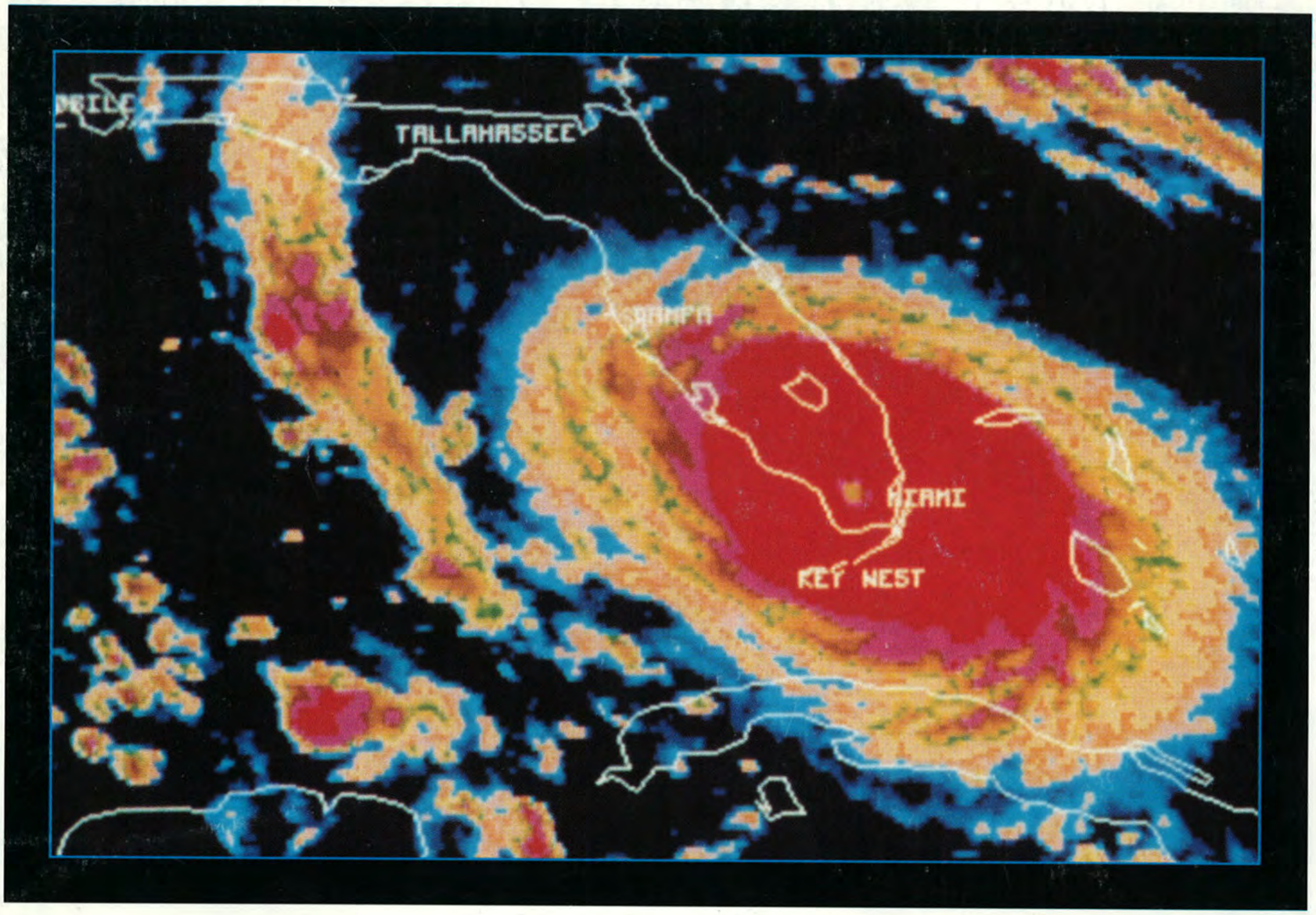

BUILDING PERFORMANCE: HURRICANE ANDREW IN FLORIDA

OBSERVATIONS, RECOMMENDATIONS, AND TECHNICAL GUIDANCE

FEDERAL EMERGENCY MANAGEMENT AGENCY
FEDERAL INSURANCE ADMINISTRATION

FIA–22
(2/93)

COVER PHOTO:

HURRICANE ANDREW, AUGUST 24,1992
Courtesy of the National Oceanic and Atmospheric Administration, National Weather Service

Building Performance: Hurricane Andrew In Florida

Observations, Recommendations, and Technical Guidance

Federal Emergency Management Agency
Federal Insurance Administration

December 21, 1992

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EXECUTIVE SUMMARY

On August 24, 1992, Hurricane Andrew struck southern Dade County, Florida, generating high winds and rain over a vast area of the county. Although the storm produced high winds and high storm surge, the effects of storm surge and wave action were limited to a relatively small area of the coastal floodplain. It was evident from the extensive damage caused by wind, however, that wind speeds were significant.

In September 1992, the Federal Emergency Management Agency's (FEMA's) Federal Insurance Administration (FIA), at the request of the FEMA Disaster Field Office staff, 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.) FIA was tasked because of its extensive experience in assessing building damage caused by hurricanes. 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. The basis for performing the survey is that better performance of building systems can be expected when causes of observed failures are corrected using recognized standards of design and construction. Collectively, the team has invested over 1,500 man-hours of effort conducting the site survey, preparing documentation, and assessing damages. Documentation of findings made during ground level and aerial surveys included field notes, photographs, and videotaping.

In conducting its survey, the assessment team investigated primary structural systems of buildings, i.e, systems that support the building against all lateral and vertical loads experienced during a hurricane. The building types observed were one- and two-story light wood-frame, masonry wall, combination masonry first floor with light wood-frame second floor, wood-frame modular, and manufactured homes. In general, it was observed that masonry buildings and wood-frame modular buildings performed relatively well.

In addition, the performance of the exterior architectural systems, such as roofing, windows, and doors was analyzed. The analysis included the effects of debris and the quality of construction workmanship. The breaching of the building envelope by failure of openings (e.g., doors, windows) due to debris impact was a significant factor in the damage to many buildings. This allowed an uncontrolled buildup of internal air pressure that resulted in further deterioration of the building's integrity. Failure of manufactured homes and other metal-clad buildings generated significant debris. Numerous accessory structures, such as light metal porch and pool enclosures, carports, and sheds, were destroyed by the wind and further added to the debris.

The loss of roof material and roof sheathing and the failure of windows and doors exposed interiors of buildings to further damage from wind and rain. The result was significant damage to building interiors and contents that rendered many buildings uninhabitable.

Field observations concluded that the loss of roof cladding was the most pervasive type of damage to buildings in southern Dade County. To varying degrees, all of the different roof types observed suffered damage due to the failure of the method of attachment and/or material, inadequate design, inadequate workmanship, and missile (debris) impact.

Much of the damage to residential structures also resulted from inadequate design, substandard workmanship, and/or misapplication of various building materials. Inadequate design for load transfer was found to be a major cause of the observed structural failures of buildings. In adequately designed buildings, the load transfer path is clearly defined. Proper connections between critical components allow for the safe transfer of loads that is required for structural stability. Where high-quality workmanship was observed, the performance of buildings was significantly improved.

Inadequate county review of construction permit documents, county organizational deficiencies such as a shortage of inspectors and inspection supervisors, and the inadequate training of the inspectors and supervisors are factors that may have contributed to the poor-quality construction observed.

The assessment team developed recommendations for reducing future hurricane damage such as that resulting from Hurricane Andrew. Recommendations included areas of concern such as building materials, construction techniques, code compliance, quality of construction, plan review, inspection, and reconstruction/retrofit efforts. The recommendations presented in this report may also have application in other communities in Florida.

This report presents the team's observations of the successes and failures of buildings in withstanding the effects of Hurricane Andrew, comments on building failure modes, and provides recommendations for improvements intended to enhance the performance of buildings in future hurricanes. Before this final report was printed, it was reviewed by other offices within FEMA. The substantive review comments received are presented in Appendix C.

1.0 Introduction

1.1 Purpose

The purposes of this report are to present the Building Performance Assessment Team's observation of the successes and failures of buildings in withstanding the effects of Hurricane Andrew in southern Dade County, Florida; to comment on the failure modes of damaged buildings; and to provide recommendations for improvements intended to enhance the performance of buildings in future hurricanes.

1.2 History and Background

Hurricane Andrew came ashore in southern Dade County during the early morning hours of August 24, 1992. Although the storm produced high winds and a high storm surge, the effects of the storm surge and wave action were confined to a relatively small area of the coastal floodplain (see Figure 1). Therefore, the flood damage from Andrew, unlike that from many other hurricanes of its size and magnitude, was minimal. Wind damage resulting from Andrew was widespread, however (see Figure 2). Consequently, considerable public interest has focused on the determination of actual windspeeds resulting from this hurricane.

The range of sustained windspeeds for a Category 4 storm, such as Hurricane Andrew, is from 131 mph to 155 mph. On September 11, 1992, the team met with various people involved in determining the wind speeds generated by Hurricane Andrew. The assessment team was informed that measurements taken over water at Fowley Rocks indicated a peak 2-minute sustained wind speed as high as 141 mph before the anemometer (a gauge for measuring the velocity of wind) stopped reporting. At the National Hurricane Center (150 feet above the ground), peak wind gusts reached speeds of over 160 mph . Wind speeds closer to the ground, and nearer to the storm

METRO-DADE

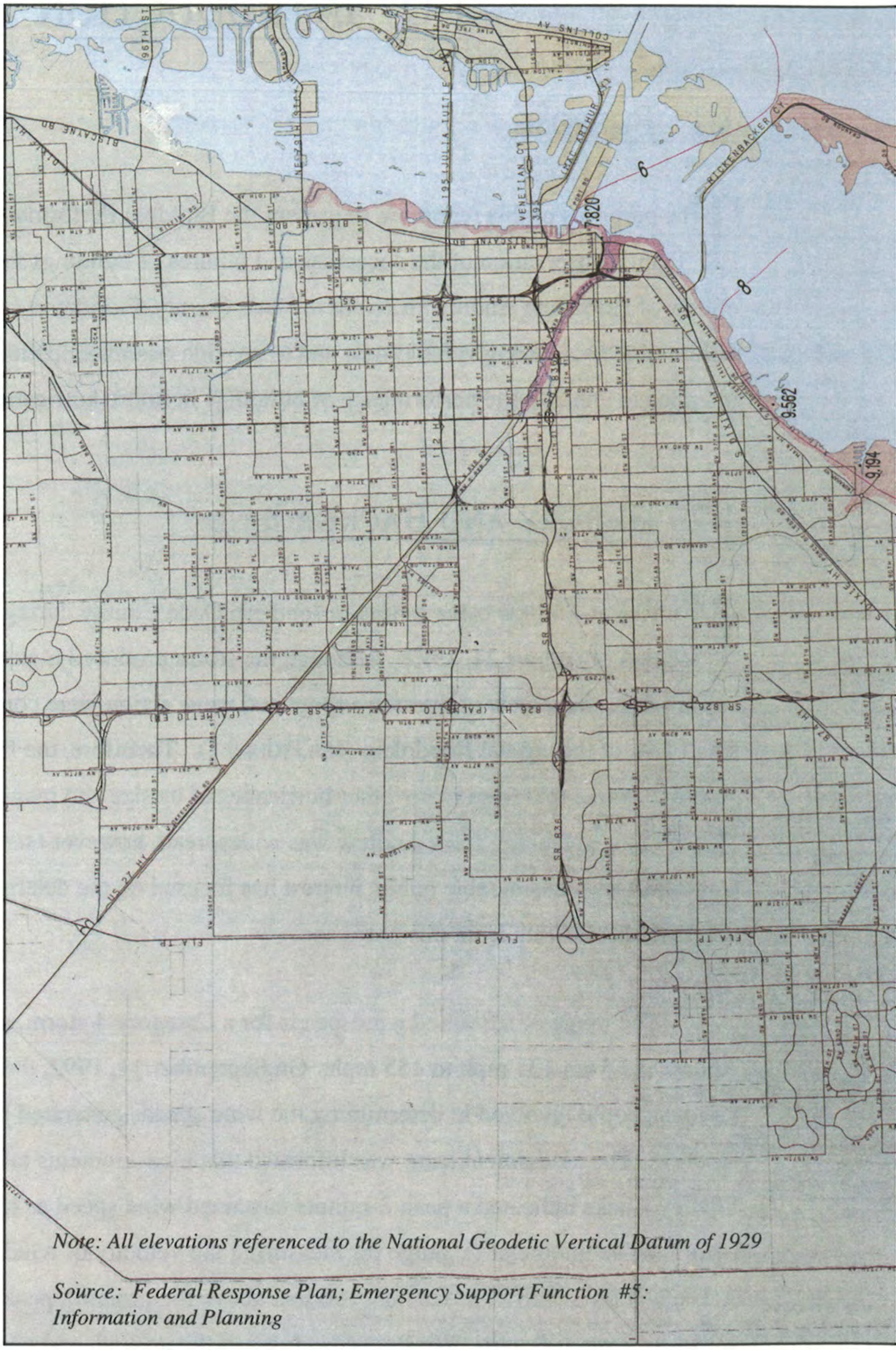
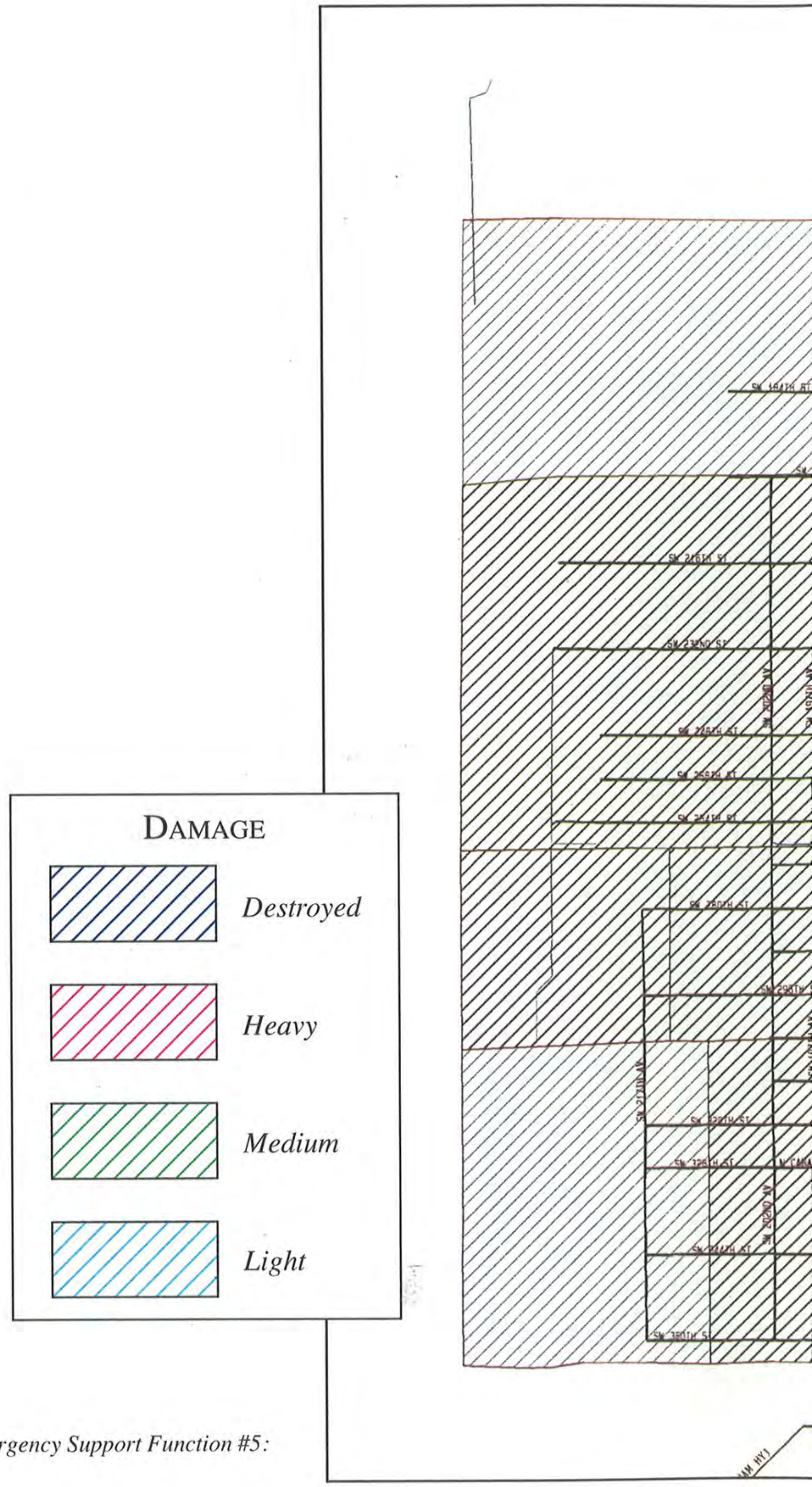


