2.0 Site Observations

2.1 Assessment Team Approach

In September 1992, FIA, at the request of the FEMA Disaster Field Office staff, in Miami, Florida, assembled a Building Performance Assessment Team. The team consisted of FEMA Headquarters and Regional staff, professional consulting engineers, and a Metro Dade County building official. (See Exhibit I for a list of team members.) The task of the team was to survey the performance of residential buildings in the storm's path and to provide findings and recommendations to both the Interagency Hazard Mitigation Team and the Dade County Building Code Task Force. Field observations of the significantly damaged areas were made by the assessment team and focused on one- to four-family residential buildings.

Observations were made of damaged and undamaged buildings of similar construction for the purpose of determining failure modes. In all, the team contributed over 1,500 man-hours of effort toward the site survey, documentation of observations, and an evaluation and assessment of building performance. The documentation that was developed during both ground level and aerial surveys included field notes, photographs, and videotaping. No testing of the buildings' materials or systems was conducted.

In support of the team's efforts, the Emergency Support Function #5, Information and Planning, of the Federal Response Plan provided numerous Geographic Information System (GIS) products. These products included maps identifying areas where wind and flood damages were sustained. Other products included maps showing clusters of significantly damaged buildings located within the floodplain. The Dade County GIS proved invaluable to the team's damage assessment efforts.

2.2 Observations Of Wind-Related Damages

Specifically, the building types observed were one- to two-story light wood-frame, masonry wall, combination masonry first floor with light wood-frame second floor, wood-frame modular, manufactured home, and accessory structures. Important observations were also made concerning exterior architectural systems, e.g., roofing components, windows, and doors.

As a result of the site survey, other important issues, such as storm debris, construction quality, workmanship, and the repair and retrofit of "partially damaged" and "undamaged" buildings, were identified and are specifically addressed in individual sections of this report.

2.2.1 Typical Building Structural Systems

Primary structural systems are those that support the building against all lateral and vertical loads. In residential applications, these systems are made up almost entirely by the exterior loadbearing walls (i.e., walls that support roof framing) and non-loadbearing wall panels (i.e., self-supporting walls only), roof structure and diaphragm, and foundation. The integrity of the overall building depends not only on the strength of these components, but also on the adequacy of the connections between them.

It was observed that when adequately engineered and constructed homes were built to define the critical "load transfer path" formed by these connections, building performance subjected to the storm conditions was dramatically improved. Where there was evidence of a breakdown in the load transfer path, the damage extent ranged from considerable to total, depending on the type of architecture and construction involved.

The roofing systems of all buildings investigated, except for modular buildings, were predominantly constructed with prefabricated light wood roof trusses. Modular homes are constructed with a roof rafter system. The discussion of prefabricated light wood trusses contained in the "Roof Framing Systems" section below is to be considered typical for each of the building types addressed.

One- to Two-Story Light Wood-Frame Buildings

The catastrophic failure of one- to two-story wood-frame buildings was observed more frequently than the catastrophic failures of other types of site-built structures. Building failure was determined to be primarily a result of negative pressure and/or induced internal pressure overloading the building envelope.

An absence of or improper installation of framing connections, load transfer straps, or bracing from non-loadbearing walls to connecting wall and roof components was noted. This condition contributed significantly to the primary failure of the framing system (see Figures 4 and 5).

The wood-frame gable ends of roof structures were found to be especially failure-prone. Wood-frame gable ends are effectively a vertical continuation of windward/leeward wall systems and require bracing from within the roof structure for lateral force resistance. A lack of an adequately defined load transfer path for the gable ends was evident. Bracing of the wood-frame gable ends was not performed with the consistency and completeness required to effectively resist and transfer the wind loads in the absence of roof sheathing. This indicates a lack of a clear understanding of the gable sections' importance to the integrity of the overall structural system during a wind storm by those responsible for the design and construction of such systems. (see Figures 6 and 7). The reliance on plywood sheathing to act as the sole stiffener of the roof diaphragm left buildings susceptible to structural damage from roof truss collapse when sheathing separated from the roof trusses.

FIGURE 4.
Exterior wood-frame non-loadbearing wall. Transfer of wind forces from wall to adjoining structure was not sufficient.

