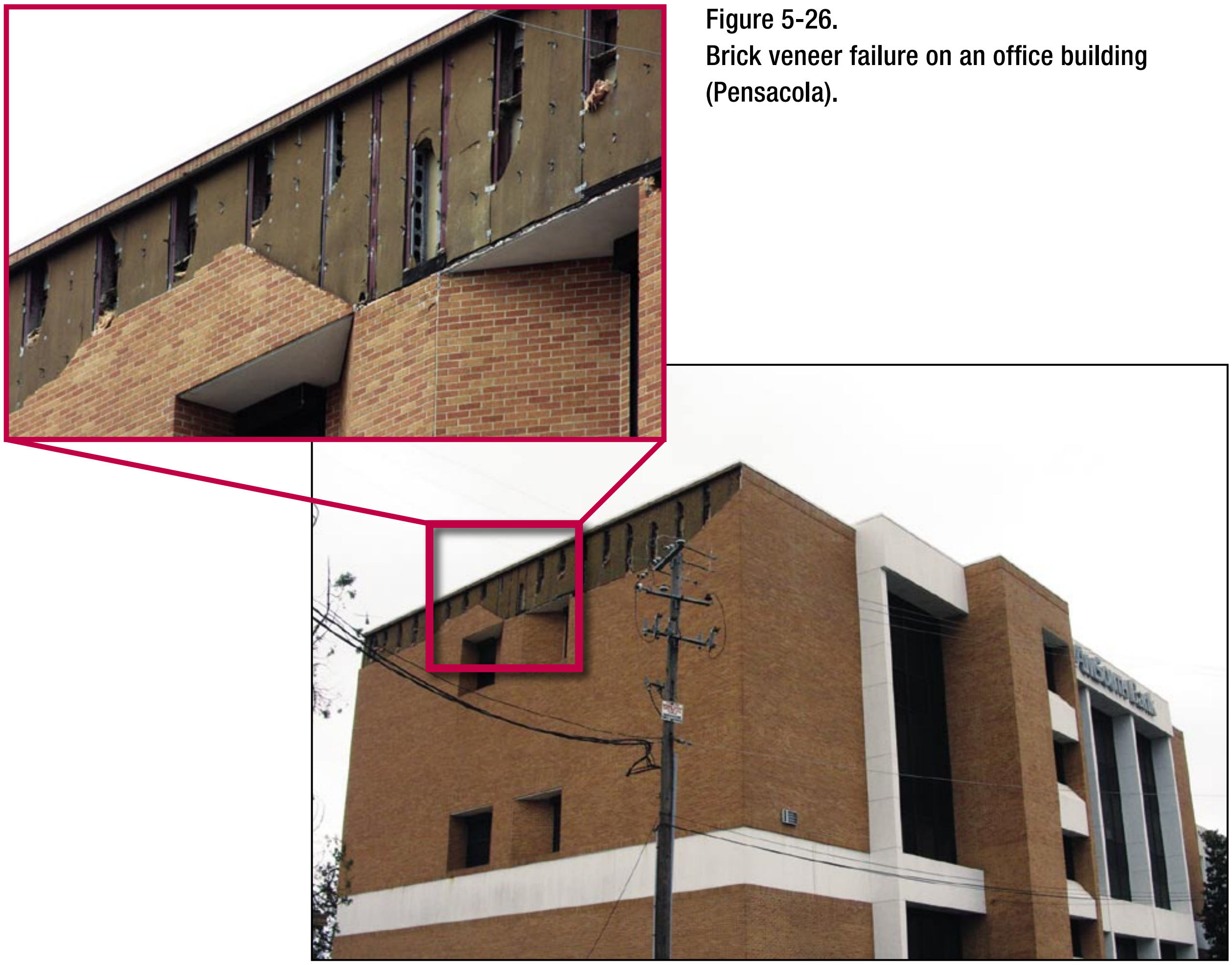


Figure 5-26.
Brick veneer failure on an office building (Pensacola).

Figure 5-27 shows failure at an older wood-framed residence. There were several failure modes:

- Several ties had never been embedded into the mortar joints
- The tie nails pulled from the studs
- Lack of bonding between mortar and brick
- Tie tension failure due to severe corrosion (this occurred on a tie embedded into the CMU foundation wall that extended about 4 feet above grade)

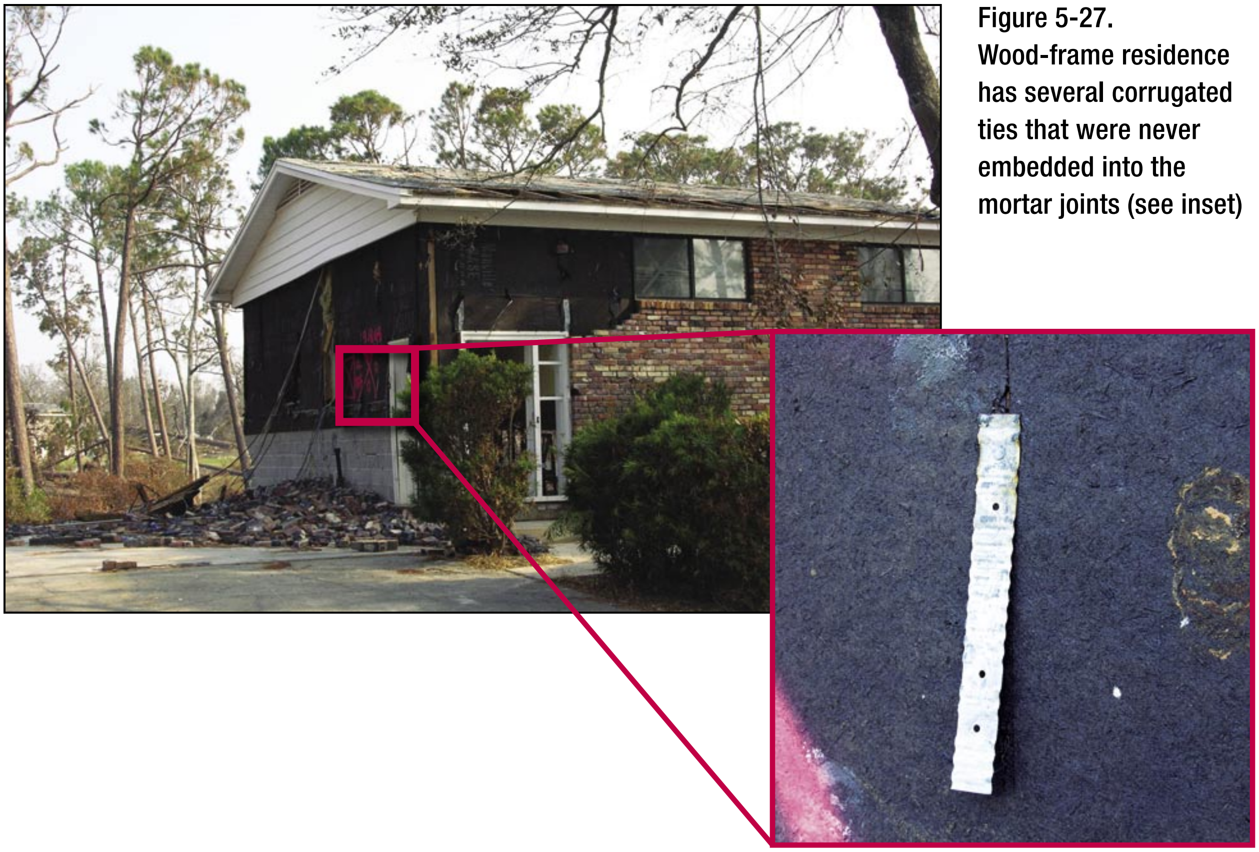


Figure 5-27.
Wood-frame residence has several corrugated ties that were never embedded into the mortar joints (see inset)

The MAT observed another house where a large number of the corrugated ties had never been embedded into the mortar joints. In areas where ties had been embedded, the smooth-shank nails pulled from the studs.