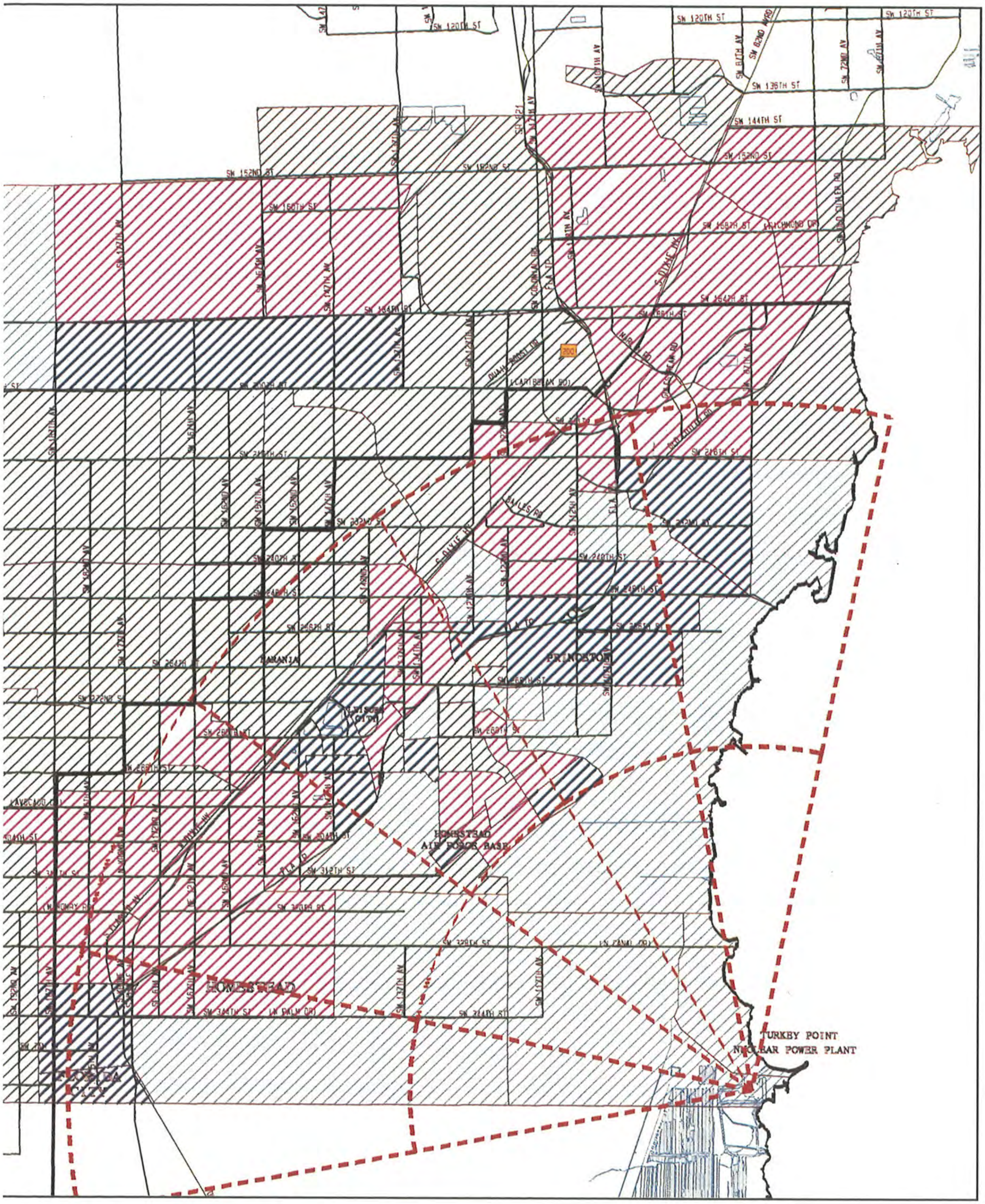
FIGURE 1. *Storm surge associated with Hurricane Andrew.*


Burger King Headquarters
Peak Recorded Surge: 16.8 feet
N
10
8
15.195
10.063
12.630
10
8.870
8.450
8
6.880



Source: Federal Response Plan; Emergency Support Function #5: Information and Planning

FIGURE 2. *Damage zones as a result of Hurricane Andrew, Dade County, Florida*


PRINCETON
HOMESTEAD AIR FORCE BASE
HOMESTEAD
FLORIDA CITY
TURKEY POINT NUCLEAR POWER PLANT
NARANJA
SW 120TH ST
SW 136TH ST
SW 144TH ST
SW 152ND ST
SW 184TH ST
SW 216TH ST
SW 248TH ST
SW 312TH ST
S DIXIE HY

center, have not been precisely determined. This may be due to varying degrees of exposure as a result of ground surface irregularities, the distance between anemometer sites, and the potential inaccuracy of anemoneters at excessively high winds.

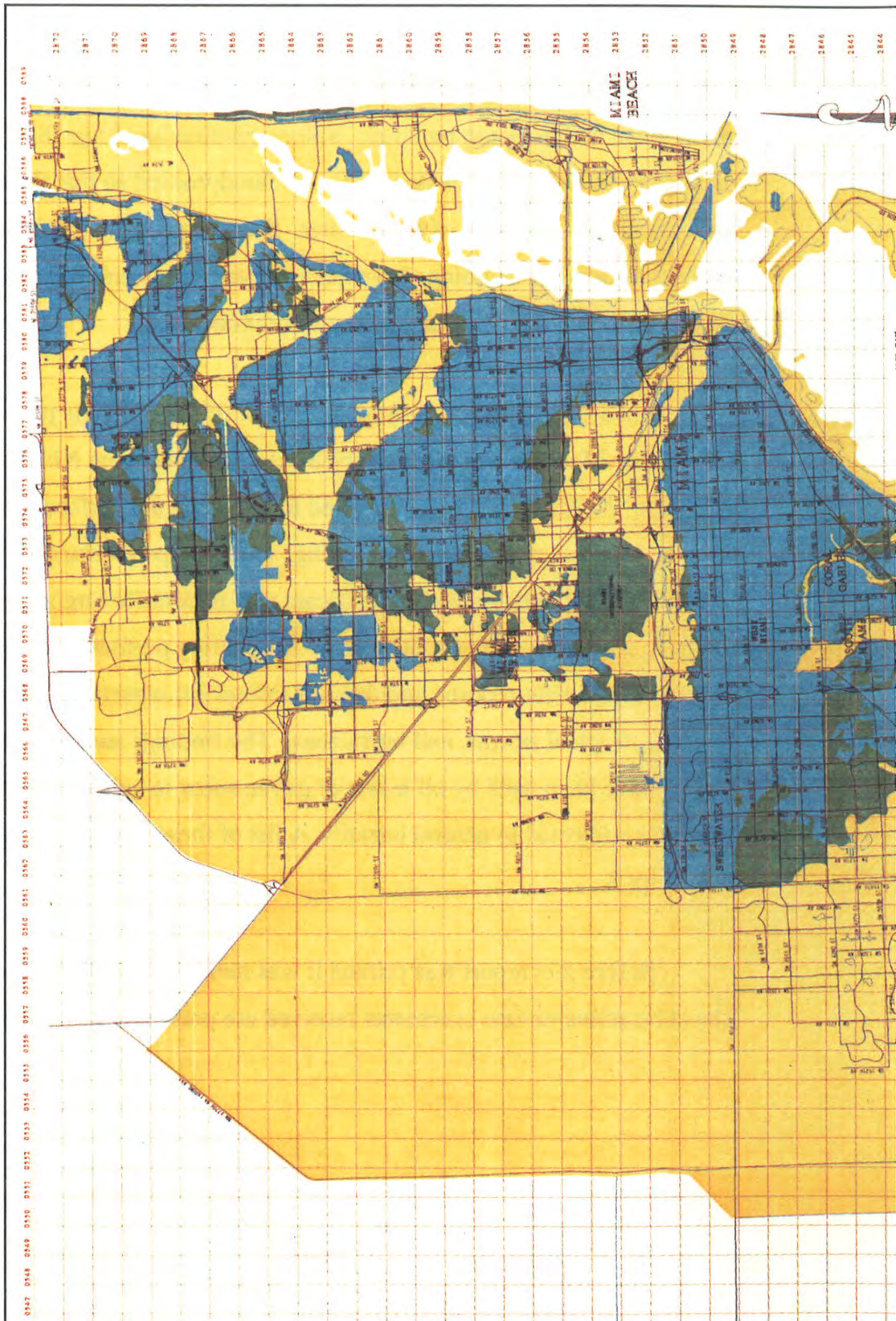
In 1957, to address the need for hurricane-resistant construction, Dade County developed and began enforcing the South Florida Building Code (herein referred to as the Code). The Code contains both detailed prescriptive and performance measures for meeting minimum load requirements. The Code requires that structures be able to resist wind pressures produced by a velocity of "not less than 120 mph at a height of 30 feet above the ground." The code also requires that safety factors varying from 1.0 to 4.0 be applied in structural designs depending on which building component is being designed. The Code also has high wind pressure and fastest-mile wind speed requirements for buildings located in coastal zones, in accordance with Florida State requirements. Fastest-mile wind speed for a given storm is generally recorded by weather instruments that automatically record wind speeds averaged over the time interval required for the passage over the anemometer, located 30 feet above the ground, of a horizontal column of air with a length of 1 mile. Though it appears that, in some areas, the wind speeds associated with Hurricane Andrew exceeded those prescribed in the Code, properly designed and constructed buildings should have experienced fewer storm-related damages when factors of safety required by the Code are taken into consideration.

The National Flood Insurance Program (NFIP) was created by an Act of Congress in 1968 to make flood insurance available to property owners in floodprone areas in return for a community's commitment to enact and administer floodplain management regulations. These regulations require that new and substantially improved buildings in floodprone areas be built in such a manner as to reduce flood hazards and loss of life and property resulting from floods.

In 1972, Dade County was issued a Flood Insurance Rate Map (FIRM) from the NFIP that shows the flood zones in the county (SEE FIGURE 3 ON PAGES 12 AND 13). The community adopted, and began enforcing, NFIP-compliant floodplain management regulations in 1974. An important provision that the county was required to include in its floodplain management regulations is the requirement that the lowest floor of substantially damaged residential buildings be elevated to the base flood elevation (BFE) when those buildings are repaired. Non-residential buildings that have been substantially damaged can either be elevated or be dry-floodproofed so that they are substantially impermeable to the entry of flood water. Based on county-provided estimates, as many as 4500 floodprone buildings have been substantially damaged by Hurricane Andrew and may have to be either elevated or dry-floodproofed.

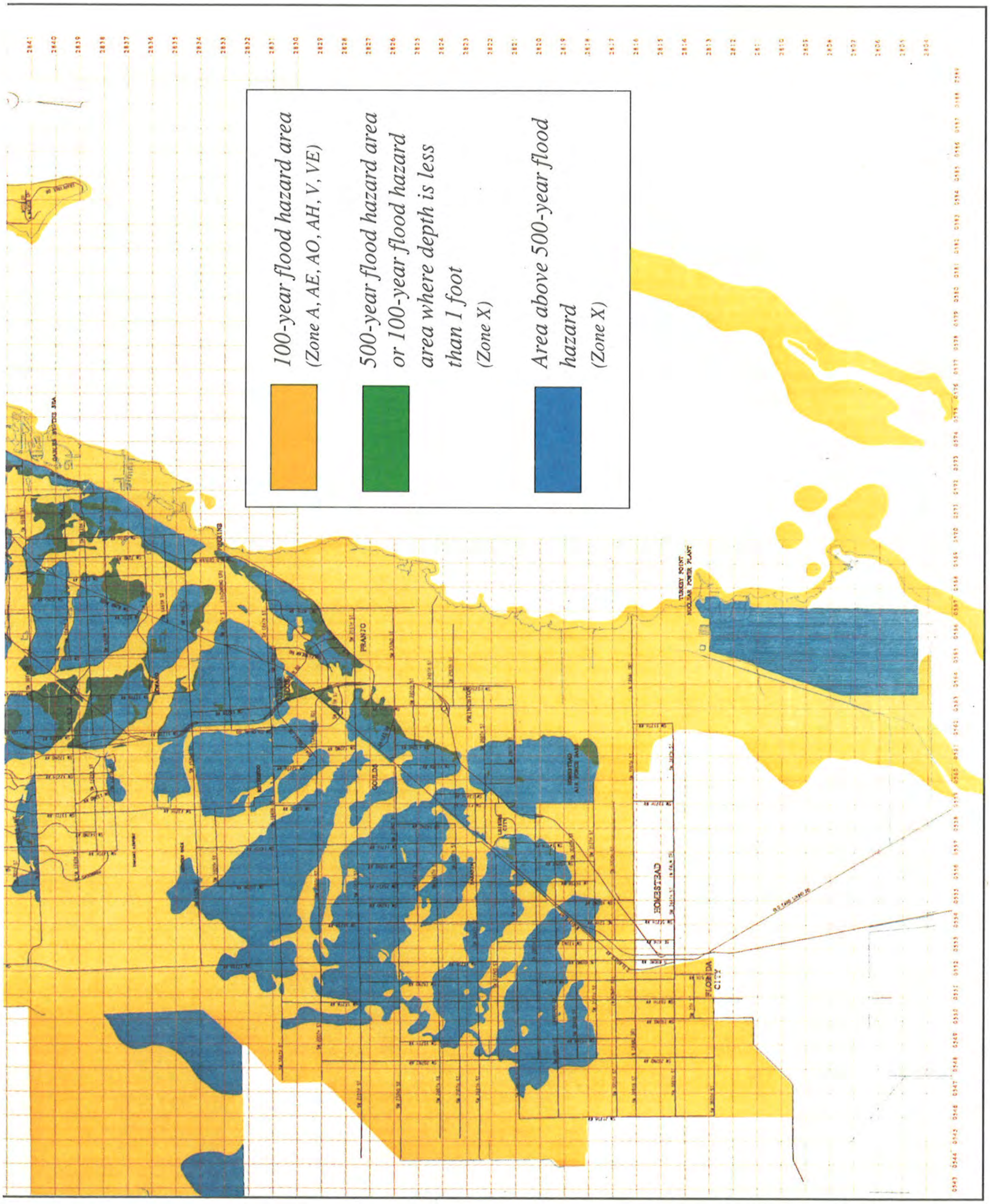
The Federal Insurance Administration (FIA), which is part of the Federal Emergency Management Agency (FEMA), administers the NFIP. Since the creation of FEMA in 1979, FIA has been involved in assessing the performance of buildings affected by riverine and coastal flooding. Building performance has also been assessed in cases where winds played a significant role in contributing to damages. To date, FIA has been involved in the preparation of 26 building performance assessment reports, damage assessment reports, and damage mitigation reports for areas subject to riverine flooding, tropical storms, and hurricanes. The findings and recommendations of these reports have been used by all levels of government to enhance the performance of buildings subjected to natural hazards. A list of these documents can be found in Appendix A.