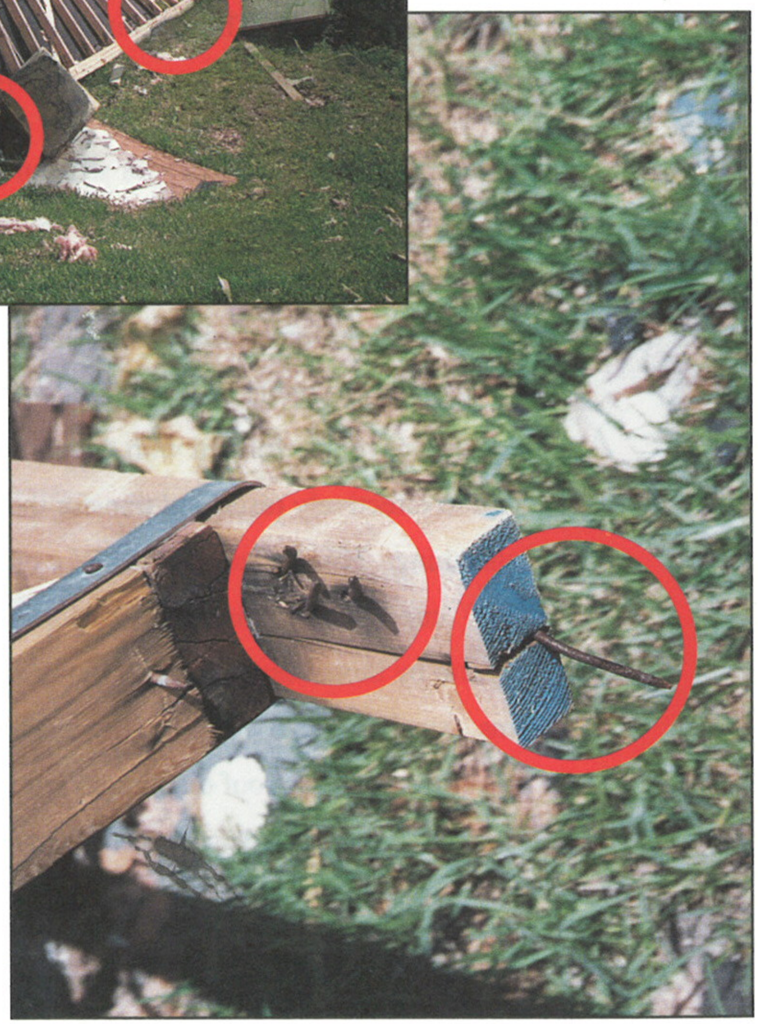

FIGURE 5.
End of exterior non-loadbearing wall top plate. Transfer of forces on entire wall depended on a limited number of nails.

FIGURE 6. *Entire wood gable separation. Bracing connection, if completed, may have prevented this from occurring.*

FIGURE 7. *Typical gable failure. Inadequate bracing support and ridge blocking evident in inward collapse.*

Individual structural members were observed to have been built and connected without adequate attention to design and construction details. Deficiencies included improper sill-to-masonry and sill-to-concrete foundation connections (SEE FIGURE 8), unbraced stud-columns, inadequate connections between exterior and interior shear walls (SEE FIGURE 9), and faulty spliced wall top-plate systems (SEE FIGURE 10). These deficiencies compromised the integrity of entire wall and roof systems.

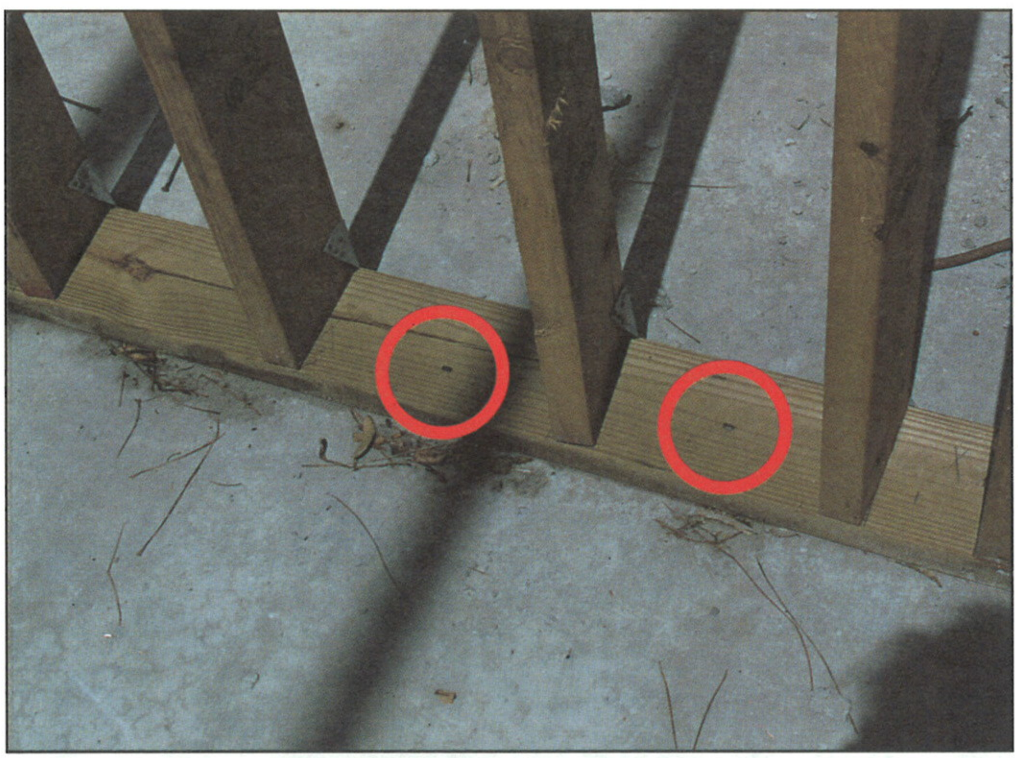

FIGURE 8. *Bolts not used in sill plate. Cut nails had no capacity to prevent pullout.*