At a house under construction, ties had been embedded into the CMU foundation wall that extended a few feet above grade – the brick had not been installed. The ties were spaced at 16" on center vertically. At one area, the horizontal spacings were 22", 30", 20 ½", and 26 ½". BIA *Technical Notes 44b – Wall Ties for Brick Masonry* specifies a maximum vertical and horizontal spacing of 18" and 32" respectively.

For the building shown in Figure 5-26, because the contract documents were not available, it is unknown whether use of the incorrect ties was a design or application error. For the residence shown in Figure 5-27, failure to embed the ties into the mortar joints was a major workmanship error. Failure to embed ties was documented in a Hurricane Opal report by The Masonry Society (*An Investigation of the Effects of Hurricane Opal on Masonry*, The Masonry Society, July 1996). Opal struck the Florida Panhandle in 1995.

The Masonry Society deployed a team to assess performance of reinforced and unreinforced masonry and brick veneer. The team's report included limited information on performance of brick veneer. The report recommended a "close review of all brick veneer design," but the report did not provide specific guidance.[2]

Metal Panels

The MAT observed a limited number of metal wall panel failures. Failures were observed at two schools (Figures 3-25 and 5-28). Both schools used similar panels. The panels were attached with concealed screws. The screws were installed through concealed portions of the standing seams. The failures occurred due to unlatching of the seams.

Another wall panel failure was observed at a hangar (Figure 5-29). New panels had been installed over older panels. In one area, the top leg of a channel had been screwed at 63" and 43" to the old panels. The bottom leg had been screwed at 21" and 43". The new panels were attached with clips that were screwed at 12" on center to the hat channels. There were two screws per clip. The connections of the new panels to the hat channels were much stronger than the connections between the hat channels and old panels.

Figure 5-28.
These panels were attached with concealed fasteners. They unlatched at the standing seams. In addition to generating windborne debris, loss of panels allowed significant rainwater infiltration.

[2] The Masonry Society, *Hurricane Ivan Investigation Report,* April 1, 2005.

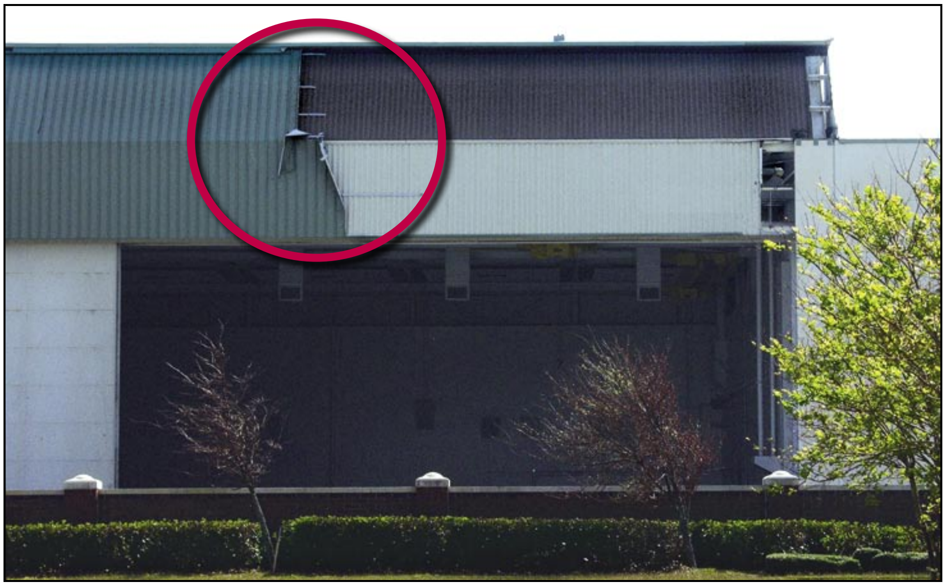


Figure 5-29.
The green fascia panels had been installed over a previous metal panel system. The original panels remained in place, but the newer panels blew off due to inadequate hat channel attachment. (Pensacola)

Vinyl Siding and Soffits

Vinyl was the predominant siding and soffit material observed on residences in the areas investigated by the MAT. Performance of the siding and soffits was very poor (see Figure 5-30). There were numerous significant failures throughout the areas observed by the MAT. Failures were observed on both new and old buildings. When vinyl siding was blown off, the underlayment (either asphalt-saturated felt or housewrap) was also often blown away, as shown in Figure 5-31. With loss of the siding and underlayment, wind-driven rainwater was then able to enter the wall cavity, causing water damage and initiating mold growth. Vinyl sidings that became windborne debris were capable of breaking unprotected glazing.

Figure 5-30.
Loss of vinyl soffits was common. Loss often led to water penetration into the building, with damage to attic and wall insulation, gypsum board ceilings, and building contents. (Orange Beach)

Vinyl siding manufactured for high-wind areas is available, but was observed on only one building (Figure 5-31). With high-wind siding, the nailing flange is folded over, so there is a double thickness of vinyl at the fastener points (Figure 5-32).

Figure 5-31.
Although a high-wind panel was used, extensive loss of siding and housewrap underlayment occurred. See Figure 5-32.

Figure 5-32.
A double thickness of vinyl occurred at the nailing flange. This provided greater fastener pull-over resistance. However, many of the panels pulled over the nail heads.

Vinyl siding that was blown off typically tore around the fastener points. Staples were used to attach the siding on some residences, but large headed nails were typically used. The 2003 IBC requires a maximum fastener spacing of 16". ASTM D 4756, *Standard Practice for Installation of Rigid Poly (Vinyl Chloride) (PVC) Siding and Soffit* also specifies a maximum spacing of 16". The 2001 FBC does not specify a maximum limit.

Thirty-four fastener spacing dimensions were measured on eight residences. The spacings on each of the residences were quite variable. On six of the eight residences, one or more spacings exceeded 16". The residence with the most excessive measurements had spacings of 27 ½", 25", 25" and 29". At the residence shown in Figure 5-31 with the high-wind siding, the greatest spacing was 21". However, of the eleven measurements taken at that residence, eight were 14" or less.

ASTM D 4756 specifies that the fasteners are to be driven into framing or furring members, rather than just into plywood or oriented-strand board (OSB). Most of the fasteners that were investigated by the MAT were just driven into sheathing. Although this practice did not comply with ASTM D 4756, no fastener pull-out problems were observed.

In some cases, the MAT believes that the blow-off was triggered by unlatching of the buttlock, which is the bottom portion of the panel (see Figures 5-33 and 5-68). Once the panel unlatches from the retainer slot just below the nailing flange, the panel is free to rotate outward where it can be caught by the wind and blow off. The magnitude of the unlatching issue, compared to the strength of the nailing flange and fastener spacing, is unknown. When unlatched, panels are very susceptible to blow-off.

Figure 5-33.
When a panel becomes unlatched, it becomes very susceptible to blow-off.

Underlayment had not been installed at all on some residences (see Figure 4-17). Not installing underlayment is a poor practice because vinyl siding (like many other types of wall coverings) does not prevent rainwater from getting behind the siding. Underlayment should always be installed to intercept the leakage and drain it out of the wall.

Neither the 2001 FBC nor ASTM D 4756 currently require underlayment underneath vinyl siding. The 2003 IBC does require underlayment.

Some vinyl siding was damaged by windborne debris, and some vinyl soffit damage was observed (see Figure 5-30). Where soffits were blown away, a significant amount of water was often driven into the attics and ultimately into living spaces. Debris damage and soffit failure was more commonly observed by the MAT that investigated Hurricane Charley. Further discussion and analysis of debris damage and soffits are presented in FEMA 488, *Hurricane Charley in Florida*.