Before this report was printed it was reviewed by other offices within FEMA. The substantive review comments received are presented in Appendix C.



Source: Federal Response Plan; Emergency Support Function #5: Information and Planning

FIGURE 3. *Dade County flood zones as identified on the Flood Insurance Rate Map*


100-year flood hazard area
(Zone A, AE, AO, AH, V, VE)
500-year flood hazard area or 100-year flood hazard area where depth is less than 1 foot
(Zone X)
Area above 500-year flood hazard
(Zone X)
HOMESTEAD
FLORIDA CITY

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.

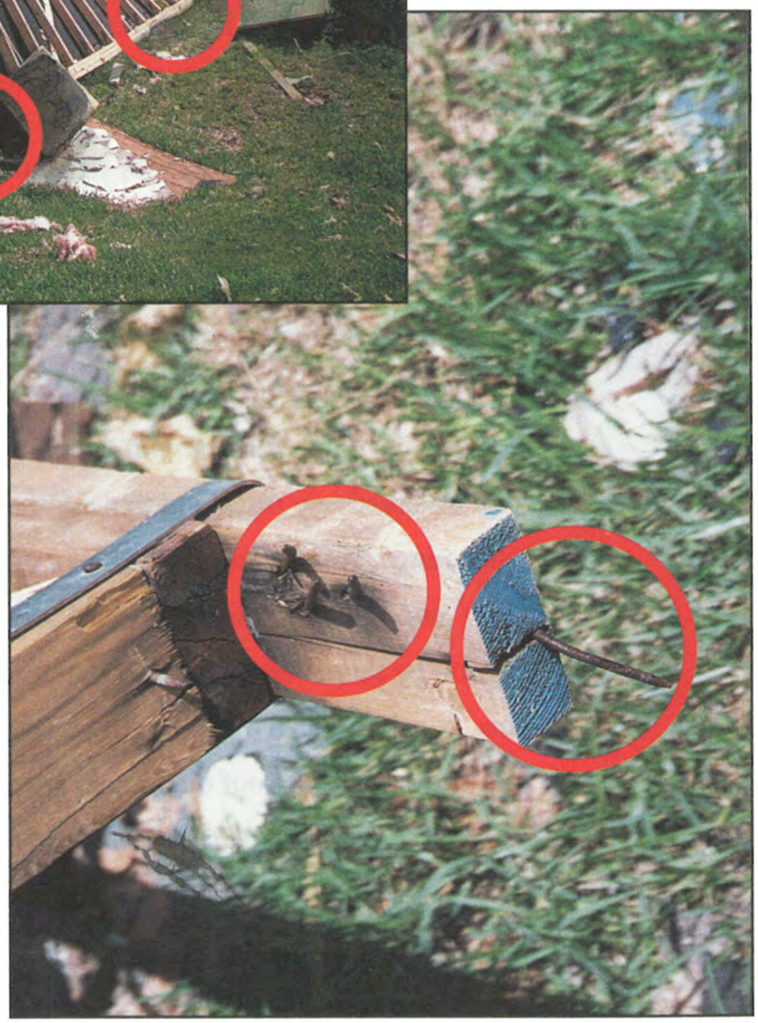


FIGURE 5.
End of exterior non-loadbearing wall top plate. Transfer of forces on entire wall depended on a limited number of nails.

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.

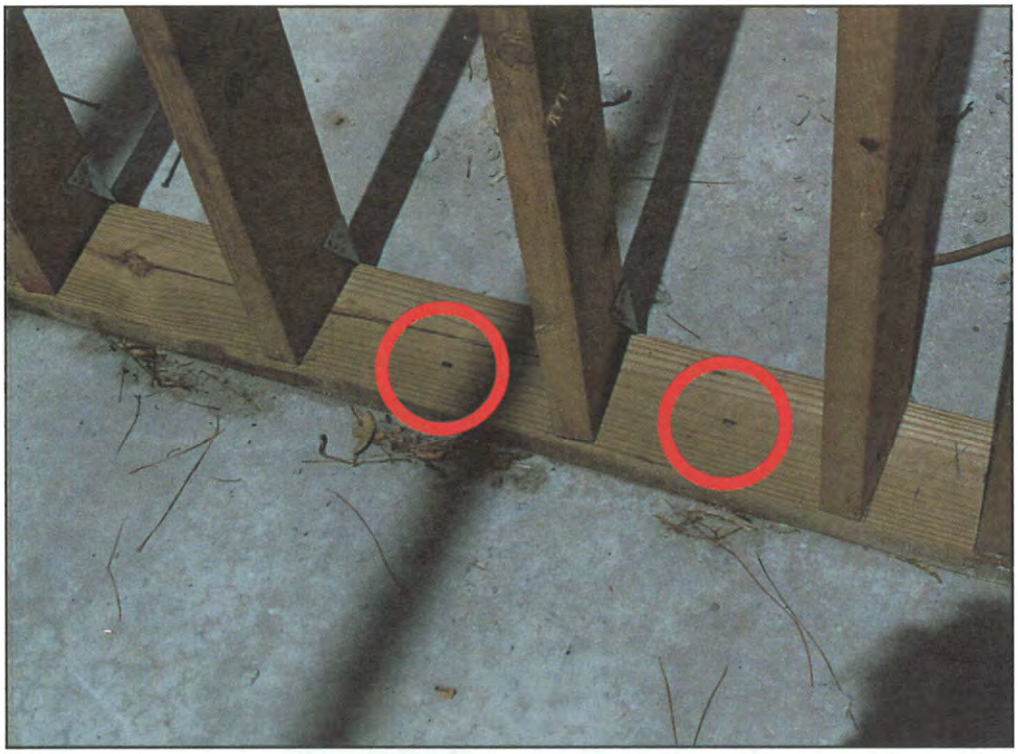


FIGURE 8. *Bolts not used in sill plate. Cut nails had no capacity to prevent pullout.*

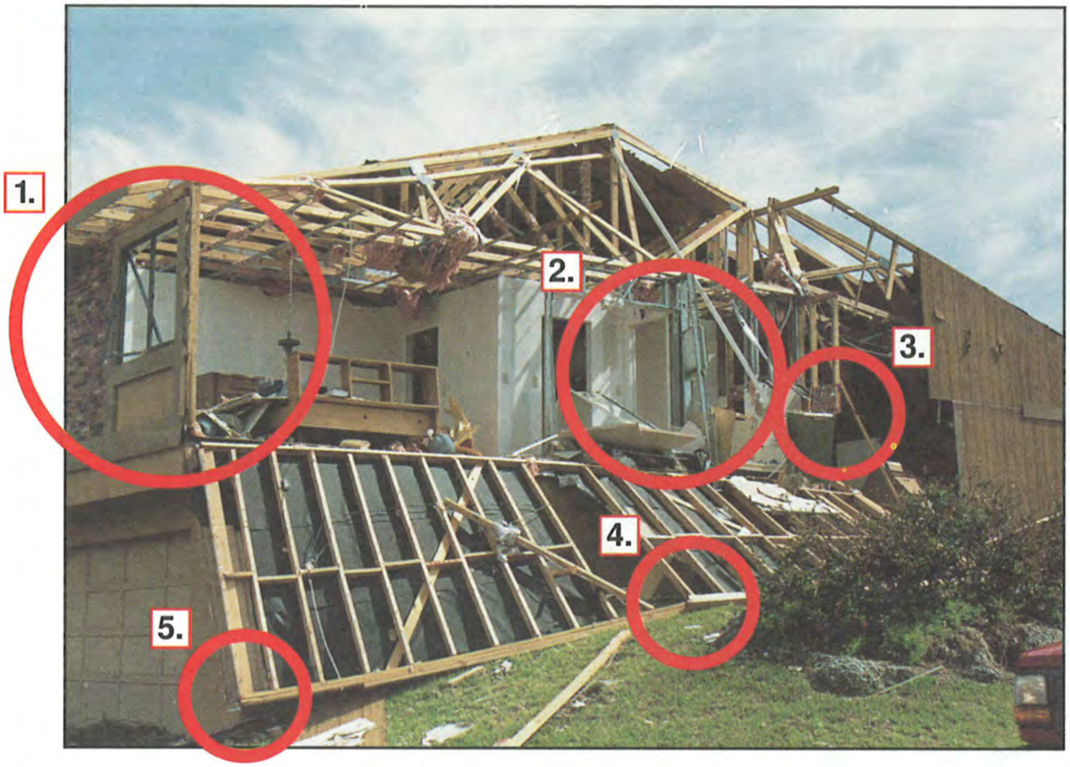


FIGURE 9. *Failure of non-loadbearing wall. Connections of exterior wall were not adequate.*

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).

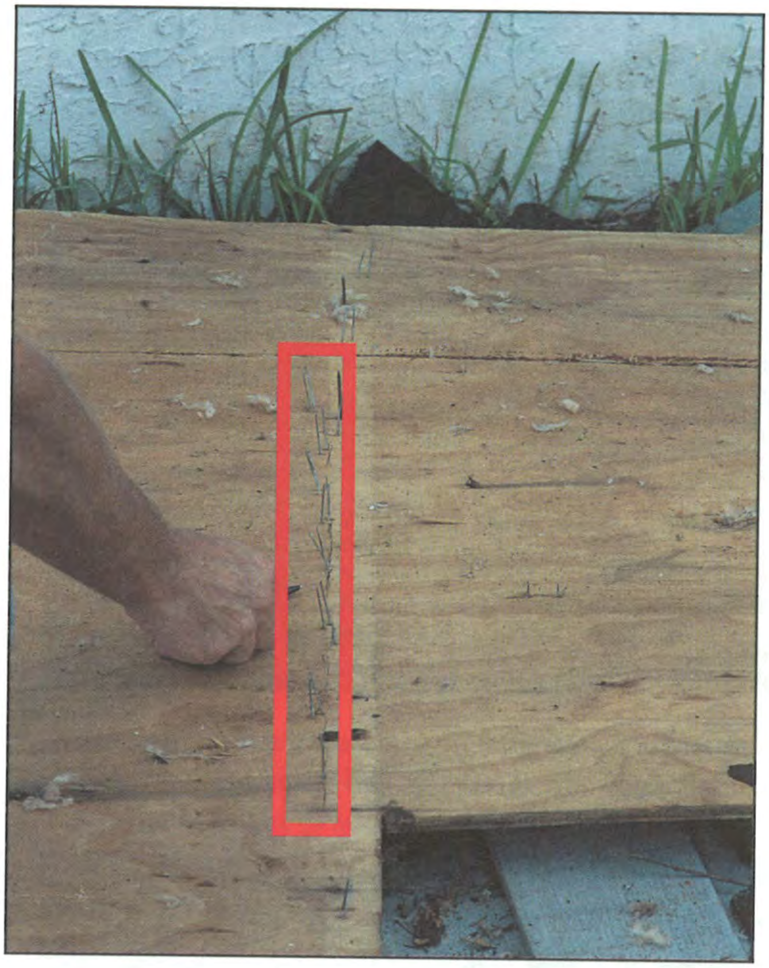


FIGURE 11.
Roof sheathing found in debris. Staples were off-line and therefore not connected to supporting truss top chord.

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.)