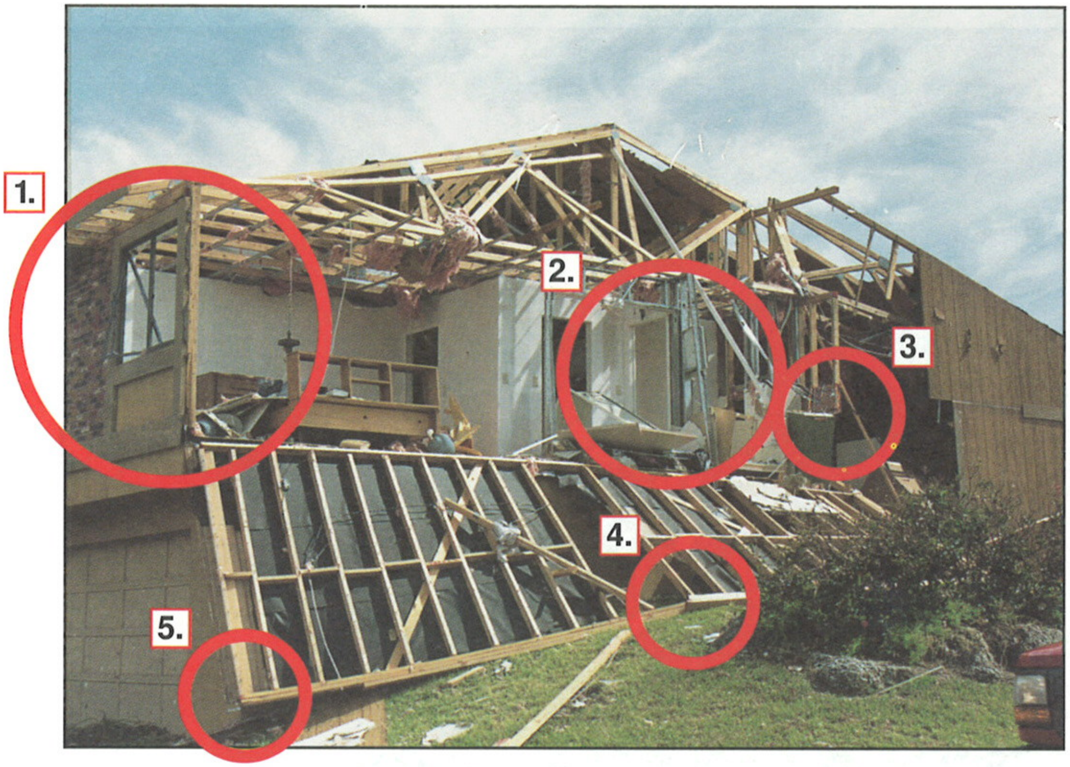

FIGURE 9. *Failure of non-loadbearing wall. Connections of exterior wall were not adequate.*

Key:

1. *End column separated from roof.*
2. *Load transfer from outside wall to interior shear wall inadequate.*
3. *Beam separated from beam seat/connector.*
4. *Improperly spliced composite tie-beam/connector.*
5. *End of top plate connection inadequate.*

FIGURE 10. *Top plate splice not able to transfer horizontal loads.*

ROOF FRAMING SYSTEMS

The roof framing systems observed were composed typically of prefabricated light wood trusses and plywood sheathing. While the trusses were found to have performed well under the wind forces, the connection of the sheathing (which forms the horizontal diaphragm of the building system) to the trusses was inadequate. Substandard workmanship in the anchoring of sheathing to trusses (by either improper stapling or improper nailing) was evident (SEE FIGURE 11).