The vinyl siding damage was related to application deficiencies (i.e., excessive spacing between fasteners). However, other factors also likely contributed to the damage. In most of the failures investigated by the MAT, it did not appear that the siding was any stronger than that used in areas of the United States that have a 90-mph basic wind speed. There also appear to be weaknesses in the ASTM product and testing standards. ASTM D 3679, *Standard Specification for Rigid Poly (Vinyl Chloride) (PVC) Siding*, specifies a 1.5 safety factor. Considering the simplicity of the test method and the number of wind failures, the 1.5 factor appears too low.

ASTM D 5206 *Standard Test Method for Windload Resistance of Rigid Poly (Vinyl Chloride) (PVC) Siding* requires holding the test load for only 30 seconds before increasing to the next pressure level. ASTM E 1592 (a test for metal roof and siding panels) specifies that each load increment be maintained for a minimum of 60 seconds and until the gauges indicate no further increase in deflection. The load duration and deflection criteria in E 1592 appear prudent for vinyl siding. Another weakness is that D 5206 is a static test. Static tests can over-estimate the wind resistance of systems that experience significant deformations and/or fatigue failure. Considering the flexible nature of vinyl siding and the dynamic nature of wind loading, a dynamic test appears to be prudent for vinyl siding.

Wood Siding

Several residences had wood siding, either textured plywood or boards. The wind performance of wood siding was typically very good. Although there were several instances of failure of wood-framed exterior walls, such as that shown in Figure 5-34, loss of just the plywood wall siding was very rare (see Figure 5-35). Loss of board siding was also rare. There were instances where failure of other elements, such as decks or walls resulted in some progressive failure of board siding.

However, failure propagation was typically quite limited. An attribute of board siding is that it is typically very resistant to progressive failure, as shown in Figure 5-34. Large portions of the exterior wall failed in two areas, but loss of siding beyond the failed wall area was minimal. Had the building in Figure 5-34 been covered with vinyl siding or EIFS, the vinyl or EIFS failure would have undoubtedly significantly propagated beyond the wall failures.

The generally good performance of plywood and board siding is likely due to their inherent strength and stiffness. Low-energy missiles can easily penetrate vinyl siding and EIFS, but wood siding is quite resistant.

Figure 5-34.
Failure of wood framed exterior walls covered with wood siding

Figure 5-35.
Vinyl siding had been installed over textured plywood siding. Although a large area of vinyl blew off, the plywood was not damaged, leaving the building envelope intact. This scenario was observed on several buildings.

5.4 Roof Systems

Historically, damage to roof coverings and rooftop equipment is the leading cause of building performance problems during hurricanes. In the rains accompanying a hurricane, rainwater entering a building through damaged roofs can cause major damage to the contents and interior. Unless quick action is taken to dry a building, mold bloom can quickly occur in the hot, humid southern climate. Drying of buildings was hampered after Hurricane Ivan by the lack of electrical power to run fans and dehumidifiers. These damages are frequently more costly than the roof damages themselves. Rainwater leakage can also disrupt the functioning of critical and essential facilities and weaken ceilings and cause them to collapse. Although ceiling collapse is unlikely to result in death, it can cause injury to occupants and further frighten them as they ride out the hurricane.

5.4.1 Asphalt Shingles

The observations of the Hurricane Ivan MAT were similar and consistent with the observations of the Hurricane Charley MAT. Failures of hip/ridge trim shingles, and failures along the eaves and rakes were common. Enhancement of hip/ridge, eave, and rake details, and enhanced underlayment protection such as that shown in Hurricane Recovery Advisory Numbers 1 and 2 (see Appendix D) were not observed. Incorrect execution of the starter course was a common problem (Figure 7-12). Fastener mislocation was also common. Observed fasteners were typically located too high and too close or too far away from the ends of the shingles. Use of four nails per shingle rather than six was frequently observed, including on the school shown in Figure 6-8.

One notable difference between the Hurricane Charley and Ivan observations was shingle damage associated with raking. With the raking installation method, shingles are installed from eave to ridge in bands about 6-feet wide. Where the bands join one another, at every other course, a shingle from the previous row needs to be lifted up to install the end nail of the new band shingle. Sometimes installers do not install the end nail – in these applications, the shingles are vulnerable to unzipping at the band lines, as shown in Figure 5-36. The National Roofing Contractors Association recommends that the raking method not be used. Rather, starting at the eave, shingles should be laid one course at a time from rake to rake.

Figure 5-36.
The vertical lines of missing shingle tabs are indicative of installation via the raking method. When raked, end nails are frequently not installed.

A limited number of ridge vents were investigated. Figure 5-37 shows a metal ridge vent failure. Where the vent lifted, it was attached with roofing nails spaced at 22 ½" and 19¾" on one side of the ridge, and 21" and 17 ¾" on the other side. In an area where the vent was not blown off, the nails were spaced at 18 ½", 10", 11 ½" and 11 ½". The nails were moderately corroded. This residence was not originally constructed with a continuous ridge vent. The slot through the plywood roof decking was cut during a reroofing project. When the slot was cut, the blade of the power saw was not adjusted to suit the deck thickness. As a result, a deep cut was made through the trusses and metal connectors (Figure 5-37 inset).

Although the exposed opening through the roof at the damaged ridge vent was small, a substantial amount of water entered the residence during the storm. At the time of the investigation, the roof had been open for 15 days.

A few tabs blew off the roof shown in Figure 5-37. Where the tabs blew off, the fasteners were incorrectly located, and a nail was missing at one of the shingles (Figure 5-38). However, tab blow-off occurred because the tabs had not sealed rather than because of nailing problems.