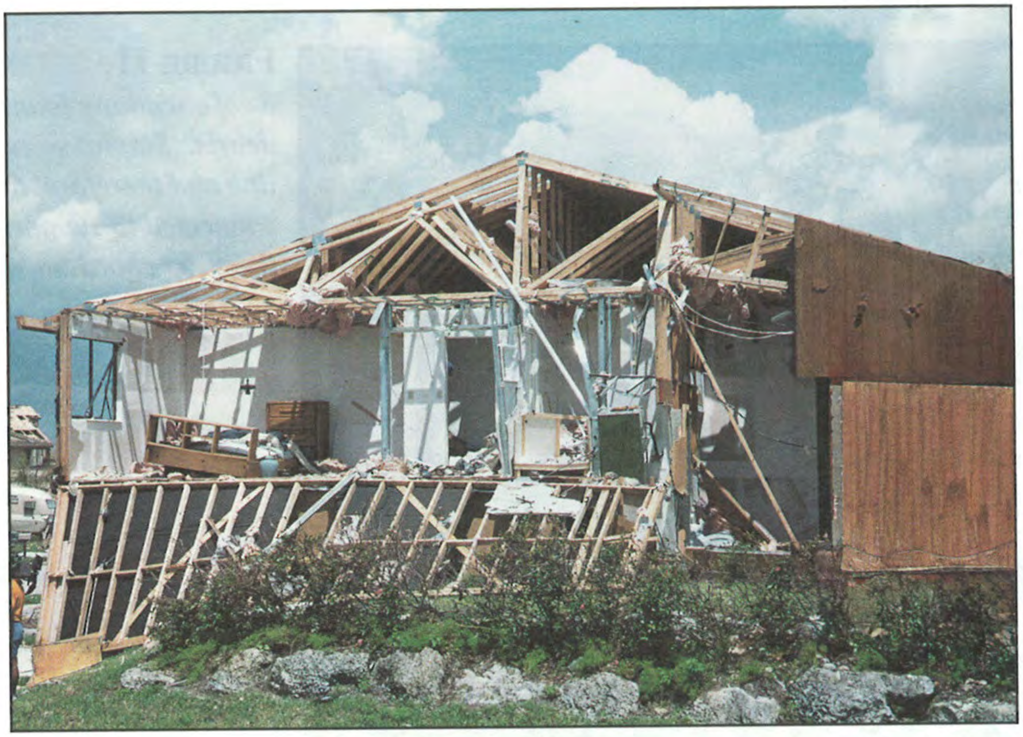


FIGURE 12. *End wall failure of typical first floor masonry/second floor wood-frame building. Truss bridging and lateral bracing, and adequately installed roof sheathing, would have greatly reduced the likelihood of such a failure.*

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.*

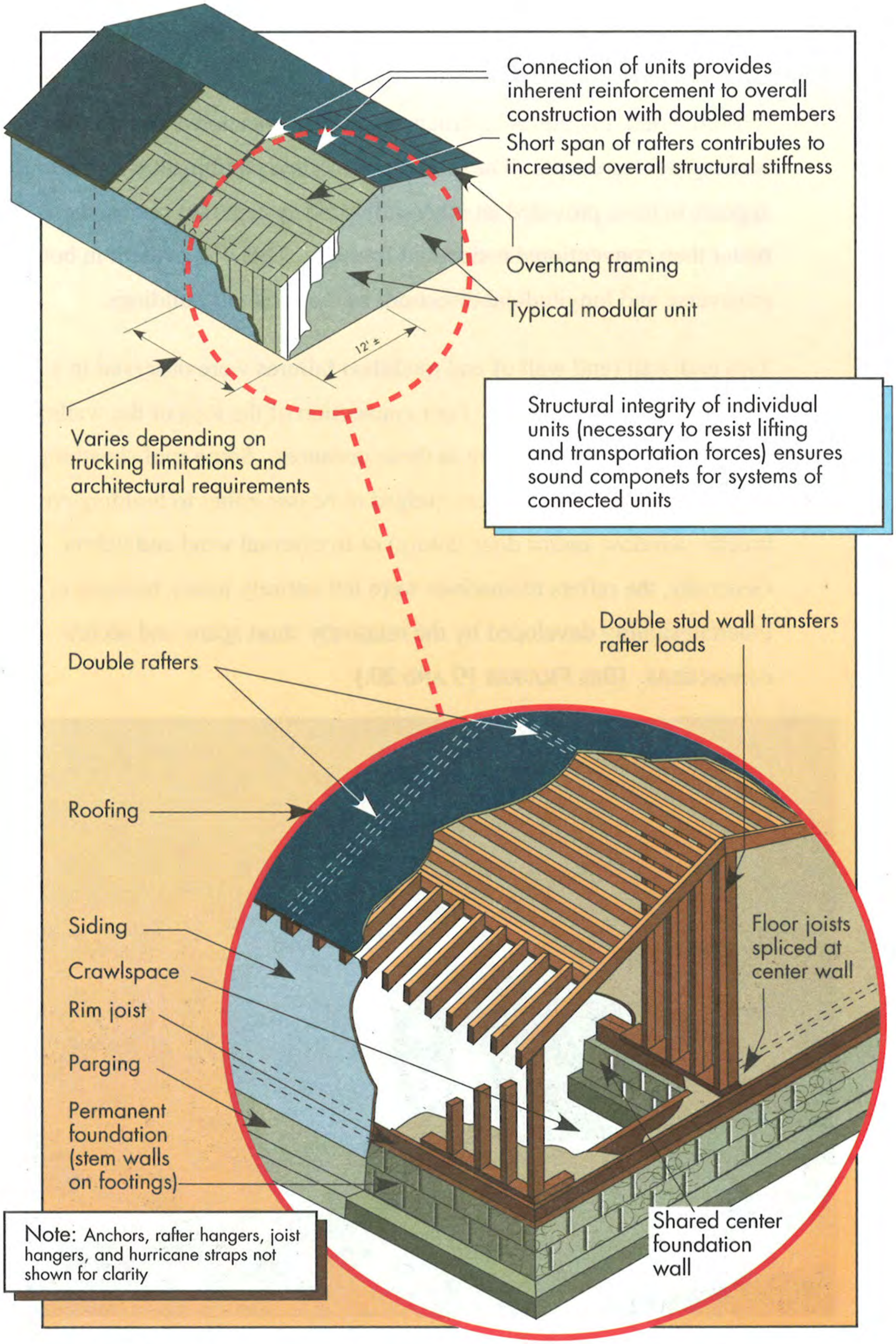


FIGURE 20. *Inherent structural strength of modular construction.*

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.

3.0 RECOMMENDATIONS

The basis for performing this survey is the premise that better performance of building systems can be expected when causes of observed failures are corrected using recognized standards of design and construction. Attention should be paid to the correct design and construction of horizontal and vertical load transfer systems to resist future building failure. The recommendations presented in this report may have application to other communities in Florida.

The field observations indicate the existence of systematic deficiencies in the construction practices that were employed in the observed areas. This was true irrespective of the obvious severe wind conditions brought about by Hurricane Andrew.

3.1 GENERAL RECOMMENDATIONS

The following recommendations are based on the findings of the team and are made for the purpose of promoting general improvements to the Dade County construction process.

1. Quality of construction workmanship should be improved.

— An increased knowledge of proper construction techniques and the consequences of high-wind and flood loads should be provided through the development of an adequate program of training and continuous education for construction tradespeople, supervisors, and inspectors. This could be accomplished through a State or local government certification, registration, and licensing requirement which includes specific continuing education requirements.

— A multifaceted certification program for inspectors and supervisors that focuses on specific areas of design and construction should be developed.

For example, inspectors performing framing inspections should be trained and certified in that particular area and method of construction.

2. The South Florida Building Code, Dade County version, should be expanded to include prescriptive design elements for lateral load transfer and should include illustrations and details as needed.

3. Proper guidance concerning the correct method of transferring loads must be provided to building contractors.

— Permit drawings for construction should include a narrative that explains a building system's transfer of lateral loads. An explicit depiction in the form of construction details may be necessary.

— Permit drawings should be submitted with a completed load transfer path plan-checklist that is specific to the building type being designed.

4. A licensed design professional should have increased participation in the inspection of construction.

5. Inspector supervision should be increased or improved, especially in developments where large tracts of homes of repetitive design occur.

6. Enhancement and maintenance of the Dade County GIS should be encouraged. The information contained within the databases the Department of Building and Zoning contributes to this system can be of value in improving the implementation of the Code. Employment of this technology will strengthen disaster mitigation efforts applied to the Dade County land development process. One example would be the substantial damage provisions contained in the NFIP regulations.

3.2 Specific Recommendations

The following recommendations apply to individual types of buildings and building components. Engineering drawings and photographs are provided where appropriate to support or illustrate the recommendations.

Roof Cladding and Roof Framing Systems

1. In addition to the existing program of systematic framing inspections, a specific roof bracing and sheathing inspection should be required prior to installation of roof underlayment (see Figures 26-29). Note the extra bracing recommended for gable ends in particular.

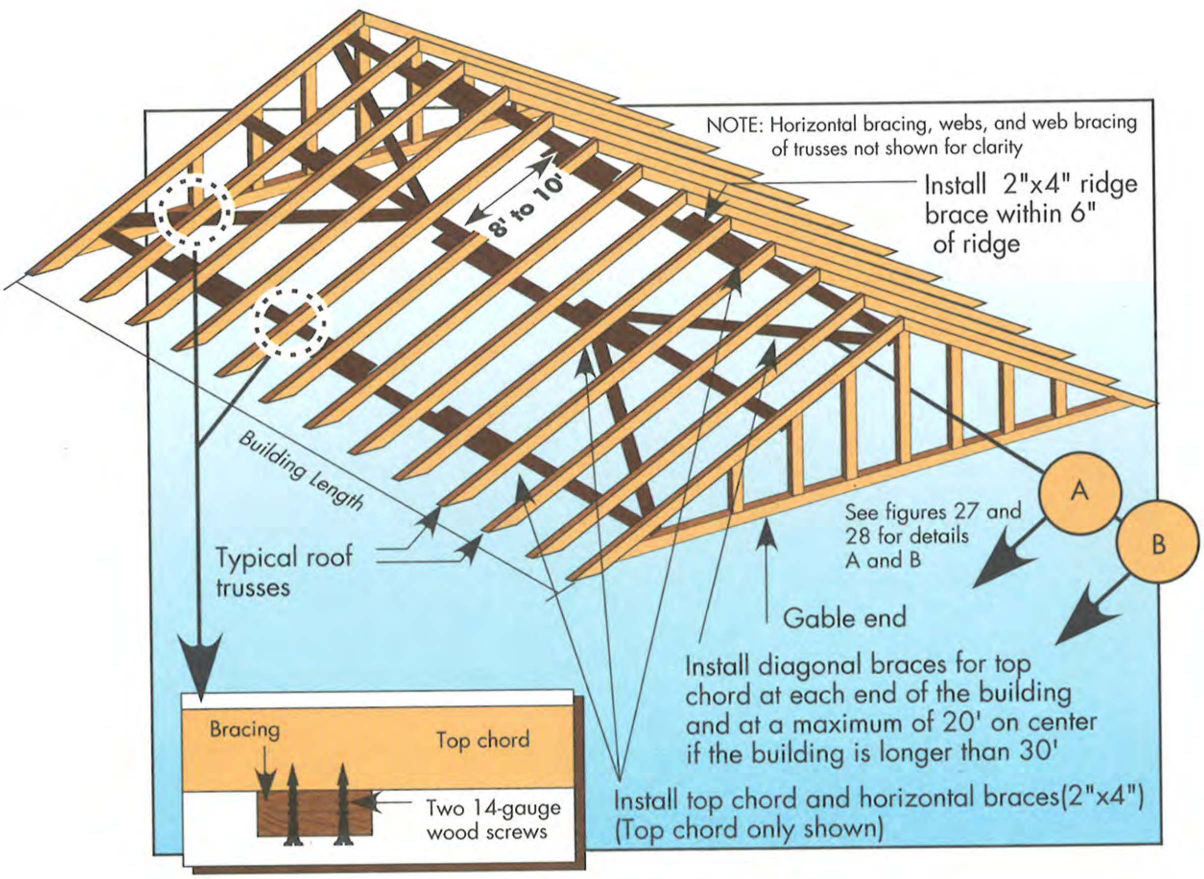


Figure 26. *Typical roof truss top chord bracing.*

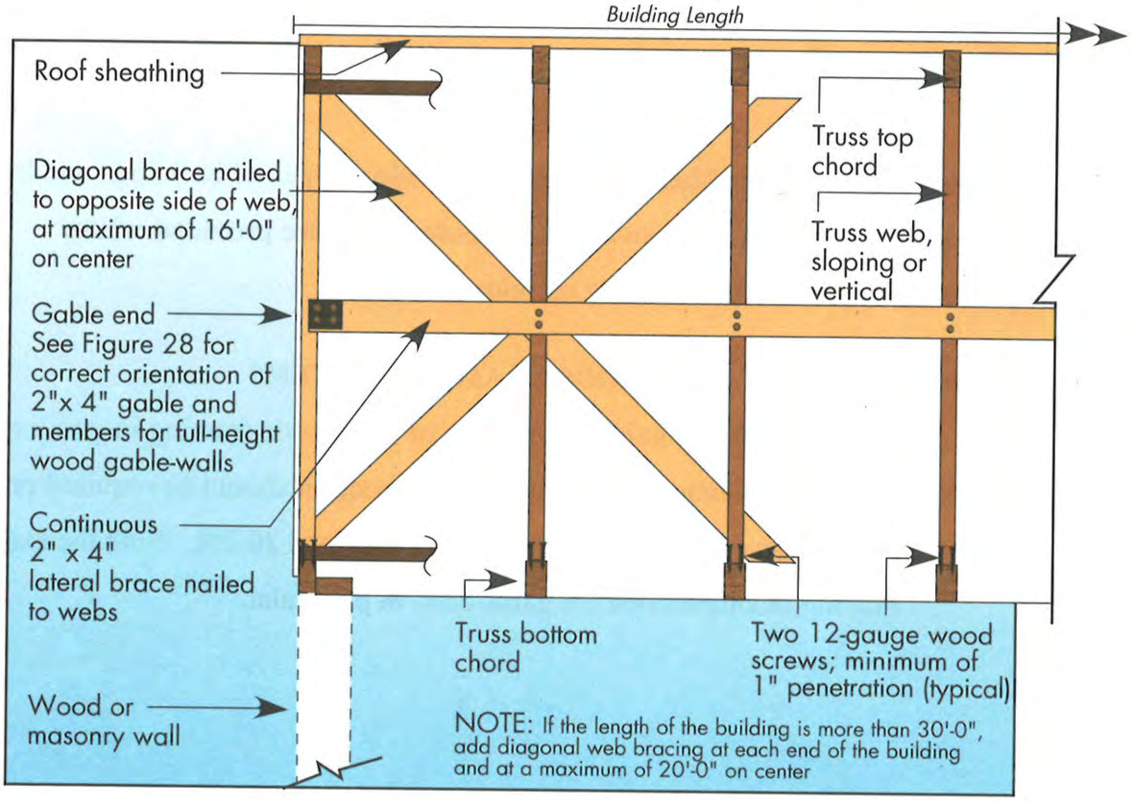
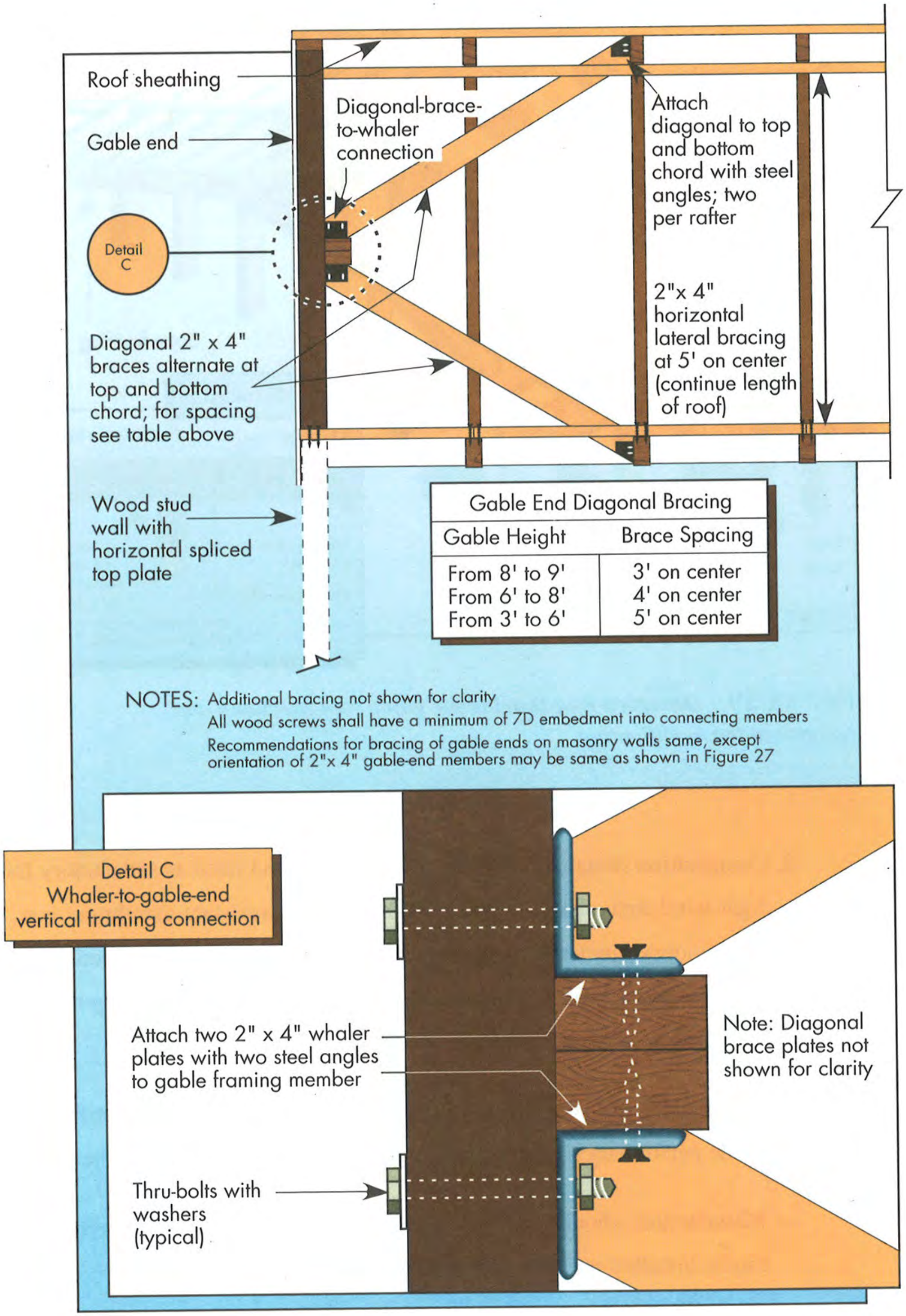