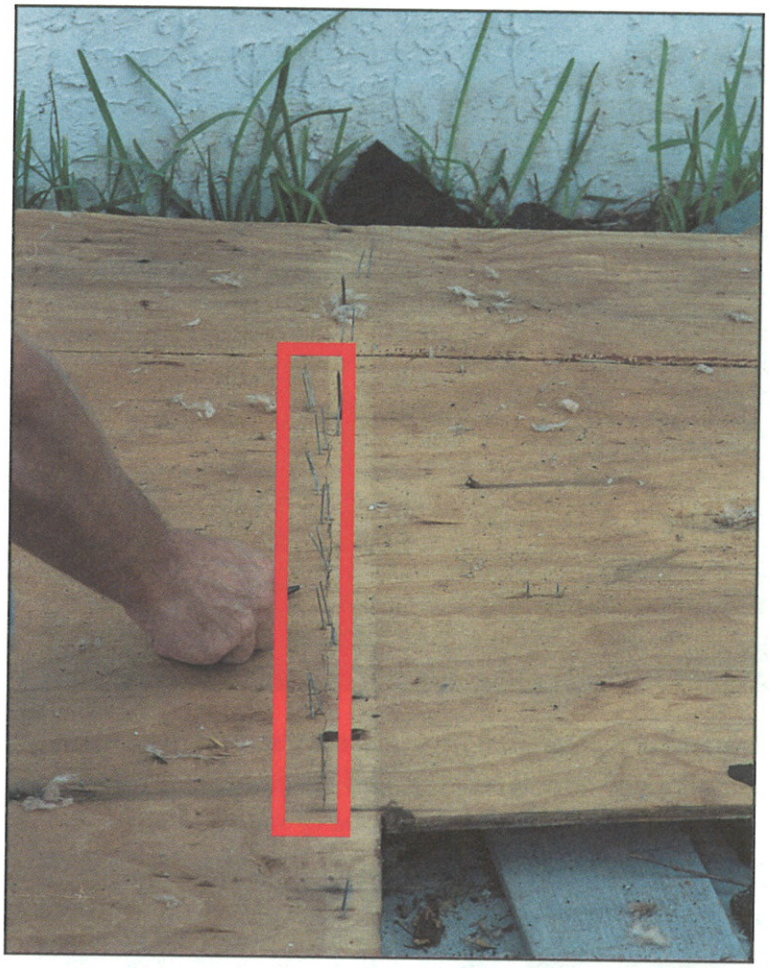

FIGURE 11.
Roof sheathing found in debris. Staples were off-line and therefore not connected to supporting truss top chord.

The lack of adequate truss bridging, improper system-wide lateral bracing, inadequate cross-bracing at end trusses, and the lack of stiffening of gable ends were determined to have compromised the integrity of the structural roof systems. It is the opinion of the assessment team that reliance on sheathing for truss-roof bracing, and the corresponding loss of the sheathing, was a major cause of the total damage of the building systems. (SEE FIGURES 12, 13, AND 14.)

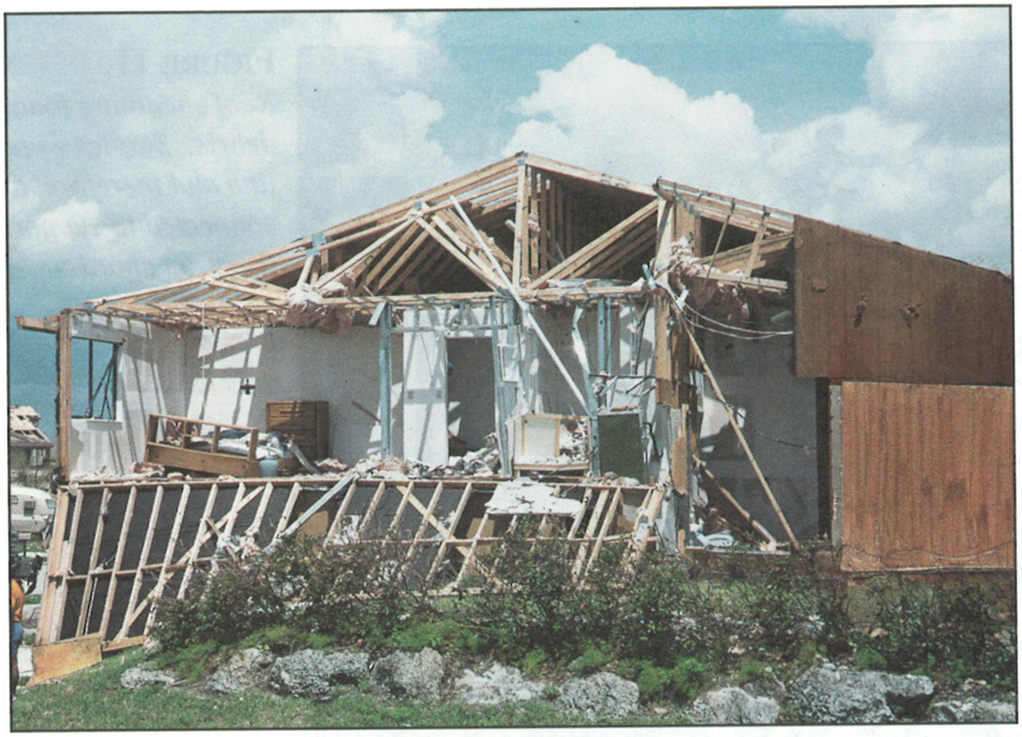

FIGURE 12. *End wall failure of typical first floor masonry/second floor wood-frame building. Truss bridging and lateral bracing, and adequately installed roof sheathing, would have greatly reduced the likelihood of such a failure.*