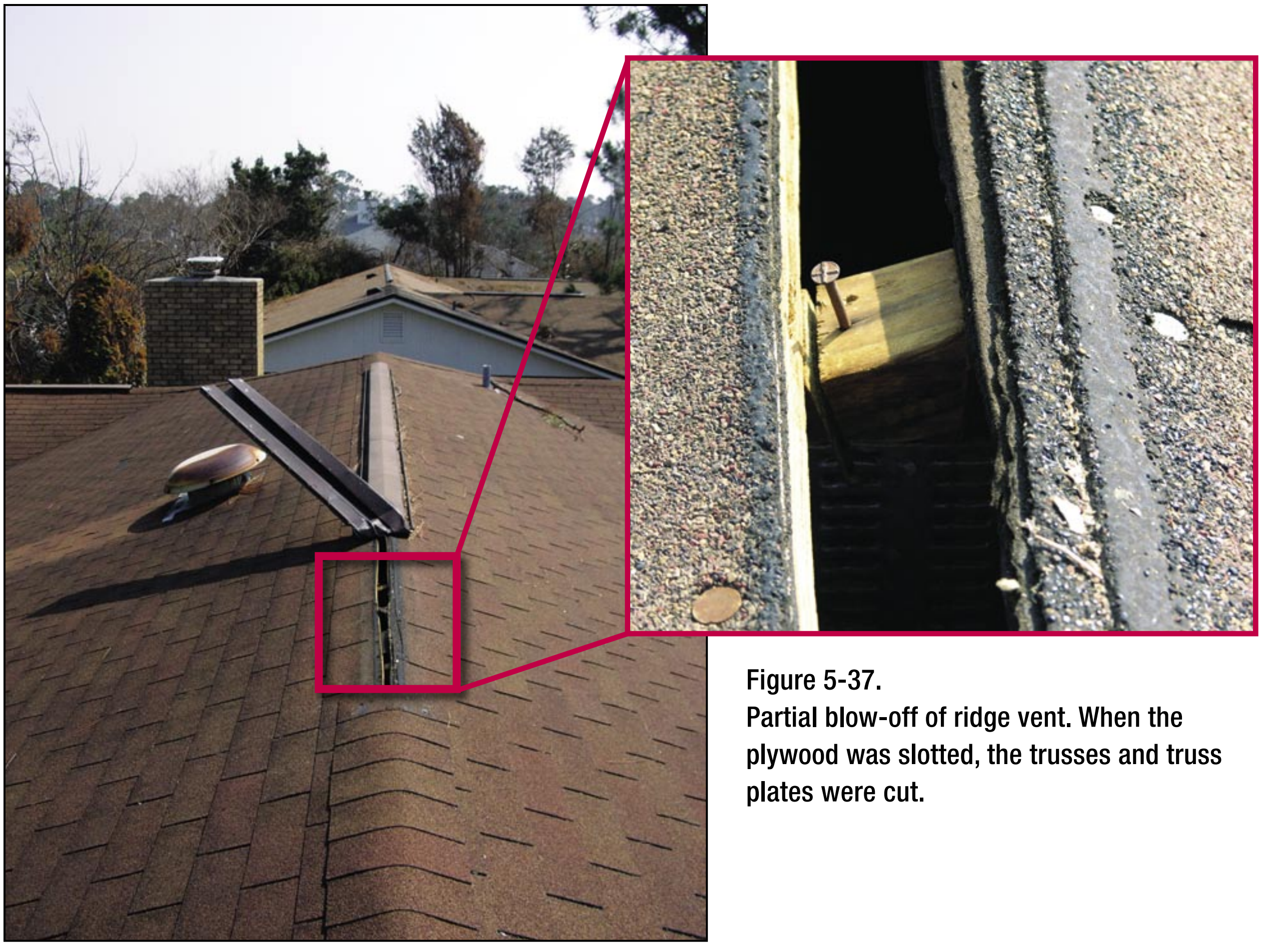


Figure 5-37.
Partial blow-off of ridge vent. When the plywood was slotted, the trusses and truss plates were cut.

Figure 5-38.
Missing tabs. All of the nails were installed too high, and two of the end nails were too far from the end. An end nail had not been installed at the lower tab.

5.4.2 Tile

Clay and concrete tiles were observed, with concrete being the most common. A variety of tile profiles (e.g., S-tile and flat) were observed, but no significant wind performance differences were attributed to profile. Mortar-set, mechanically attached, and foam-set (adhesive-set) attachment methods for tile roofs were observed during the assessment. The observations of the Hurricane Ivan MAT were similar and consistent with the observations of the Hurricane Charley MAT. However, tile roofs were more common in the areas impacted by Hurricane Charley. Observations from Hurricane Charley, Frances, and Ivan were the basis for Hurricane Recovery Advisory Number 3 (see Appendix D).

Figure 5-39 illustrates typical tile damage in areas that experienced modest wind speeds. Eave, hip, ridge, and rake tile failures were common. In areas with higher wind speeds or on higher elevation roofs, large areas of tiles were blown away, such as shown in Figure 5-40, 5-43, and 5-46.

Figure 5-39. This roof is indicative of tile failure at modest wind speeds, wherein failure of eave, hip, and rake tiles were most common.

Mortar-Set Tile Roofs

As observed after Hurricane Charley and Frances, mortar-set tile roofs typically experienced larger blow-off areas than did any of the other attachment methods.

Mechanically Attached Tile Roofs

Figure 5-40 shows a direct-to-deck mechanically attached clay tile roof that experienced large blow-off areas. The tiles were attached with two nails per tile; however, both nails were located in one corner (Figure 5-41). A clip near the end of the tile occurred along the eave row. However, the clips were ineffective. Many of the tiles were displaced by wind pressure, but much of the tile damage was caused by tiles or tile fragments impacting other tiles. The hip tiles were nailed with a single nail to a ridge board and set in mortar. However, similar to Figure 5-51, this attachment method was ineffective.

Figure 5-40. Direct-to-deck mechanically attached clay tile. The tiles were attached with two nails per tile. The nails typically remained in the deck. See Figure 5-41.

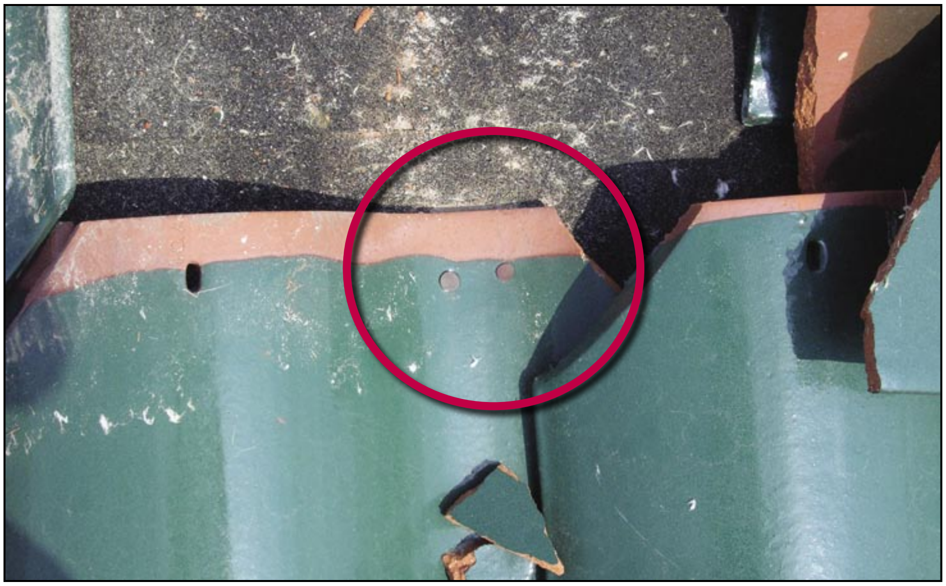


Figure 5-41.
Both nails were located in the right corner. Better load distribution would have been achieved by placing one of the nails in the far left nail hole.

Another direct-to-deck roof is shown in Figure 5-42. This six-year-old residence was adjacent to the ocean. Several of the fastener heads had corroded off, thus allowing the tiles to lift over the fasteners.

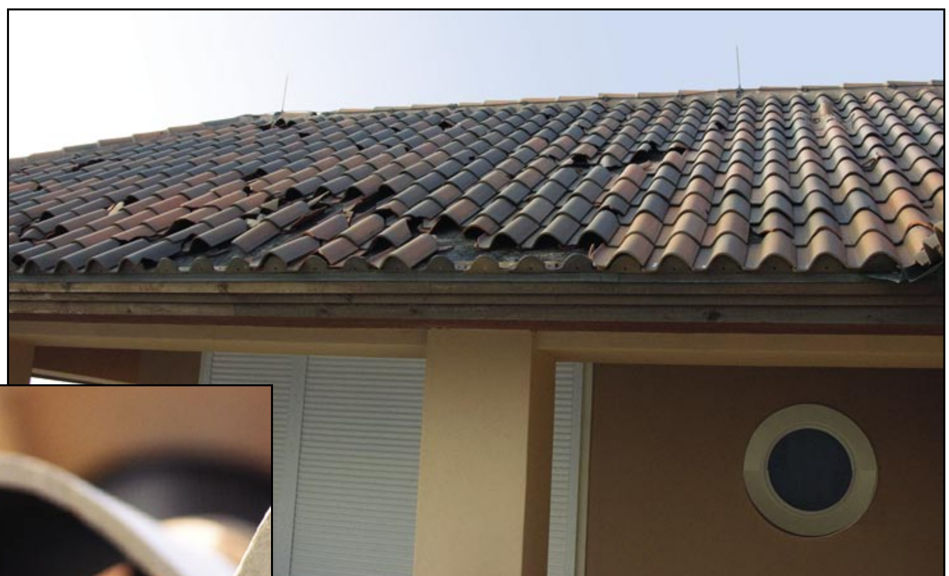


Figure 5-42.
The fastener heads on this direct-to-deck mechanically attached tile roof had corroded. The six-year old house sat near the ocean.