FIGURE 27. *Detail A — Typical truss web bracing. Diagonal web bracing as shown, at each gable end of building.*



Gable End Diagonal Bracing

Gable Height	Brace Spacing
From 8' to 9'	3' on center
From 6' to 8'	4' on center
From 3' to 6'	5' on center

NOTES: Additional bracing not shown for clarity
All wood screws shall have a minimum of 7D embedment into connecting members
Recommendations for bracing of gable ends on masonry walls same, except orientation of 2"x 4" gable-end members may be same as shown in Figure 27

FIGURE 28. *Detail B — Typical wood gable-wall bracing.*

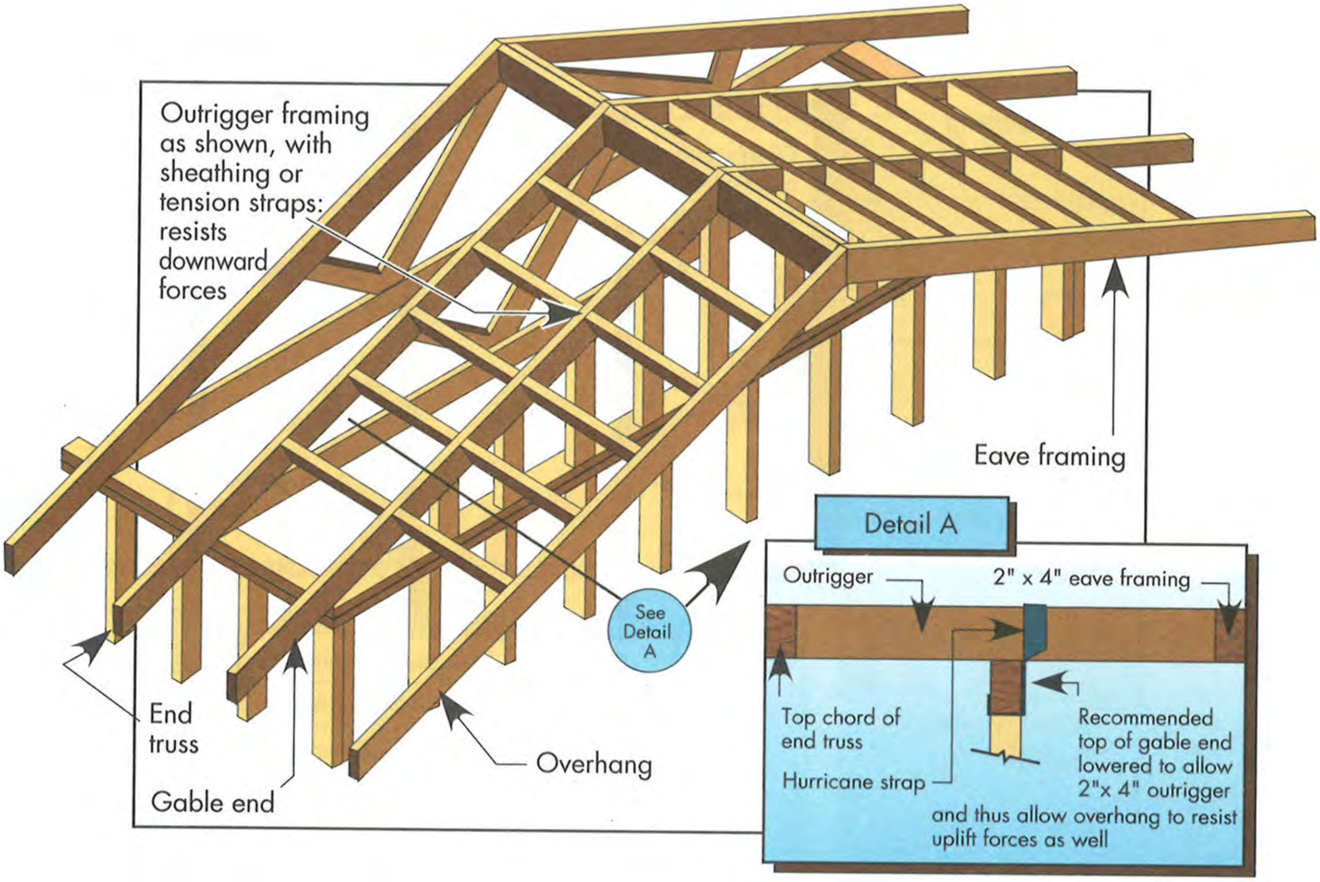


FIGURE 29. *Observed roof bracing for gable roof overhang and recommended modification.*

2. Composition shingles should be manufactured and rated as satisfactory for high-wind areas. In the absence of this, a water-resistant membrane, e.g., a hot-mopped underlayment, should be installed to provide protection from the water infiltration that may result from the loss of roofing material during high-wind storms (SEE FIGURES 30 AND 31).

3. Manufacturers of roof tile products should provide testing and verification of tile performances under realistic conditions (as addressed by the Code).

— Manufactures should verify that mortar used with extruded concrete tiles can be installed to Code requirements.

FIGURE 30. *Composition shingle and underlayment failure.*

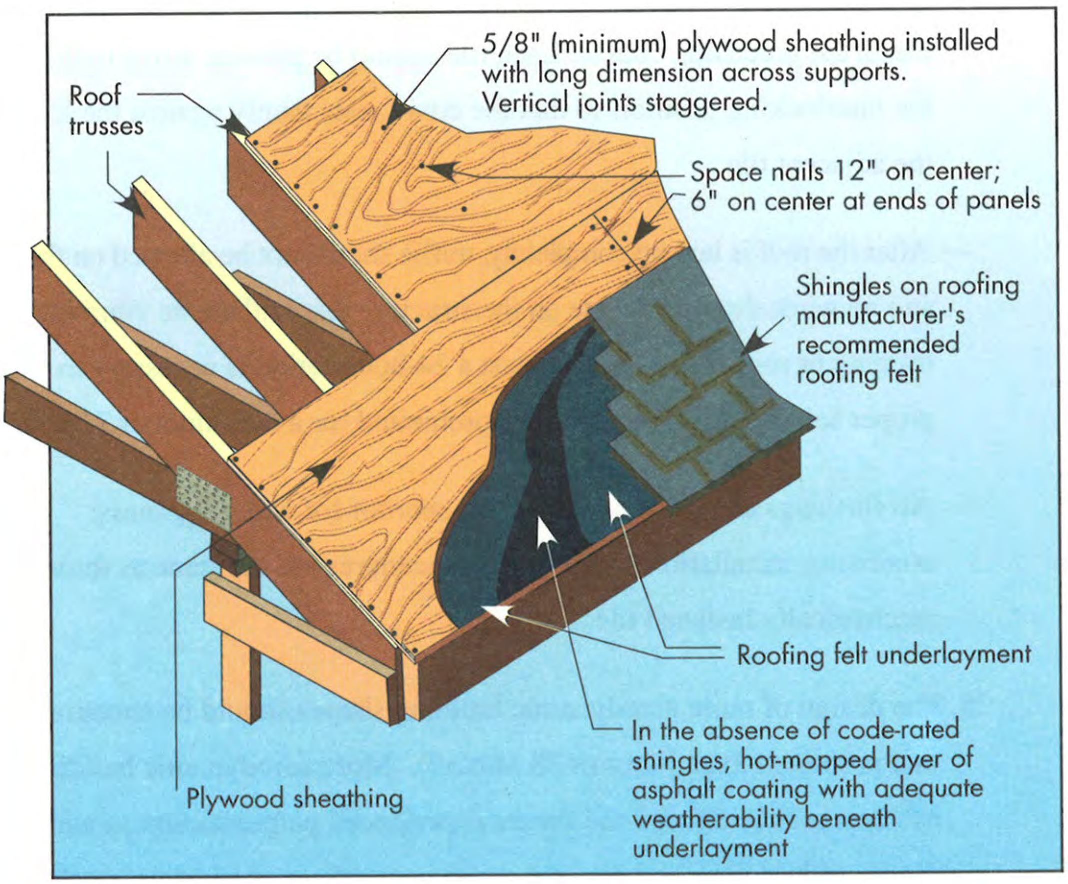


FIGURE 31. *Composition shingle roofing system showing sheathing and hot-mopped underlayment.*

4. Quality control of roof tile installation should be improved by ensuring both consistent mortar pad placements and installation in accordance with manufacturers' requirements, as specified by the Code. (SEE FIGURES 32-37). Though this would improve the survivability of roof tile systems, continued debris impact will result in damage occurring from future wind storms.

— The roof should be marked off vertically and horizontally. Interlocking lugged or unlugged tile should be laid with minimum headlaps in accordance with manufacturers' recommendations (2 1/2 – 3 1/2 inches minimum).

— Prefabricated eave closure strips should be used to elevate the butt end of the first, or eave, tile to attain the proper slope.

— A full 10-inch mason's trowel of mortar should be placed under each tile (under the pan section of "S" or barrel tiles), beginning at the head of the tile in the preceding course. Each tile should be pressed down tightly in the interlocking position so that the cover rests firmly against the lock of the adjacent tile.

— After the roof is laid up completely, traffic should not be allowed on the roof, and no work should be done on the structure that will create vibration in the framing or roof sheathing. At least a 24-hour period is necessary to ensure proper set. Roof traffic should be prohibited for a minimum of 72 hours.

— All flashings should be sealed to the subroof for water tightness; otherwise, installation and flashing procedures are the same as those for mechanically fastened tile.

5. The design of more aerodynamic building shapes should be encouraged and promoted (SEE FIGURES 38 AND 39). More aerodynamic building systems reduce direct wind forces experienced perpendicular to windward planes of buildings and also the consequent effect of whirling air flows, called vortices, that accumulate at the corners and edges of the planes. The

FIGURE 32. *Failure of extruded concrete flat tile roofing. Bond failure between tile and mortar and between mortar and underlayment was observed.*

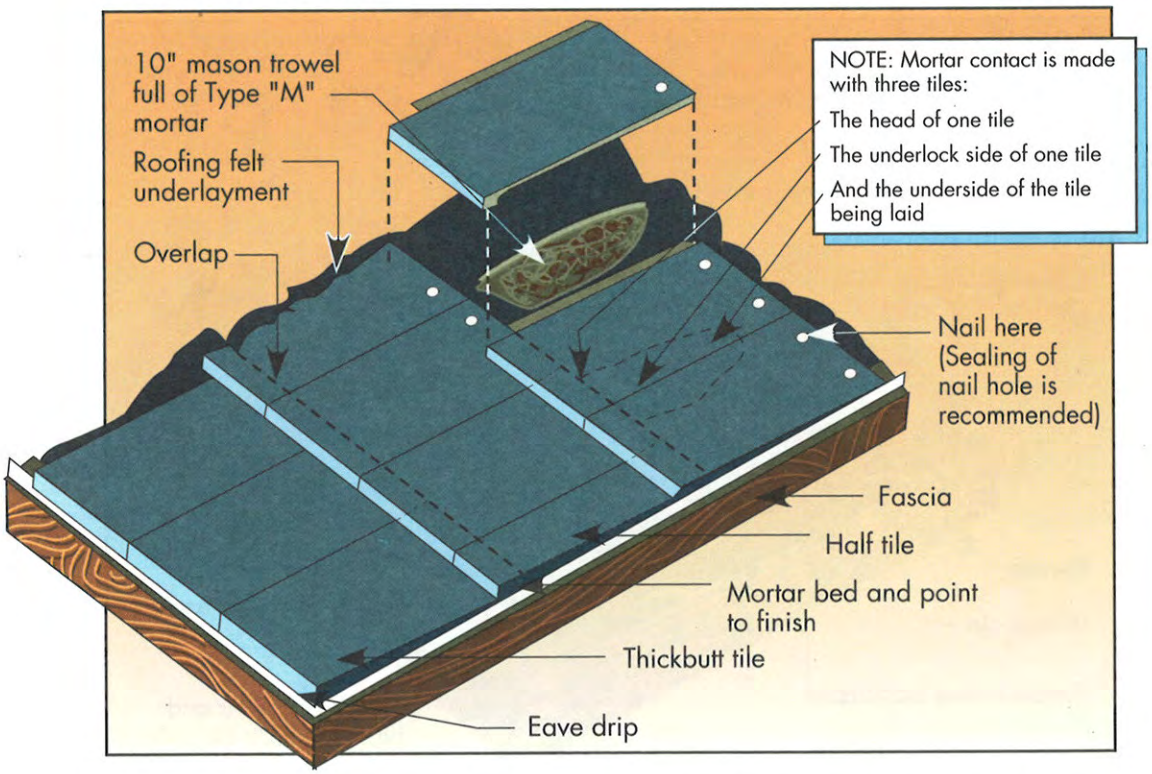


FIGURE 33. *Recommended tile and mortar placement for extruded concrete flat tile roofing system.*