FIGURE 13. *Roof structure failure due to inadequate bracing.*

FIGURE 14. *Roof structure failure due to inadequate bracing.*

MASONRY WALL BUILDINGS

The main cause of failure of masonry buildings was a lack of vertical wall reinforcing (SEE FIGURE 15). Typically, concrete block and stucco (CBS) systems performed much better than all-wood-frame construction. This was due primarily to the heavier mass of the masonry walls and the tendency of a continuously constructed system to be less prone to failure from a lack of attention to design and construction details.

FIGURE 15. *Masonry construction building. Wall separated from building envelope due to inadequate vertical wall reinforcing in connection to horizontal tie-beam.*

Where failures of the buildings did occur, the following conditions were observed: poor mortar joints between wall and monolithic slab pours; lack of tie-beams (SEE FIGURE 16), horizontal reinforcing, tie columns, and tie-anchors; and misplaced or missing hurricane straps between walls and roof structure.

Discontinuous second-story CBS walls (typical firewall design) were prone to failure at their connecting edges and suffered separation from various building envelopes. Improved wall performance through continuous CBS construction was observed in the performance of gable ends that were CBS-constructed (SEE FIGURE 17).

In addition, it was generally observed that CBS walls were not susceptible to penetration by airborne debris.

FIGURE 16. *Two-story masonry buildings. Lack of continuous tie-beam led to failure of wall that was already weakened in design by window openings.*

FIGURE 17. *Two-story masonry building. While forces were sufficient to blow off entire roof structure, continuous masonry gables held.*

Combination Masonry First Floor With Light Wood-Frame Second Floor Buildings

Typically, failure of wood-frame second floor systems was observed to be similar to failure of the all-wood-frame buildings (see "One- to Two-Story Light Wood-Frame Buildings"). The failure of the wood-frame gable ends, the failure of connections of wood sill plates to first-story CBS walls, and inadequate anchoring of sole plates to masonry were observed. Where sufficient numbers of bolted anchors may have been provided, some of the bolts were not secured by nuts and washers. In many instances, the use of unapproved anchoring methods (e.g., cut nails) was observed. (See Figure 18.)(Also See Figure 8, which shows a sill plate connected to a concrete foundation with cut nails.)

FIGURE 18. *Second story wood framing (on first story masonry). End gable and wall failure.*

Wood-Frame Modular Buildings

Overall, relatively minimal structural damage was noted in modular housing developments. The module-to-module combination of the units appears to have provided an inherently rigid system that performed much better than conventional residential framing. This was evident in both the transverse and longitudinal directions of the modular buildings.

Two end-wall (end wall of end modules) failures were observed in a modular home subdivision. Poor connection of the tops of the walls to the roof diaphragms was evident in these instances. Some roof sheathing was observed missing from rafters, judged to be due either to building envelope breach (window and/or door failure) or to external wind and debris. Generally, the rafters themselves were left entirely intact, because of the inherent rigidity developed by the relatively short spans and secure connections. (See Figures 19 and 20.)

Figure 19. *Modular home. End wall of end unit separated from unit; withdrawal of nails along eave line and roof sheathing failure were also observed.*