Several batten-attached roofs were observed. Tiles flying from a mid-rise building, such as that shown in Figure 5-43, can sail a considerable distance and have very destructive energy.

Figure 5-43. Loss of several batten-attached tiles from a mid-rise building

The tiles shown in Figure 5-44 were partially shielded from wind by nearby buildings. Hence, while some of the tiles were damaged by wind pressure, the majority were damaged by windborne debris (which included tile fragments from this roof). The field tiles were attached with a single 2 ½" long screw. The row of tiles along the eave were attached with two screws per tile.

Figure 5-44.
Although some of these batten-attached tiles were damaged by wind pressure, the majority were damaged by windborne debris (which included tile fragments).

The batten-attached tile damage shown in Figure 5-45 was due to increased wind pressure associated with turbulence created by the building projection at the upper right of the photograph. Elsewhere on this roof, there was intermittent damage to field tiles from windborne debris, likely consisting of tiles that were missing from the upper level roof and/or tiles blown from the area shown in Figure 5-45.

Figure 5-45.
The majority of these batten-attached tiles were displaced by wind pressure. The fasteners typically remained in the battens.

The batten-attached tile damage shown in Figure 5-46 was primarily caused by wind pressure. Several of the battens were blown away, thus indicating inadequate attachment of the battens.

Figure 5-46.
The majority of these batten-attached tiles were displaced by wind pressure. Many battens were blown away. See Figure 5-47 for a view of the lower-sloped roof.

Foam-set Tile Roofs

The building shown in Figure 5-46 had a lower-level roof that had a relatively low-sloped roof. The foam-set attachment method was used on the lower roof. The damage shown in Figure 5-47 was caused by wind pressure and windborne debris.

Figure 5-47.
The tiles on the lower sloped roof were foam-set. The damage on this roof was due to a combination of wind pressure and windborne debris.

Tiles were blown off of several areas of the roof shown in Figure 5-48. These failures were caused by significant workmanship errors, wherein too little adhesive was applied (Figures 5-49 and 5-50).

Figure 5-48.
These tiles were foam-set. See Figures 5-49 and 5-50.

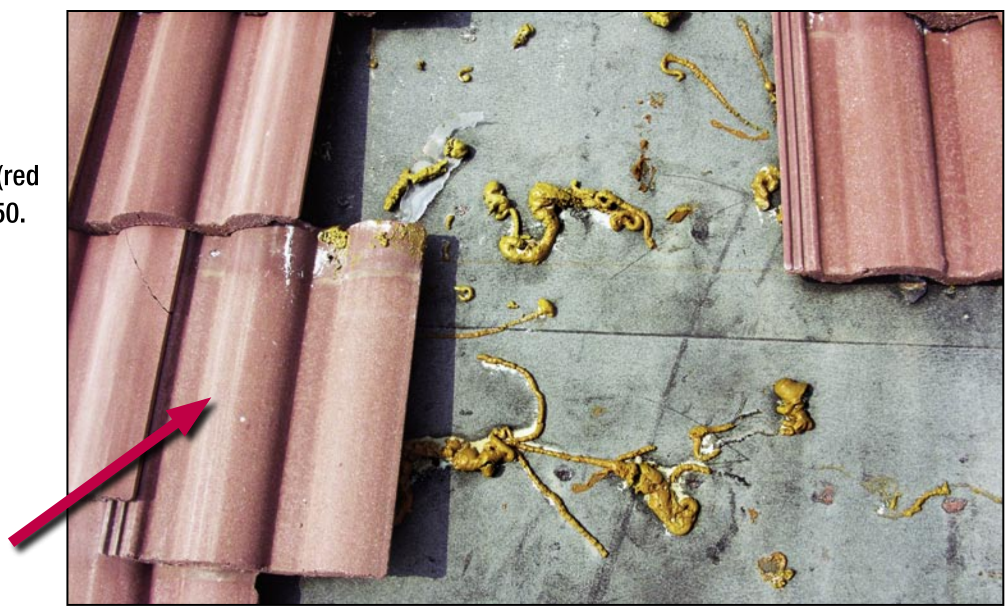


Figure 5-49.
A minuscule amount of foam was installed. Note that one tile slid down-slope about 2" (red arrow). See Figure 5-50.

Figure 5-50.
View of the underside of the tile that slid in Figure 5-49. Note the very limited amount of foam on the underside of the tile and underlayment.

Hip and Ridge Tiles

As observed in Hurricanes Charley and Frances, blow-off of hip and ridge tiles was very common, even when the trim tiles were nailed to a ridge board and set in mortar (Figure 5-51). On one of the observed roofs, the hip tiles were foam-set, but failure also occurred with this attachment method (Figure 5-52). Hurricane Recovery Advisory Number 3 (see Appendix D) provides recommendations for enhancing attachment of hip and ridge tiles.

Figure 5-51.
Significant loss of hip and ridge tiles. The trim tiles were set in mortar and were attached to a ridge board with a single nail near the head of the trim tile.

Figure 5-52.
These hip and ridge tiles were foam-set.

5.4.3 Metal Panel and Shingle Roofs

A variety of standing seam and exposed fastener panel systems was observed, as well as metal shingles. The observations of the Hurricane Ivan MAT were similar and consistent with the observations of the Hurricane Charley MAT. The performance of metal roofing varied greatly. Figure 5-53 shows a complex that lost several standing seam panels. At one area the panels remained on the roof, but a few of the seams opened up (Figure 5-54). In the opened condition, the panels were very susceptible to progressive failure, and they were no longer in a watertight condition.

Figure 5-53.
Loss of standing seam metal panels. See Figure 5-54. (Pensacola)

Figure 5-54. These panels nearly blew away. The seams on three of the panels opened up. (Pensacola)

As with Hurricane Charley, excellent performance was typically observed with 5-V crimp metal panel systems. Figure 5-55 shows special attention given to attachment along a rake.

Figure 5-55.
This 5-V crimp metal panel roof performed very well. The screws along the rake were very closely spaced; thus, this potentially vulnerable edge condition was well secured.

More metal shingles were observed in the area impacted by Hurricane Ivan than in the area impacted by Hurricane Charley. Several batten-attached metal shingles that simulated the appearance of tile were observed. While some of the metal shingles performed well, many failures similar to Figure 5-56 were observed. As with other types of roof coverings, attention to connections (including attachment of the battens for batten-attached systems) is important with metal shingles.

Figure 5-56. This residence had metal shingles that simulated the appearance of tile. The shingles typically blew off the battens, but some of the battens were also blown away.

5.4.4 Low-slope Membrane Systems

The MAT observed several types of low-slope roof systems. These systems included built-up roofs (BURs), modified bitumen, and single-ply. Membrane damage was typically caused by windborne debris punctures and tears, and by membrane lifting and peeling after lifting of either the gutter, edge flashing, or coping. Figure 5-57 shows an edge flashing at a hospital that partially lifted. With the flashing in a lifted position, the membrane was very susceptible to peeling. Apparently, the winds subsided before this occurred.

Figure 5-57. Although the metal edge flashing lifted, a progressive membrane lifting and peeling did not occur. Some aggregate ballast was blown off an adjacent higher roof. (Pensacola)

Another type of edge failure is shown in Figure 5-58. At this hospital, the wooden nailer at the roof edge was bolted to a brick wall, but because of an inadequate load path, the bricks lifted up with the nailer. The nailer failure resulted in progressive lifting and peeling of the roof membrane. Nailer lifting may have also initiated the failure on the hospital roof shown in Figure 6-3, although as discussed in Section 6.2.2, that failure may have been initiated by lifting and peeling of the edge flashing or by debonding of the insulation from the concrete roof deck. The 4' x 8' polyisocyanurate insulation boards had been attached to the deck with hot asphalt. This attachment method can be very effective, but it requires good contact between the boards and asphalt, which can be difficult to achieve if the deck surface is not a relatively flat plane. The use of 4' x 4' versus 4' x 8' boards facilitates conformance to irregular substrates. Use of relatively thin boards (e.g., 1 ½" thick) also facilitates conformance.