FIGURE 34. *Failure of "S" tile roofing. Bond failure between mortar and tile was observed.*

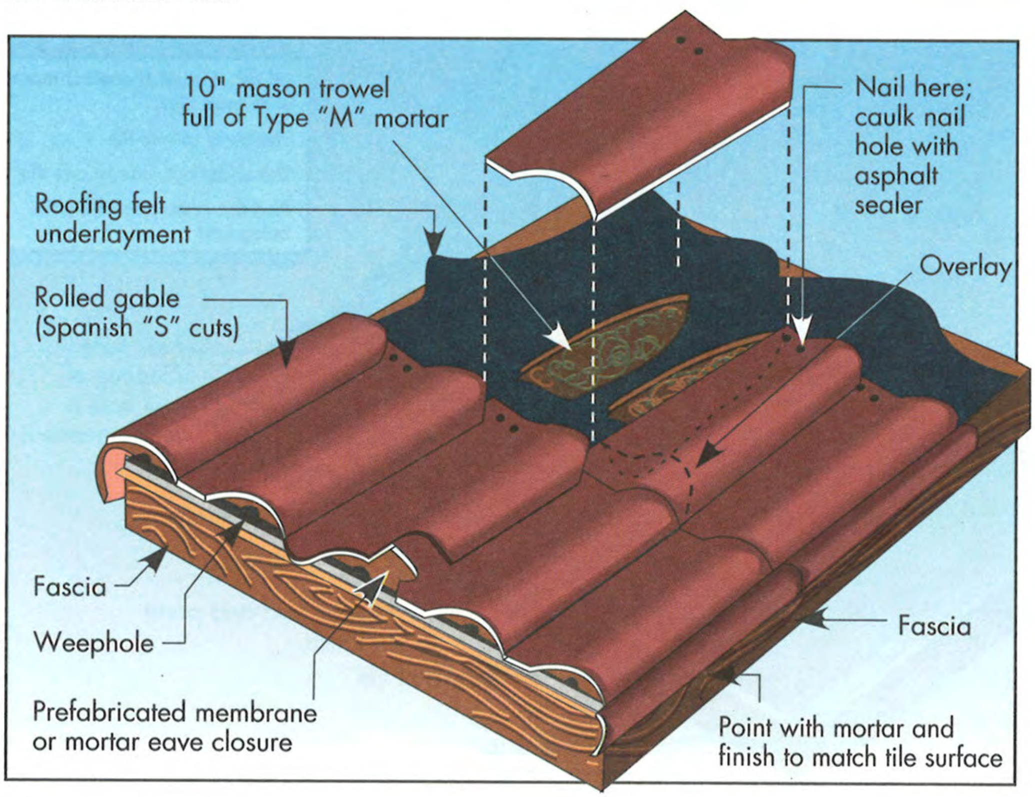


FIGURE 35. *Recommended tile and mortar placement for "S" tile roofing system.*

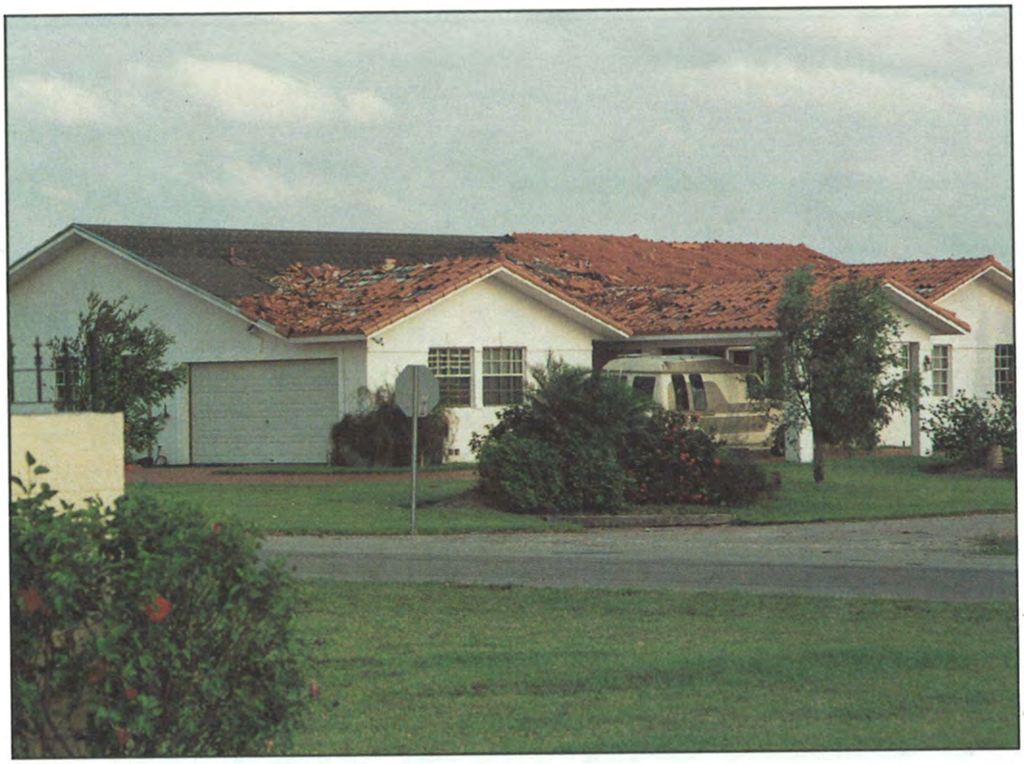


FIGURE 36. *Failure of barrel tile roofing. Bond failure between underlayment and mortar and between mortar and tile was observed.*

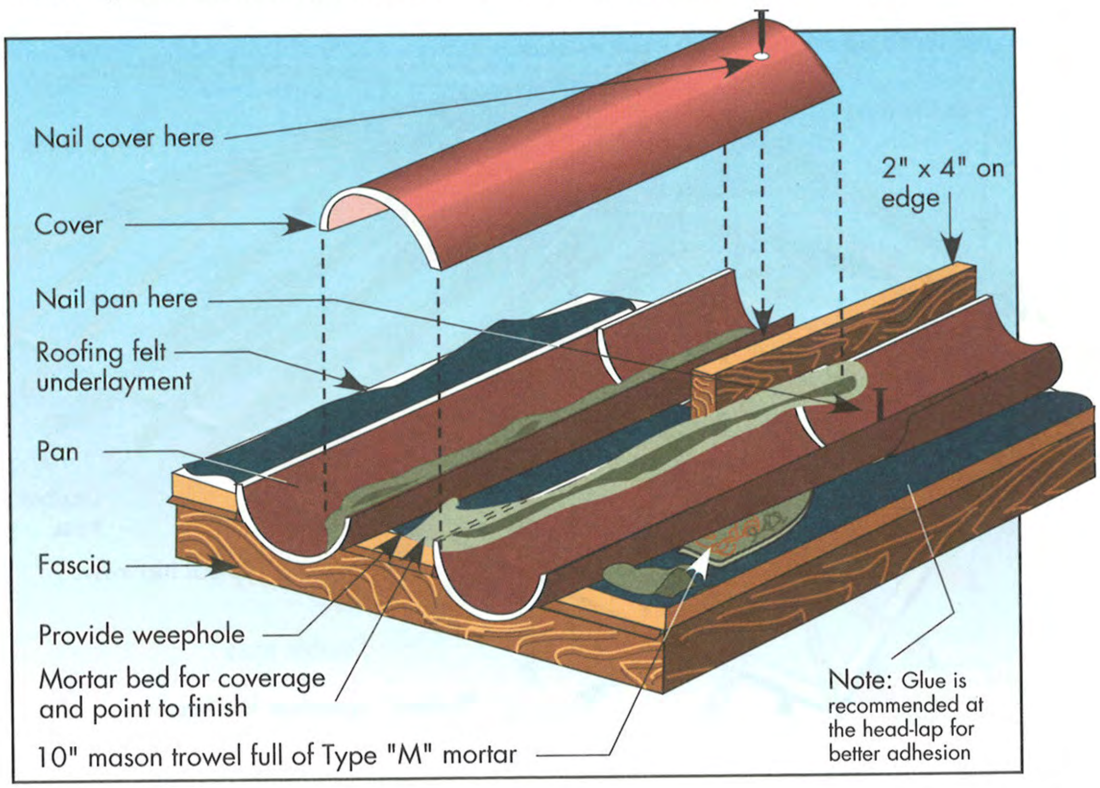


FIGURE 37. *Recommended tile and mortar placement for barrel tile roofing system.*

FIGURE 38. *Hip roof.*

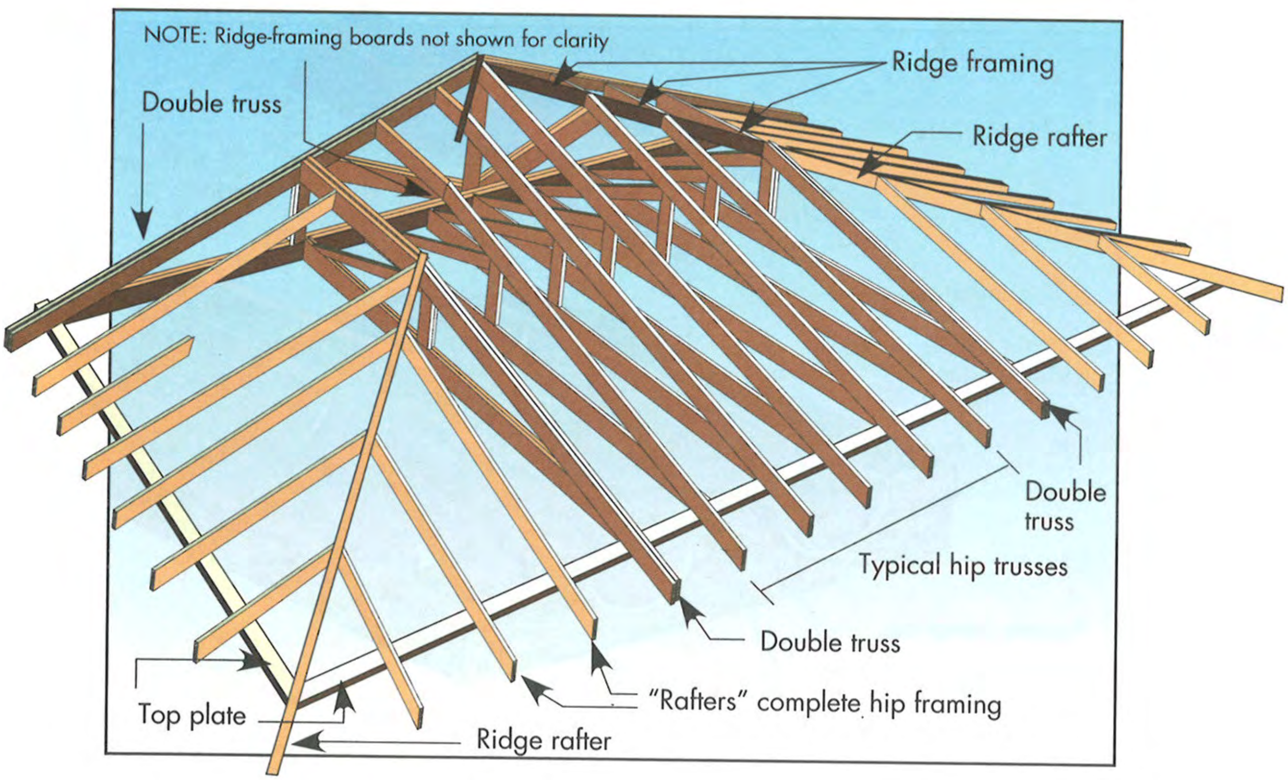


FIGURE 39. *Recommended hip roof framing.*

accumulation of both the direct and negative pressures resulting from these wind flows is particularly prevalent in the more abrupt or orthogonal planes of gabled roof systems.

6. The use of braced truss roof systems that will sufficiently resist lateral forces independent of roof sheathing should be required. Roofing systems could be considerably improved if simple secondary bracing or blocking were to be applied within the truss network (thus relieving the roof's reliance on diaphragm sheathing action alone) (SEE FIGURES 26-29).

7. Substituting hip roofs for gable ends is a particularly advantageous solution and should be encouraged. The construction of a hip roof results in an inherently braced roof system (SEE FIGURE 39).

8. Venting with adequate openings to relieve induced internal pressures on roof structures is recommended (SEE FIGURE 40). However, venting must be installed in such a manner that the entry of uncontrolled air flow is not allowed. Such uncontrolled air flow could result in a buildup of induced internal air pressure.

FIGURE 40. *Roof gable louvered venting and convertible awning/storm shutters.*

EXTERIOR WALL OPENINGS

A breach of a building's envelope (i.e., the system by which the building resists wind penetration) is particularly hazardous during wind storms. Not only does penetration of wind and rain cause damage to the interior contents of buildings, but additional direct internal wind pressures combine with suction pressures on exterior faces, causing partial or complete blowouts of major structural systems such as walls and roofs (SEE FIGURE 41). Double-car garage doors and entry doors especially should be held secure during wind storms.

1. The specifications for garage doors should be increased to meet a factor of safety of at least 2.5.

— Manufacturers' certificates should be required on all garage doors.