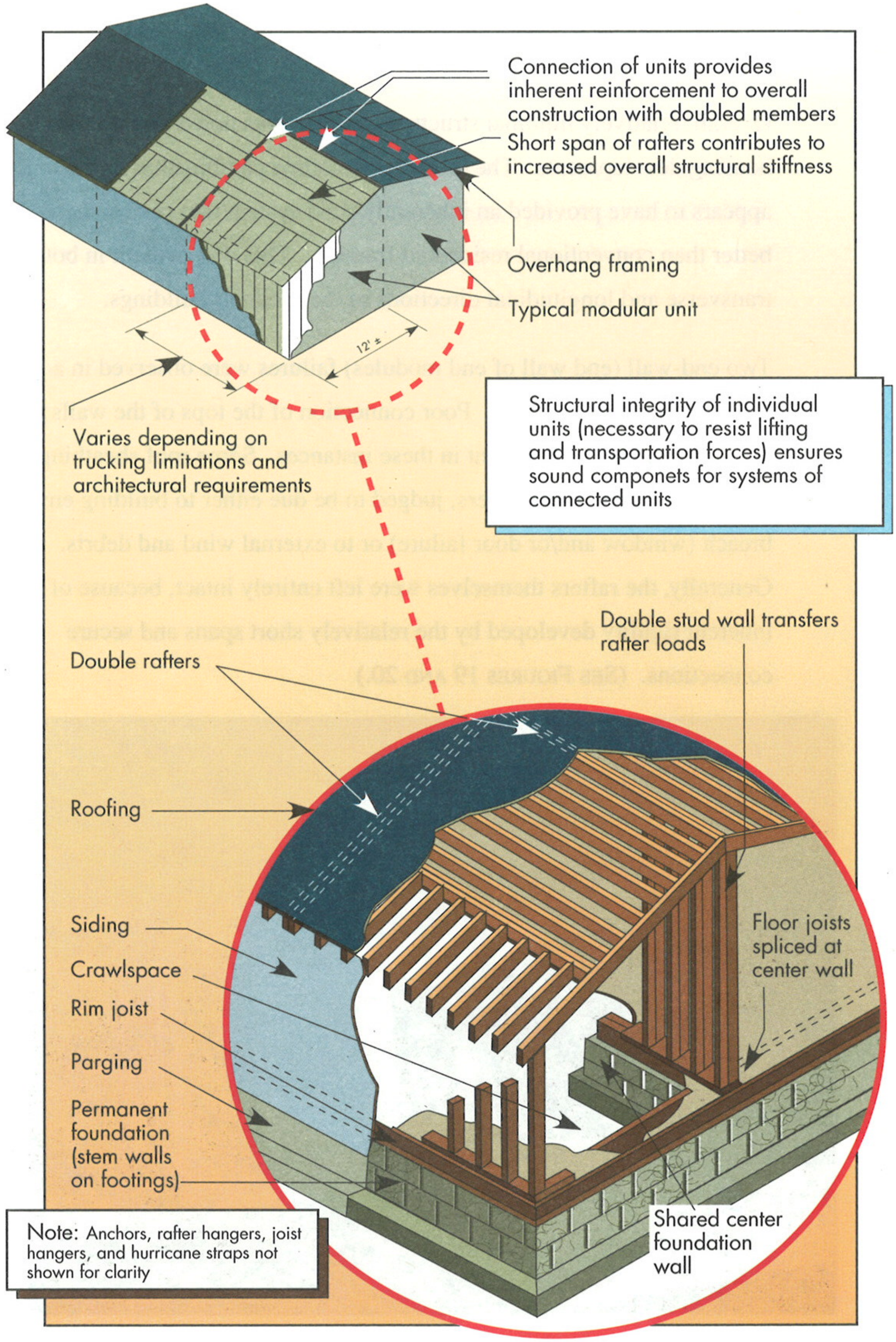

FIGURE 20. *Inherent structural strength of modular construction.*

Manufactured Homes

Manufactured homes possessed poor ability to withstand the high wind loads generated by Hurricane Andrew (see Figure 21). In several subdivisions, many of these homes suffered total losses.

It was observed that the breakup of corrugated metal siding and roofed buildings such as manufactured homes and pre-engineered metal frame buildings contributed significantly to the generation of airborne debris. This was evident from debris damage to nearby downwind structures.

Appendix B provides background information concerning manufactured housing.