Figure 5-58.
The edge nailer on top of an old brick wall was inadequately attached to the wall. Failure of the nailer caused a progressive lifting and peeling failure of the roof membrane. (Pensacola)

Figure 5-59 shows blow-off of a large portion of a BUR on an Emergency Operations Center (EOC). The membrane was mechanically attached to a lightweight insulating concrete (LWIC) deck. In one area the base sheet had been attached along the side lap with fasteners spaced at 8 ½", 9 ½" and 8½". At one of the adjacent intermediate rows, the fasteners were at 32 ½" and 32". The typical base sheet attachment specification is 9" at the laps and 18" at two intermediate rows. The failure may have been initiated because of inadequate attachment of the base sheet; however, it may have initiated at the parapet base flashing. The base flashing was mechanically attached to the parapet. Turbulence at a corner area (inset in Figure 5-59) likely generated high suction loads on the base flashing, which may have been sufficient to pull the base flashing off the parapet and cause a progressive lifting and peeling of the membrane. Parapet base flashing damage was also observed on a new hospital addition (Figure 5-60).

Figure 5-59.
Loss of a mineral-surfaced BUR installed over LWIC. Failure may have been due to inadequate attachment of the base flashing to the parapet (see inset). (Pensacola)

Figure 5-60.
Minor base flashing displacement on a new hospital roof (Gulf Breeze)

Figure 5-61 shows a single-ply membrane on a school that had been torn by windborne debris. This tear was still unprotected six days after it was damaged. Although this is a minor problem compared to a large blow-off such as shown in Figure 5-59, a substantial amount of water can enter the roof system through a tear such as this. Unless there is a secondary membrane as discussed in FEMA 424, *Design Guide for Improving School Safety in Earthquakes, Floods, and High Winds*, January 2004, significant interior water damage can be caused by minor punctures and tears. Figure 5-62 shows a hospital roof that was punctured in several locations by windborne debris.

Figure 5-61. Single-ply membrane torn by windborne debris (Pensacola)

Figure 5-62. This hospital roof had been punctured in several locations by windborne debris. When punctured, a secondary membrane, as discussed in FEMA 424, is needed to avoid water infiltration. (Pensacola)

Aggregate ballasted single-ply membrane roofs were observed at two hospital complexes (Figure 5-57 and 5-64). Some aggregates blew off of at least one of the roof areas. None of these roofs comply with the current edition of ANSI/SPRI RP-4 *Wind Design Standard For Ballasted Single-ply Roofing Systems*. Use of aggregate ballast on a hospital roof in a hurricane-prone region is not prudent.

5.5 Windows, Shutters, and Skylights

Exterior windows are very susceptible to missile breakage unless they are impact resistant (via use of laminated glass or shutters). The probability that any one window will be struck by windborne debris is typically small; however, when it does occur, the consequences can be significant. The probability of impact depends upon local wind characteristics and the amount of natural and manmade windborne debris in the vicinity. The greater the wind speed, the greater the amount of windborne debris that is likely to become airborne. Windows can also be broken by over-pressurization, but this damage is not as common as debris-induced damage.

The 2001 FBC defines windborne debris regions as those specified in ASCE 7-02, except in the Florida Panhandle, where the 2001 FBC has different requirements than ASCE 7. This difference in windborne debris regions is discussed in Section 2.2.4.3. In windborne debris regions, the 2001 FBC requires glazing to be impact resistant or protected by shutters (glazing above 60 feet from grade is exempt).

The MAT observed shutters on several residential and commercial buildings along the coast and inland areas. However, shuttering was not as prevalent as in the areas impacted by Hurricane Charley and Frances.

5.5.1 Unprotected Glazing

Figure 5-63 shows a residence along the coast. Several of the ocean-facing windows were broken by debris from the failed deck. Figure 7-10 also shows several ocean-facing windows in a mid-rise condominium that were broken by windborne debris that included balcony railings and non-load-bearing stucco wall components. The MAT observed many instances of windborne debris-induced failure of unprotected ocean-facing windows.

Although windborne debris-induced failure of unprotected glazing was more frequently observed on the barrier islands than in inland areas, broken glazing was observed in inland areas, including the

Pensacola area, as shown in Figures 5-4, 5-16, 5-64, and 6-4. In both coastal and inland areas, glazing damage more commonly occurred on the lower floors of buildings due to the greater amount of debris flying at lower elevations. However, broken glazing was observed on upper levels as shown in Figures 5-16 and 7-15.

As discussed in the Hurricane Charley MAT report, damage to unprotected glazing in inland areas is more likely to occur when wind speeds are 120 mph (3-second gust) or greater. With declining wind speed, the incidence of glazing damage is reduced. The Hurricane Charley MAT observed very few broken windows in inland areas where the wind speed was estimated to be less than about 100 mph 3-second gust. The Hurricane Ivan MAT's observations are consistent with those from Hurricane Charley. In the Pensacola area, where the estimated Exposure B wind speeds were between 90 and 100 mph 3-second gust, glazing damage was limited, except in areas where significant amounts of windborne debris were flying, as illustrated in Figures 6-4 and 5-16. Had Hurricane Ivan been closer to a design wind speed event, the amount of glazing damage in inland areas would have undoubtedly been higher.

At the condominium shown in Figures 7-8 and 7-9, an unusual window failure resulted in extensive secondary damages. The lower portion of the small windows shown in Figure 7-8 were inward-opening hopper windows (i.e., they were hinged along the bottom of the window frame). Because the latch at the top of the hoppers was very weak and incapable of resisting the positive wind pressure applied to the glazing, many of the hoppers opened. The open windows allowed an increase in the internal pressure. The high internal pressure pushed over the interior partitions (Figure 7-9). The high internal pressure also exerted load on the curtain wall facing the ocean, which combined with the exterior suction load to cause the curtain walls to fail. The curtain wall's metal stud tracks were attached with powder driven fasteners into the concrete slab. The number of fasteners was insufficient to resist the applied loads.

Figure 5-63.
Several windows on this ocean-front home were broken by windborne debris.

Figure 5-64.
The outer pane of this tempered glass window was broken by windborne debris (aggregate roof ballast, falling glass shards from windows above, or EIFS). (Pensacola)

5.5.2 Protected Glazing

The MAT did not observe any laminated glass that had been impacted by debris, other than a skylight as discussed in Section 5.5.3. However, a variety of shutters were observed. They were made of wood sheathing, metal panels, or plastic panels of various designs. The MAT observed a few cases where shutters were impacted by debris and were effective in preventing glass breakage (Figure 5-65).

Figure 5-65.
This shutter was impacted by high-energy debris.

A few problems were observed with shutters. At the school shown in Figure 5-66, shutters had been retrofitted. However, shutters were not placed over the windows above and below window air conditioners or over the glazed entrance doors. Although the shutters that were installed decreased the amount of exposed glass and, as a result, reduced the probability of glazing damage, a shuttering project should protect all exterior glazing. Another problem is illustrated by Figure 5-67, wherein metal panels did not completely cover the glazing. Also, at that shutter, wing-nuts were installed at only every other fastener stud. Installation of nuts on every other stud was observed on several different buildings. When all of the nuts are not installed, shutters are more susceptible of being blown away.

Figure 5-66.
Shutters had been retrofitted on this school, but the glazing above and below the window air conditioners and the glass entry doors were not protected. (Pensacola)

Figure 5-67.
These panels did not completely cover the glazing. Also, along the bottom track, a wing-nut was placed only at every other fastener stud. The shutter may have been impacted on the right side.