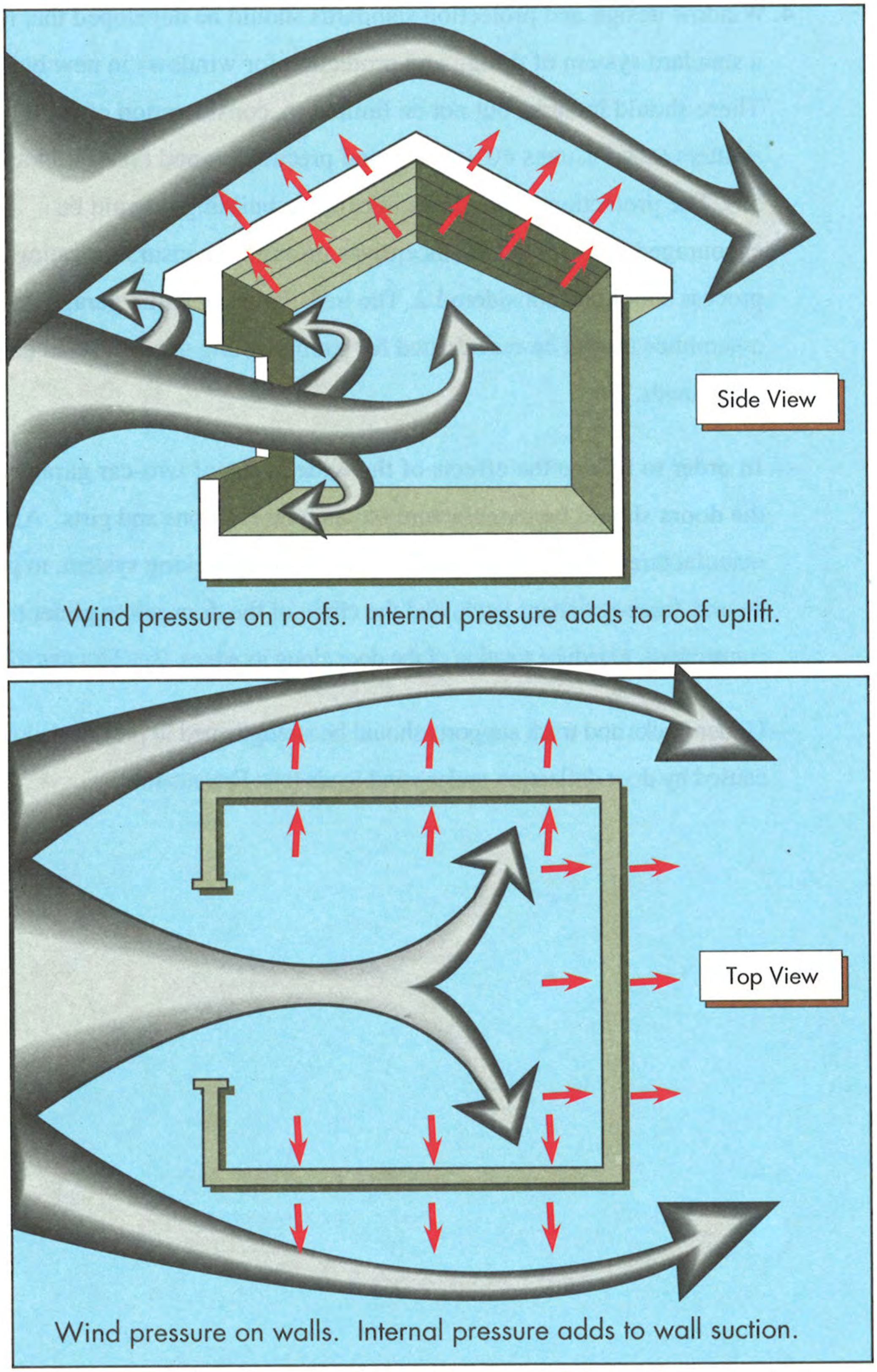


FIGURE 41. *Results of building envelope breach due to failure of external doors and windows.*

4. Window design and protection standards should be developed that require a standard system of design and protection for windows in new buildings. These should include, but not be limited to, consideration of using shutters (SEE FIGURES 40 AND 49) and precut plywood (SEE FIGURES 50-53). The protection of windows in existing buildings should be encouraged. Providing cost incentives through the insurance rating process should be considered.2. The installation of entire garage door assemblies should be reevaluated for strengthening to resist wind and flood loads.

— In order to reduce the effects of the wide spans of two-car garage doors, the doors should be manufactured to include mullions and girts. Also, manufacturers should reinforce both the security locking system, to provide a wind-force-resisitant latch, and the chain of the door pin to glider track connections, to reduce rotation of the door along its edges. (SEE FIGURES 42-45).

— Glider tracks and track supports should be strengthened to prevent failure caused by door deflection under wind loads (SEE FIGURE 46).

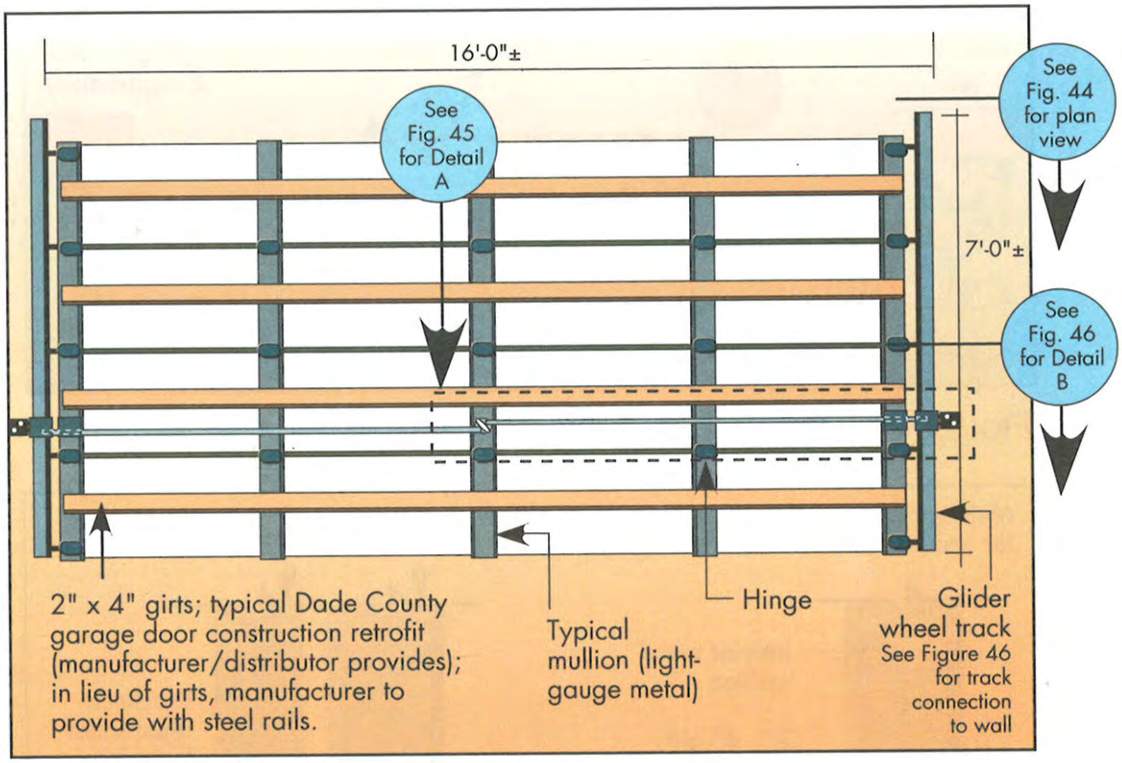


FIGURE 42. *Typical garage door elevation.*

FIGURE 43. *Example of garage door with 2"x 4" girts and metal mullions.*

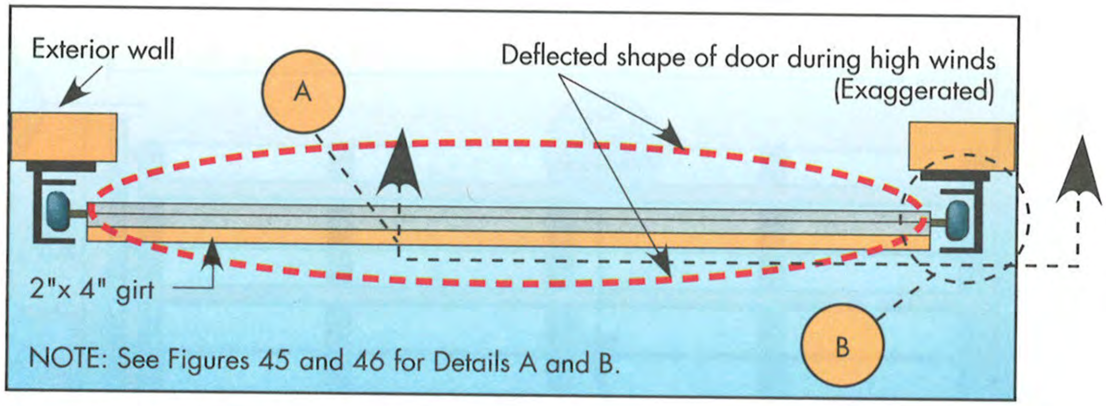


FIGURE 44. *Plan view of typical garage door.*

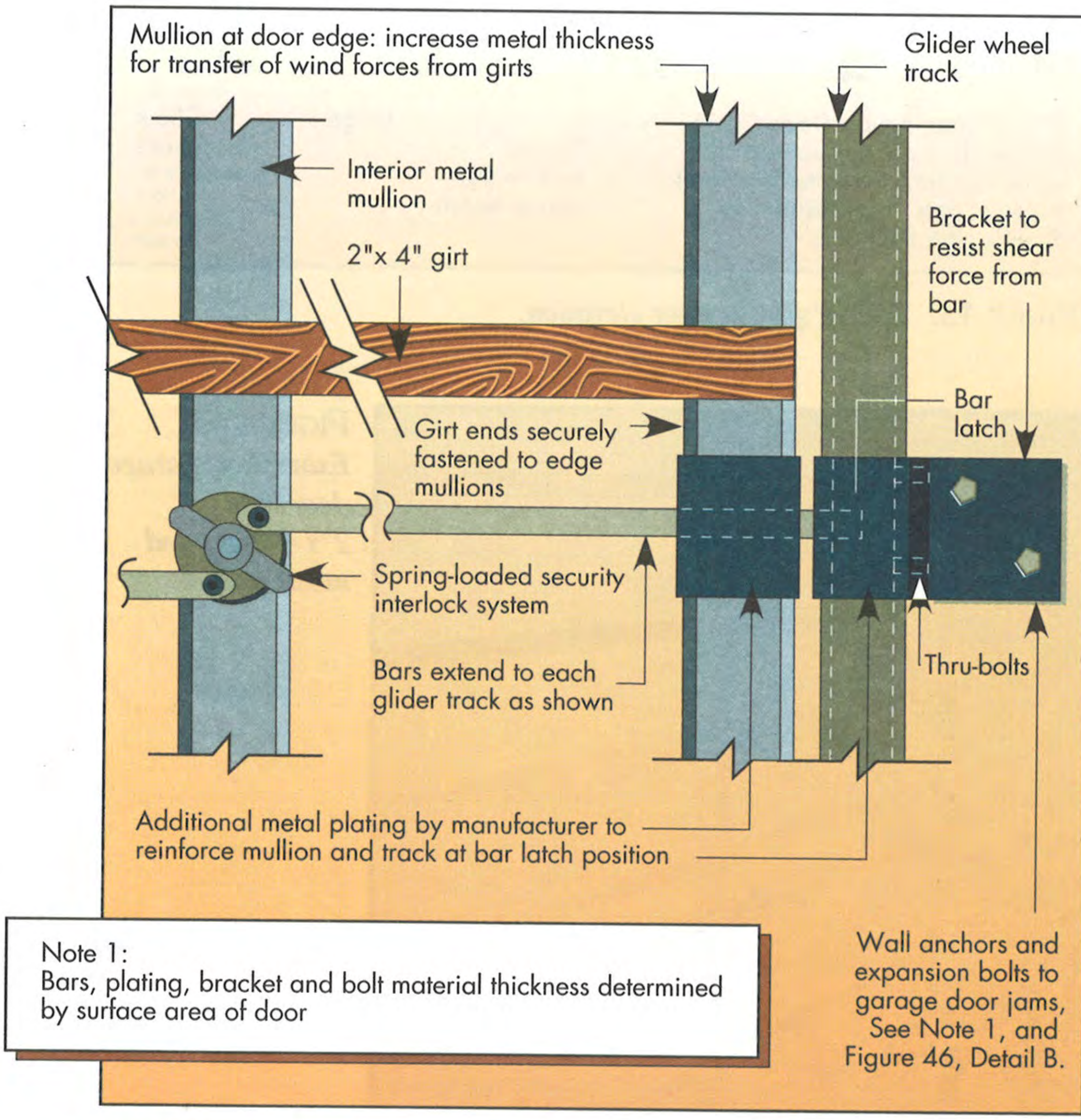


FIGURE 45. *Detail A — Recommended reinforced horizontal latch system for garage door.*

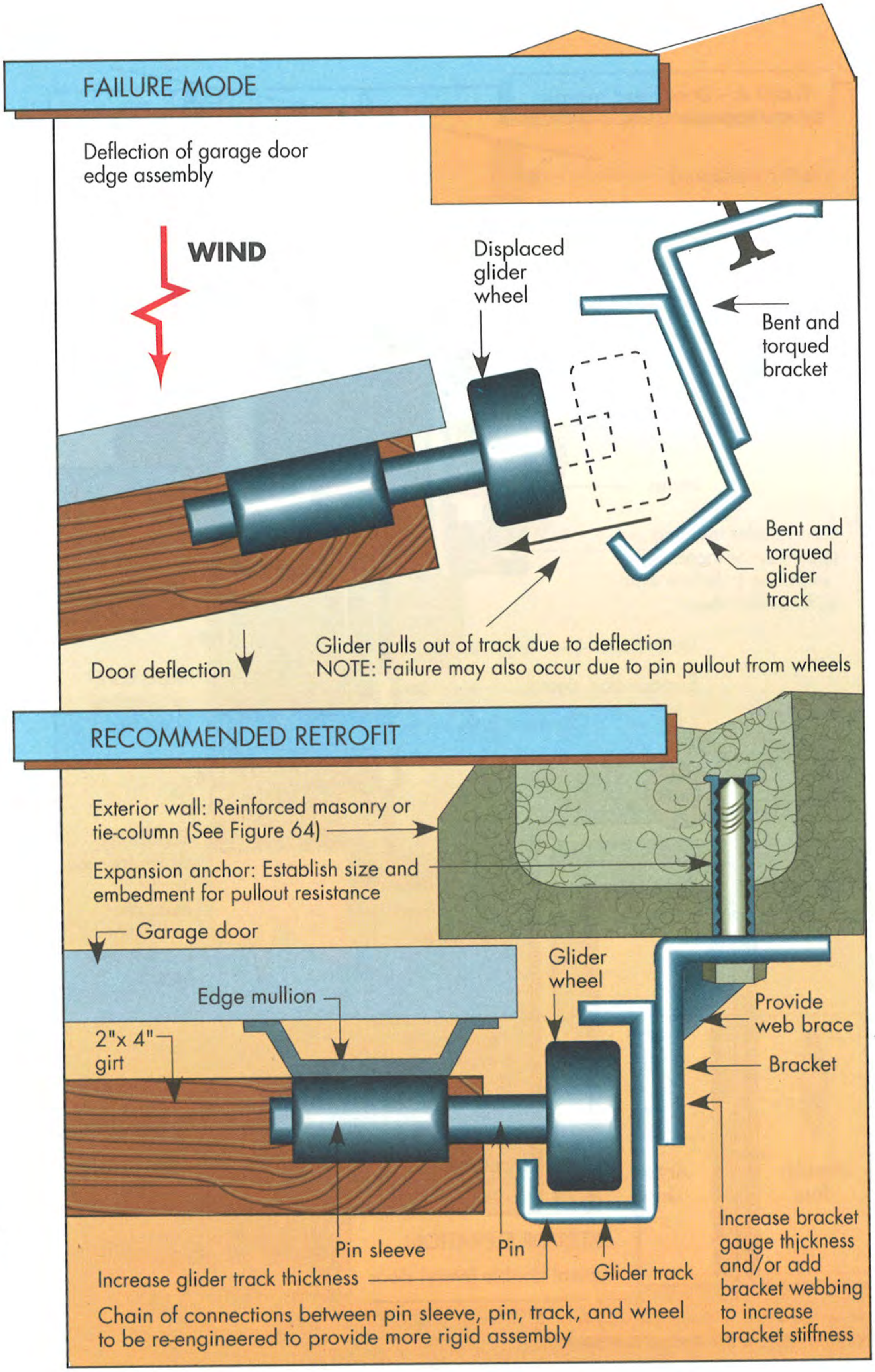


FIGURE 46. *Detail B — Garage door failure at edge and recommended assembly improvements.*