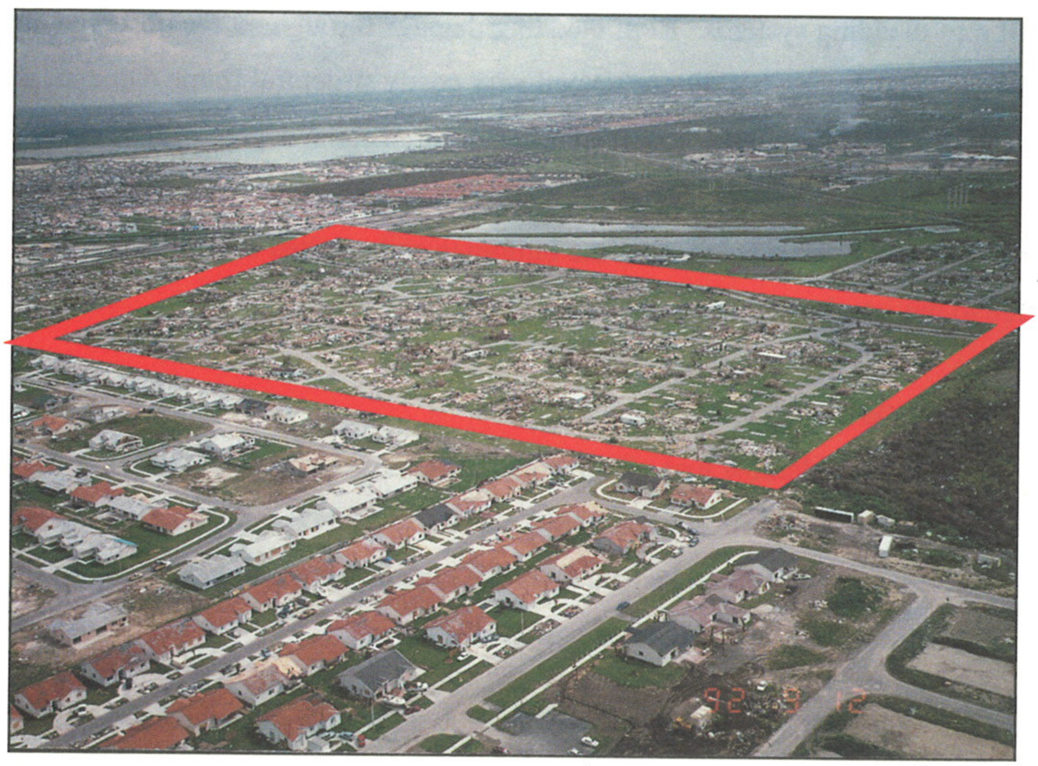

FIGURE 21. *Aerial photo of damage area. Shows building performance difference between manufactured homes (outlined in center) and conventional residential buildings (lower left).*

Accessory Structures

Accessory structures were widely observed to have been destroyed. Accessory structures consist of such systems as light metal pool and porch enclosures, carport systems, sheds, playground equipment, and light poles. The frames and attachments of screens and glazings of such systems are not adequately sized and fabricated for resistance to 120-mph wind speeds (as required by code, they are designed for 75-mph speeds with additional provisions for shape factor). These systems therefore cannot be ruled out as sources of flying debris that may cause damage to buildings.

2.2.2 Roof Cladding Systems

Roof cladding includes the underlayment material (e.g., building felt) and the topmost roof coverings (e.g, tiles and shingles) that are installed in sequential stages of overall roof cladding systems. Roof cladding damage throughout the observed areas was pervasive. While many buildings escaped very costly structural frame damage, almost all residential buildings in the observed areas suffered some degree of roof cladding damage from both wind and airborne debris. The damage to the roof cladding systems permitted wind-driven rains to enter the buildings and resulted in additional costly damage to the interiors and contents.

Composition Shingles

A considerable loss of both shingles and underlayment felt was observed. Evidence of substandard workmanship included torn shingles and inadequately attached shingles (i.e., insufficient number of staples or incorrectly located and/or oriented staples).

It appeared that many of the shingles and attachment adhesives used were not adequate for the wind speeds that occurred. This was evidenced by the observed tears and pullouts at the staple connections.

Tile (Extruded Concrete, Clay)

In general, the assessment team observed a failure of both the nailing and/or mortar connections that are integral to the attachment of precast and molded tile systems. A failure of the underlayment, lack of bond between underlayment and mortar, and lack of bond between mortar and tile were all observed (see Figures 22, 23, and 24), although it appeared that lack of bond between the mortar and tile was the common cause of failure.

Of the mortar pads visible on damaged roofs, many appeared to have been applied in a nonuniform manner. Noteworthy were the better performing flatter shaped tiles. Generally, roofs with these tiles were observed to have suffered fewer catastrophic losses of the entire tile attachment system. Clay tiles were more susceptible to shattering from impact of debris, but had

Figure 22. *Typical failure of roof sheathing-to-underlayment attachment. (Bond between underlayment and mortar pad, and between mortar pad and tile effective.)*

FIGURE 23. *Typical roofing failure. Failure of sheathing, underlayment, and extruded concrete tiles.*

FIGURE 24. *Typical roofing failure. Failure between tiles and mortar pads.*

comparatively better adhesion to mortar than extruded concrete tiles. The assessment team determined that a "domino effect" of debris impact had occurred systematically in most of the roofing failures.

2.2.3 Exterior Wall Openings

The breaching of the building envelope by failure of openings (e.g., doors, windows) due to wind or debris impact was a significant factor in the damage of many buildings. This allowed an uncontrolled buildup of internal air pressure that resulted in further deterioration of the building's integrity. In general, window protection such as precut plywood and shutters performed well. It was observed that debris impact did result in the failure of some window protection systems. Doors were not observed to have any additional protection or reinforcing.

Structures with adequate roof ventilation were observed to have performed better due to the ability of the ventilation to relieve induced internal pressure.

Garage Doors

The failure of garage doors was determined to have promoted a great deal of damage to buildings. It appears that garage doors failed when the door deflection exceeded the amount allowed for in the manufacturer's design. The deflection of the doors caused excessive deformation of the entire assembly (panel rollup doors and glider wheel tracks) and ultimately the separation of the door from the opening. Excessive rotations of the tracks followed by pullout of the door pins and glider wheels from the track was the sequence of failure (see Figure 25). Loss of the doors resulted in an envelope breach and a sudden increase in internal pressures to the buildings.

One noteworthy observation was that single-car garage doors performed better than two-car garage doors.