Two of the panes in the window unit shown in Figure 5-68 were broken because the window unit was not fully protected. It was unclear whether some of the shutter panels blew away or were never installed. At the lower shutter track, rather than employ fixed fastener studs, the studs were slid into the track at the track ends. This type of stud connector relies on friction to keep the studs from moving sideways. If the nuts are not snug, the panels can drift sideways and be blown from the track. It was clear that one of the panels had not been fabricated for this unit. This illustrates a potential problem with panel shutters. When shutter panels are removed from storage for installation, it is important for the panels to have been labeled so that the proper panels go over the intended windows.

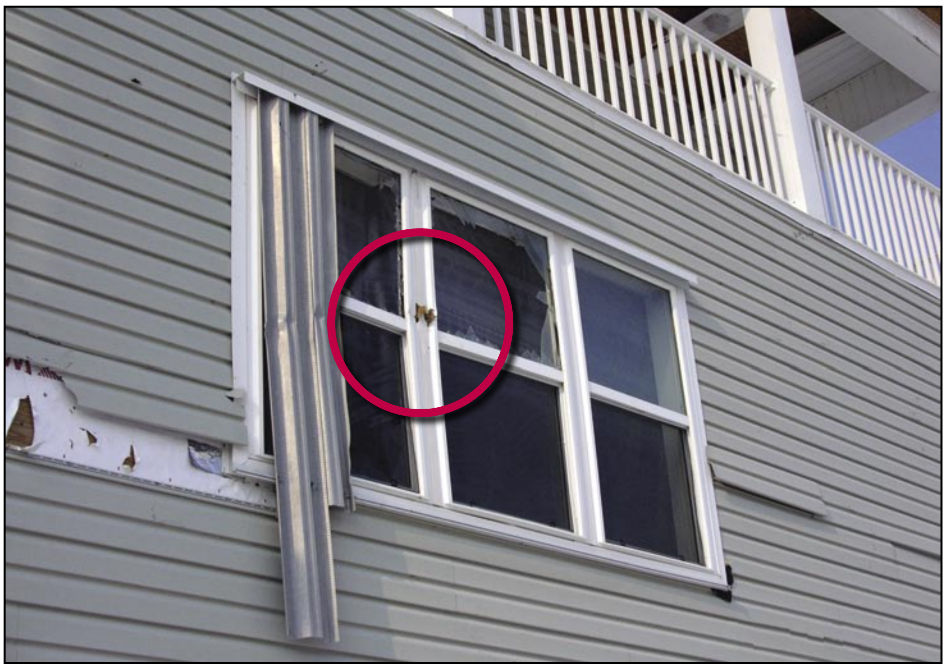


Figure 5-68.
It was unclear whether some panels blew away, or the glazing was not fully protected. Note the debris embedded in the window mullion.

5.5.3 Skylights

Figure 5-69 shows a skylight at a hospital canopy. Several of the laminated glass panels had been impacted by debris and were broken, but the glass remained in the frames.

When tempered glass breaks, it shatters into small pieces and falls out of the frame, as shown in Figure 5-64. However, as shown in Figure 5-69, when laminated glass breaks, the glass remains bonded to the plastic film between the panes, and the glazing remains in the frame. Although the broken laminated glass will need to be replaced, costly interior water and wind damage is avoided.

Figure 5-69.
Several laminated glass panes were broken, but they remained in their frames. The panes were likely broken by ballast, although falling glass shards or EIFS may have caused the damage. (Pensacola)

5.6 Exterior Mechanical and Electrical Equipment Damage

The MAT observed many damages to mechanical and electrical devices mounted on the exterior of buildings. The following factors are essential to good high-wind performance of exterior mechanical and electrical equipment: determining design wind loads on equipment and designing suitable attachments to resist the loads; special anchoring of fan cowlings and access panels; and special design of lightning protection systems (LPS) anchorage. Guidance for these design factors is provided in FEMA 424, *Design Guide for Improving School Safety in Earthquakes, Floods, and High Winds.*

For equipment susceptible to flooding, see Subsection 4.1.3.4 Utilities.

Commercial, and critical and essential facilities typically have a wide variety of mechanical and electrical equipment attached to their rooftops and elsewhere. Residences also frequently have rooftop equipment. Equipment lost included fan units and HVAC units, electrical and communications equipment, and LPS. There are several effects due to loss of this equipment: in many instances, the displaced equipment left large openings through the roof and/or punctured the roof membrane; equipment loss often affected the operational functions of the facilities; and blown-off equipment became high-energy windborne debris in some cases. The equipment observed on critical and essential facilities was not anchored more effectively than the equipment on common commercial buildings.

5.6.1 Rooftop HVAC Equipment

As frequently observed following previous hurricanes, many fan units were damaged. In some cases, the fans were blown off the curbs because too few screws were used to attach the fans to the curbs. In other cases, the fans remained attached to their curbs, but the cowlings were blown away (Figure 5-70). (FEMA 424 *Design Guide for Improving School Safety in Earthquakes, Floods, and High Winds* provides guidance for jobsite strengthening of cowlings.) Figure 5-71 shows loss of a hood over a relief air vent. The connectors attaching the hood had insufficient strength to resist the wind loads. Although the opening through the roof was small, a substantial quantity of rainwater was able to enter the school. Because of widespread damage in the Pensacola area, this opening remained unprotected for several days after the storm.

Figure 5-70.
Loss of two fan cowlings on an EOC. Blown-off cowlings can tear roof membranes and break glazing. (Pensacola)

Figure 5-71.
Loss of the hood at this relief air vent allowed rainwater to directly enter the school. (Pensacola)

Figure 5-72 shows loss of a relief air hood and displacement of a sleeper-mounted condenser. Sleeper-mounted condensers do not provide resistance to uplift or lateral wind loads.

Figure 5-72.
At this hospital, the condenser moved off the sleepers and a nearby relief air hood was blown away. (Pensacola)

Figure 5-73 shows that even large HVAC units are susceptible to damage at moderate wind speeds (winds were estimated to be 85 to 95 mph in this area). This unit reportedly weighed 18,000 pounds. It was 30' long, 10' wide, and 8' high. It was attached to a wooden curb with sixteen 1" x 1/8" thick straps. Each strap had a single screw into the unit and a single 1 ¾" long #14 screw into the curb. The majority of the screws pulled out of the curb, although some may have failed in shear. The unit was located approximately 20 feet from the edge of the building. After lifting off the curb, the unit hit and cut the roof membrane in several areas and then fell off the building and crushed two unoccupied vehicles. It was reported that approximately 2" of water collected on the second floor. The building was less than one year old.

Figure 5-73.
This large HVAC unit blew off a new medical office building. It was attached with 16 straps (see inset). (Gulf Breeze)

Another observed problem was loss of HVAC access panels (Figure 5-74). This type of problem was observed at two hospitals. Windblown panels can tear roof membranes and break unprotected glazing. Damaged rooftop ductwork was also observed at hospitals and an EOC (Figures 5-75 – 5-77). The damaged ductwork provided a direct path for water to enter the buildings. The majority of the damage was caused by wind pressure; however, the damage ductwork shown in Figure 5-77 was likely caused by roof membrane debris.

Figure 5-74.
Sheet metal access panels and shrouds were blown off this equipment at a hospital. Displaced panels can tear roof membranes and break glazing. (Pensacola)

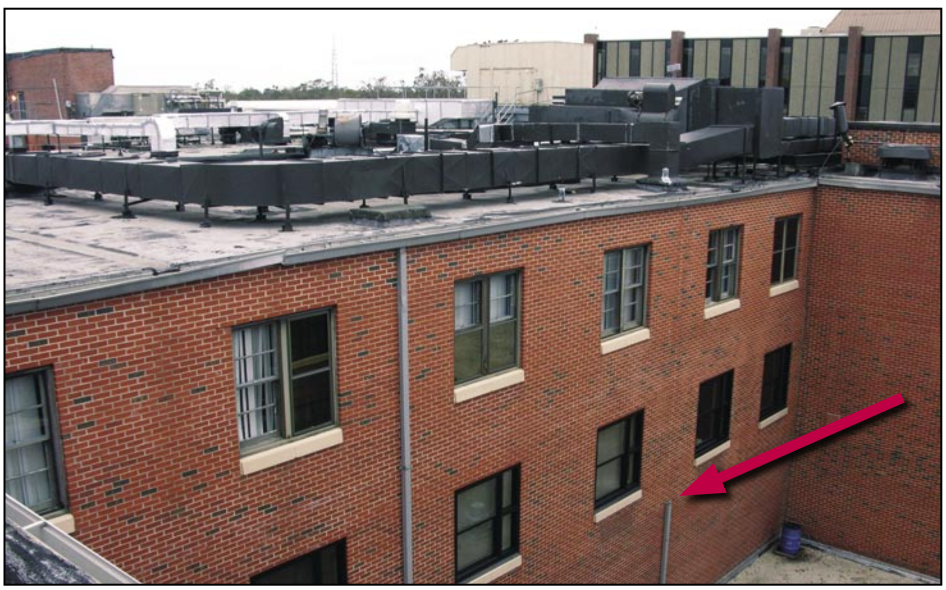


Figure 5-75.
Ductwork and fan units on this hospital were damaged in several locations. Some of the windows in this area were also broken. Note the missing downspout. (Pensacola)

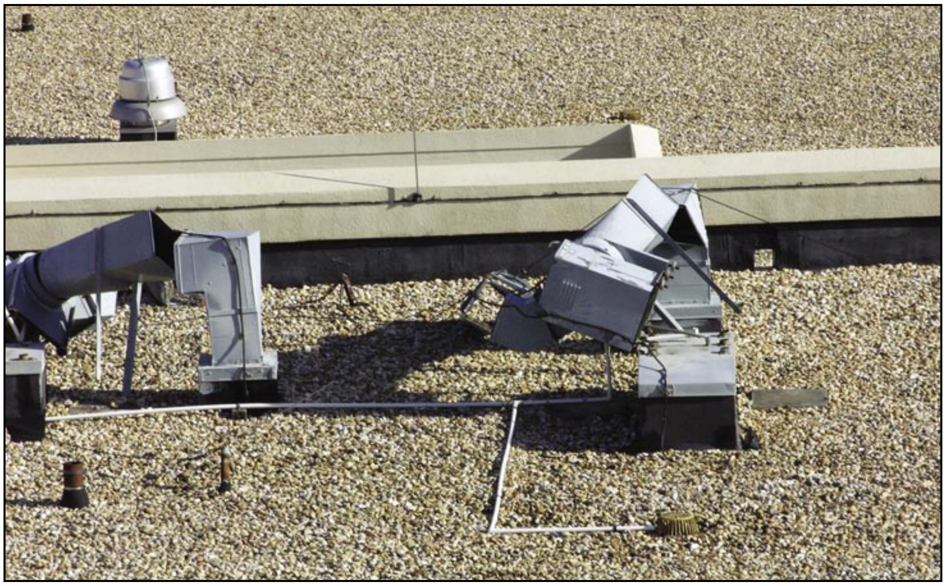


Figure 5-76. Damaged ductwork at a hospital (Pensacola)

Figure 5-77. Damaged ductwork at an EOC. This damage was likely caused by roof membrane debris that blew off a nearby area. (Pensacola)

Equipment screen damage was also observed (Figure 7-17). Screen panels that are blown away can tear roof membranes and break unprotected glazing.

5.6.2 Electrical and Communications Equipment

Rooftop electrical and communications equipment was also observed to be inadequately anchored. Problems included displacement of LPS and antenna collapse and debris damage. Collapsed parking lot light fixtures were also observed. Consequences of the damage included loss of communications, damage to roof coverings, and loss of lightning protection, the latter of which is significant, considering the frequency of lightning storms in Alabama and Florida.

LPS failures were typically the result of poorly anchored systems. Connectors often fail by opening up and releasing the conductor cable or they debond from the roof (Figure 5-78). Figure 5-79 illustrates the number of roof membrane punctures that can be caused by loose LPS conductors.

Figure 5-78.
The LPS on this hospital became detached. Loose LPS can severely damage roof membranes, and loose LPS does not provide the intended lightning protection. (Pensacola)

Figure 5-79.
The LPS conductor on this hangar became detached and punctured the roof membrane in several locations. (Arrows show ends of loose cable.) (Pensacola)

Figure 5-80 illustrates damage to antennas from windblown roof debris. Mounting the antennas on the penthouse wall was prudent, as this avoided penetrations through the roof membrane. However, to avoid damage from roof debris, the roof system needs to be sufficiently anchored to avoid blow-off. Figure 5-81 shows a collapsed communications tower. Collapse of this type of tower has frequently been observed following previous hurricanes.

Figure 5-80.
The antennas at this hospital were damaged when the roof membrane blew off. (Pensacola)

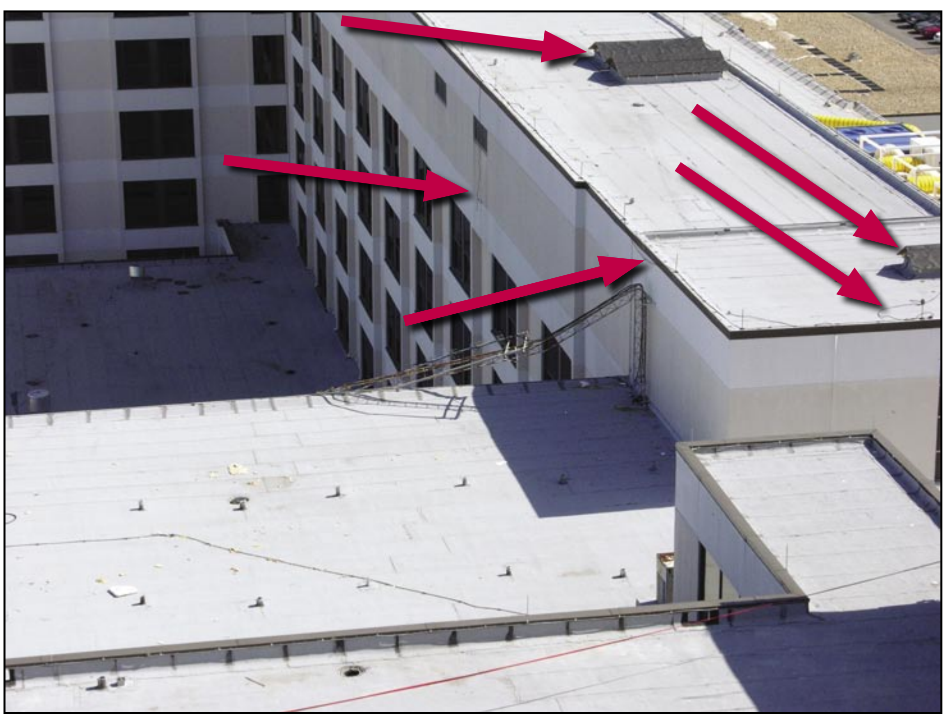


Figure 5-81.
The antenna at this hospital collapsed. The LPS was also displaced in a few areas (red arrows). Rooftop equipment was also damaged. (Pensacola)

Figure 5-82 shows collapsed light fixtures. These failures were caused by severe corrosion.

Figure 5-82.
Collapsed light fixtures at a hospital. The bottom of the tube was severely corroded (see inset). (Pensacola)