FIGURE 25. *Garage door failure. Rotation of track, and pullout of brackets at wall support.*

Entry Doors

Various entry doors, most notably french doors and wood and metal double doors, were prone to failure. It was observed that these doors failed as a result of either pullout of their center pins and/or shattering of the door leafs at the location of the center pin. It appeared that the deflection of metal double doors resulted in the pulling out of the center pins. Wood double doors resisted the deflection but shattered at the center pin location.

Window Systems

Window systems, especially the larger sliding glass doors, were very susceptible to failure from high wind pressures and debris impact. Although the frame systems were observed to have remained intact, they were not fully stressed by virtue of the glazing failures. As noted, glazing left without storm protection was especially prone to penetration by airborne materials and failure due to the wind loads.

Storm shutters and boarded windows were observed to have reduced the extent of overall damage to buildings by protecting the building envelope against wind penetration.

2.2.4 Debris

Extensive damage was caused and further promoted by airborne debris. The debris consisted largely of failed roofing materials, but also included components of metal-clad buildings, various accessory structures, and miscellaneous sources such as fences.

The failure of manufactured homes and other metal-clad buildings generated considerable windblown debris. In at least one area, it was observed that debris directly impacted and damaged several single-family houses.

2.2.5 Workmanship

Substandard workmanship was noted at many locations. Clearly, not all tradespeople were well qualified in the construction of building structural systems, structural components, and connections necessary to resist design wind loads. Where high-quality workmanship was observed, the performance of buildings was significantly improved. Inspection was inadequate to address the workmanship problems observed. In developments where large tracts of homes of repetitive design occur, there is a tendency for inadequate inspections to be performed due to the repetitive nature of the construction.

2.3 Observations Of Flood-Related Damages

It is unusual that a storm as large as Hurricane Andrew would result in such limited flood damage. While the storm surge reached a maximum recorded elevation at the Burger King Headquarters (see Figure 1), on Old Cutler Road, the landward extent of the flooding was quite limited and the surge elevation (north and south of the area) diminished quickly. This may have been a result of Hurricane Andrew being a very compact storm and to the speed at which it moved inland across Dade County. It is possible the short duration of the peak of the storm (approximately 1.5 hours) resulted in the flood water not being forced very far inland. The dense vegetation, followed inland by dense subdivision development, may have interfered with the landward movement and impeded the flow further.

Flood damage patterns, identified by both field observations and flood insurance claims, indicate widespread damage along the immediate coast resulting from hydrostatic pressure and inundation by storm surge. Some hydrodynamic damage may have occurred to easily damaged items such as a two-car garage doors and lower-area enclosures. One condominium development was completely gutted as lower-area debris, including boats, was pushed a considerable distance inland by the surge. Some of the hydrostatic pressure damage to garage doors may have been caused by the lack of openings into the garage below the flood level or by openings that were too small to allow hydrostatic pressure from floodwater to equalize. This may have been due to the rapid rise and fall of the storm surge. Buildings that had been elevated in accordance with NFIP requirements appeared to have weathered the flood event with little flood damage. Worth noting was damage to vehicles in parking garages beneath elevated condominiums in locations such as Key Biscayne.

The building that appeared to suffer the single greatest loss was the Burger King Headquarters. This post-FIRM building, built in conformance with NFIP requirements, was elevated to an elevation of 11 feet, the BFE on the community's FIRM. The surge reached an elevation of 16.8 feet, resulting in significant damage to breakaway walls below the BFE and considerable damage to the first floor of the building. High winds and wind-driven rain resulted in significant damage as well. Total damage to the building and its contents appears to be well into the millions of dollars.

Damage to residential buildings was observed in V, A, and X zones shown on the FIRM (SEE FIGURE 3). In one subdivision mapped as Zone X, located directly west of the Burger King Headquarters, many homes were flooded to depths of 1 to 3 feet. Persons in X zones, who are not required to obtain flood insurance, may well suffer significant financial losses due to a lack of insurance coverage for flood damages.

Flood damage was observed in several subdivisions along or near the coast. Subdivisions to the east of Old Cutler Ridge Road received the greatest damage. Many of these subdivisions were characterized by extensive finger canal systems off the coast, which provide water frontage for the properties. Flood depths ranged from 1 to 3 feet in many of these subdivisions. For slab-on-grade construction, damage to interiors was extensive and required that many flood damaged homes be completely gutted. This type of repair may constitute a substantially damaged building under the county Code and according to NFIP standards. In the event that the building is substantially damaged, the county Code requires that the lowest floor of the building be elevated to or above the BFE.

2.4 Repair/Retrofit of Partially Damaged and Undamaged Buildings

In many buildings, it was observed that damage occurred in one part of the building and that the remainder of the building was structurally undamaged. Based on this observation, it was concluded that the repair of only the "damaged portions" of buildings may leave the remainders of the buildings susceptible to damage from future hurricanes. Also, "undamaged" buildings constructed in a manner similar to those observed as "damaged" may be susceptible to damage by recurrent high-wind events.