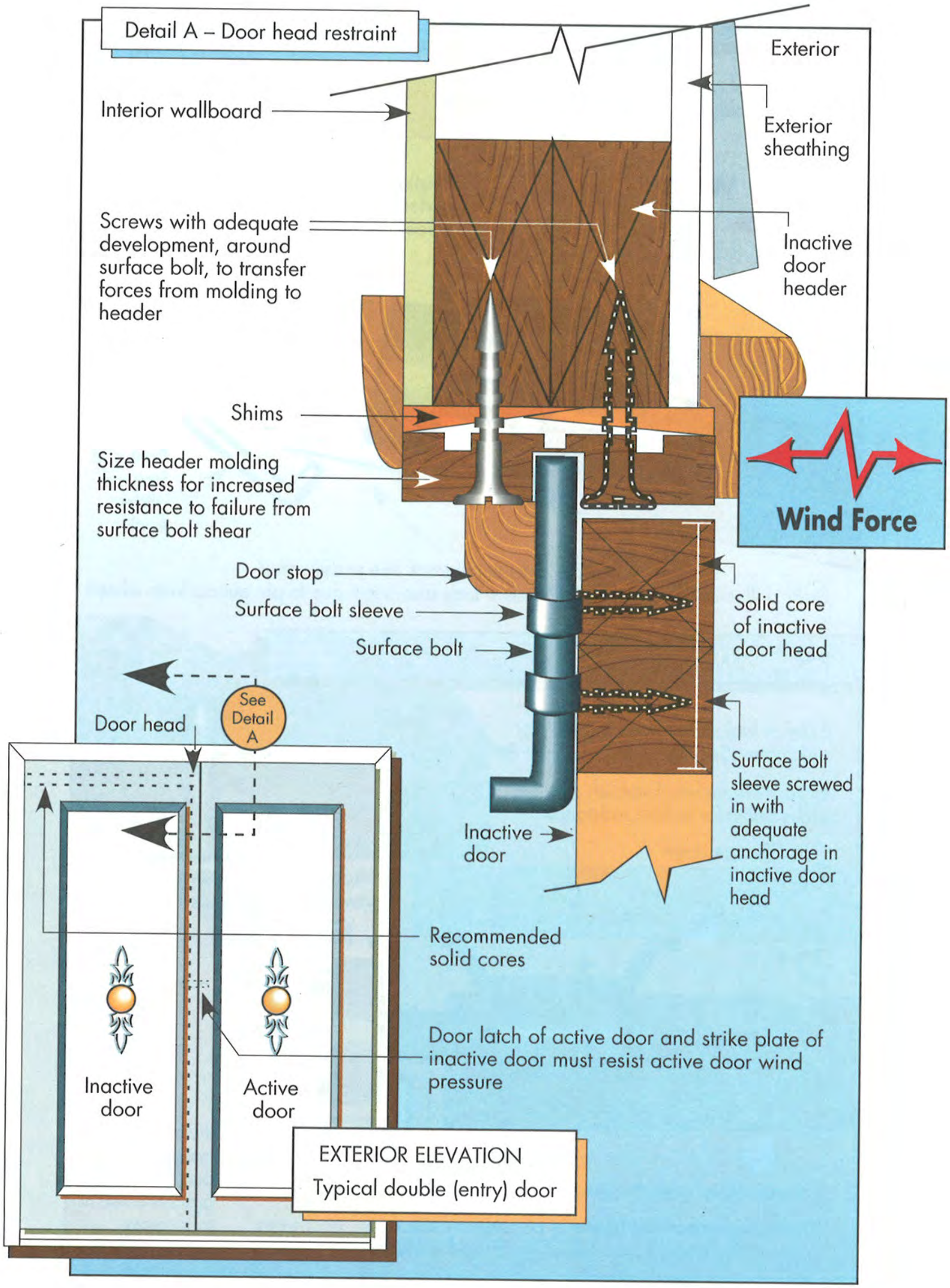


FIGURE 47. *Double entry door header recommendations.*

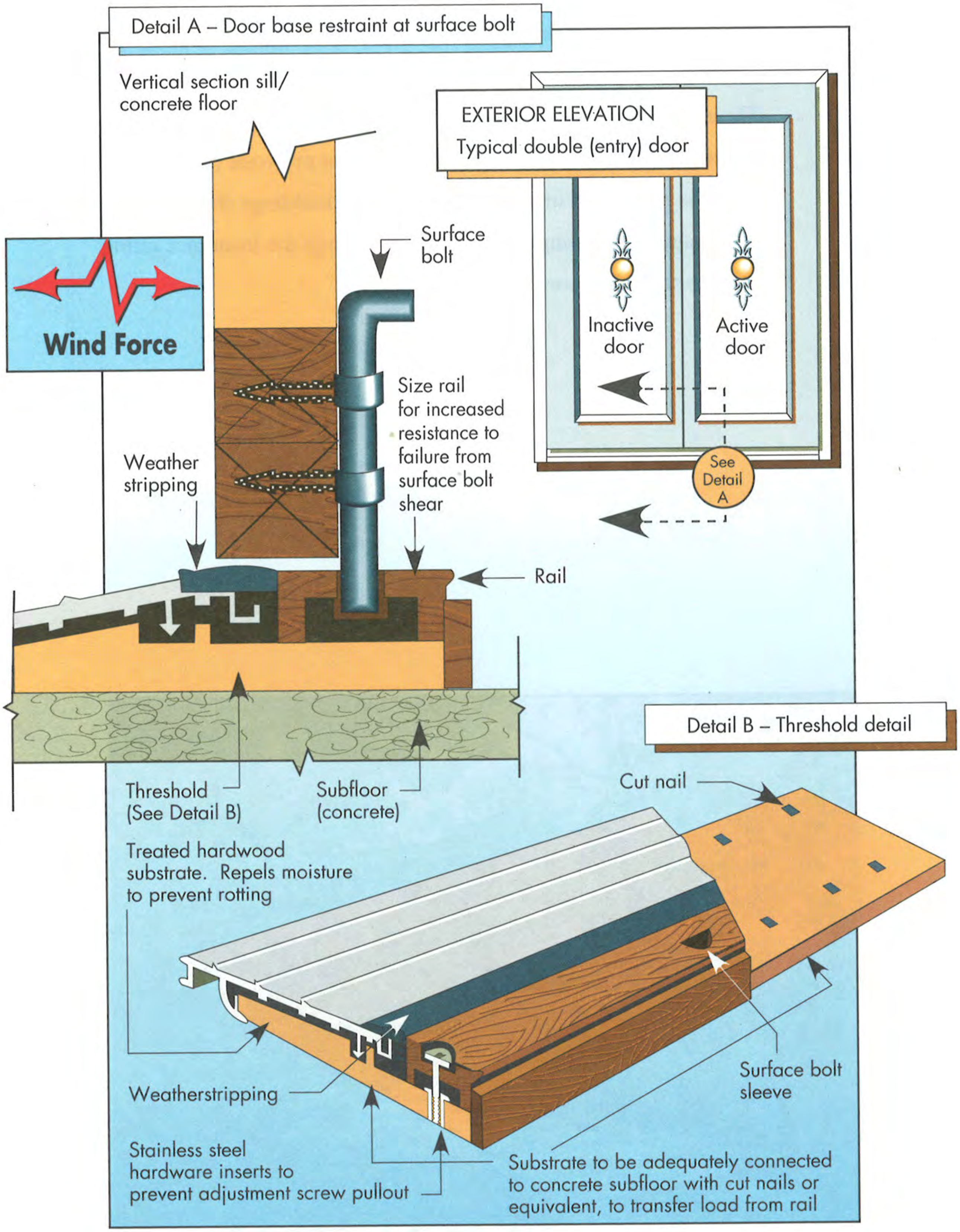


FIGURE 48. *Double entry door threshold recommendations.*

4. Window design and protection standards should be developed that require a standard system of design and protection for windows in new buildings. These should include, but not be limited to, consideration of using shutters (SEE FIGURES 40 AND 49) and precut plywood (SEE FIGURES 50-53). The protection of windows in existing buildings should be encouraged. Providing cost incentives through the insurance rating process should be considered.

FIGURE 49. *Prefabricated storm shutters.*

FIGURE 50. *Previously purchased plywood stored for use as openings protection during storm conditions.*

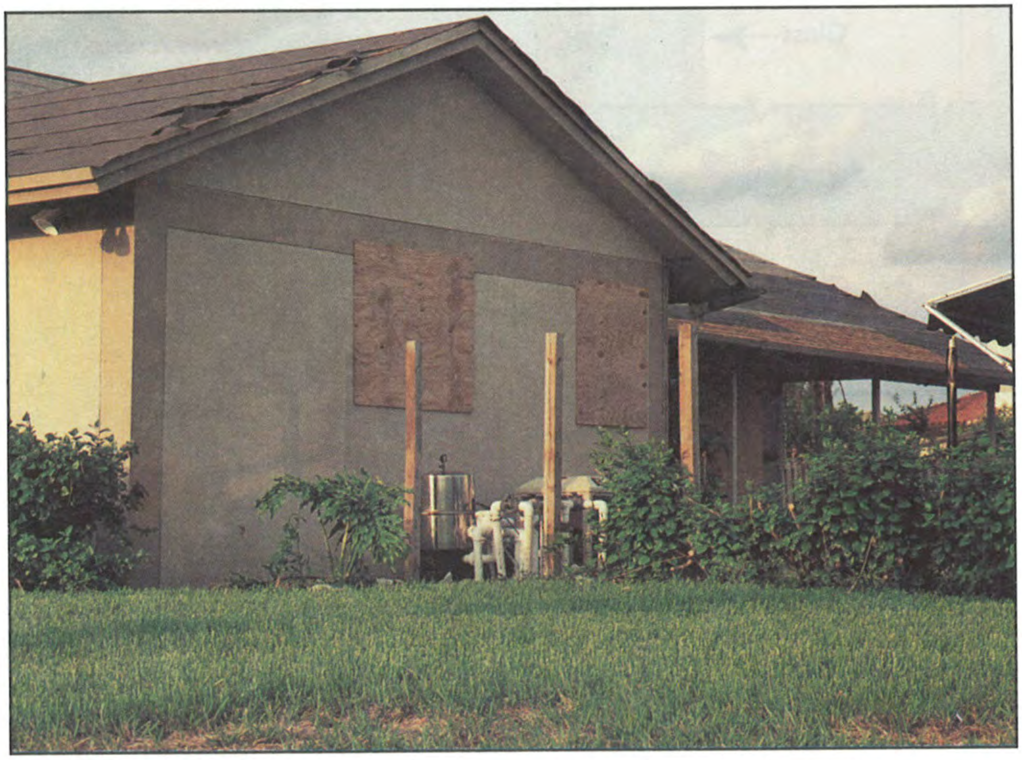


FIGURE 51. *Plywood used as openings protection installed. See Figures 52 and 53 for details.*

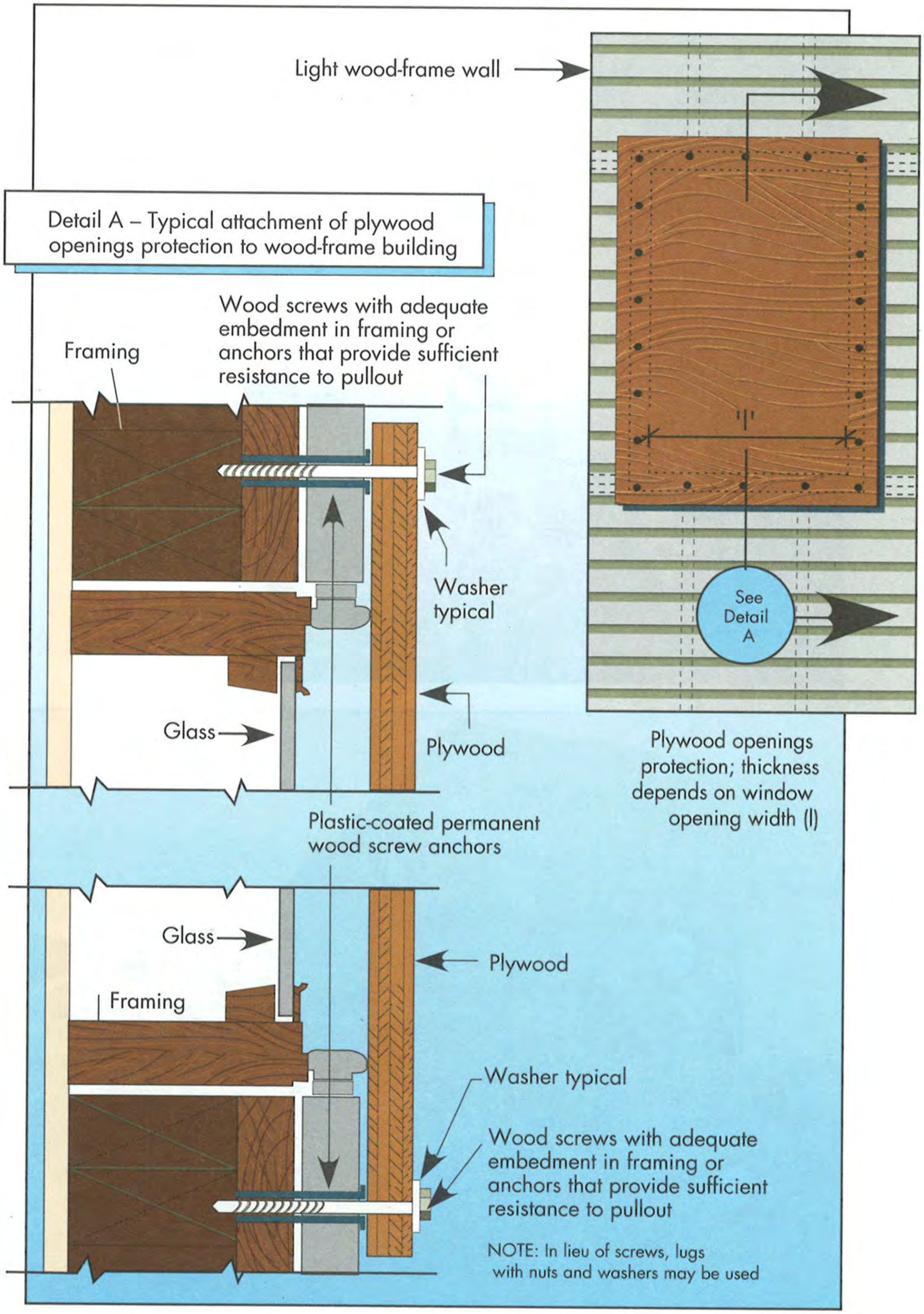


FIGURE 52. *Typical installation of plywood openings protection for wood-frame building.*

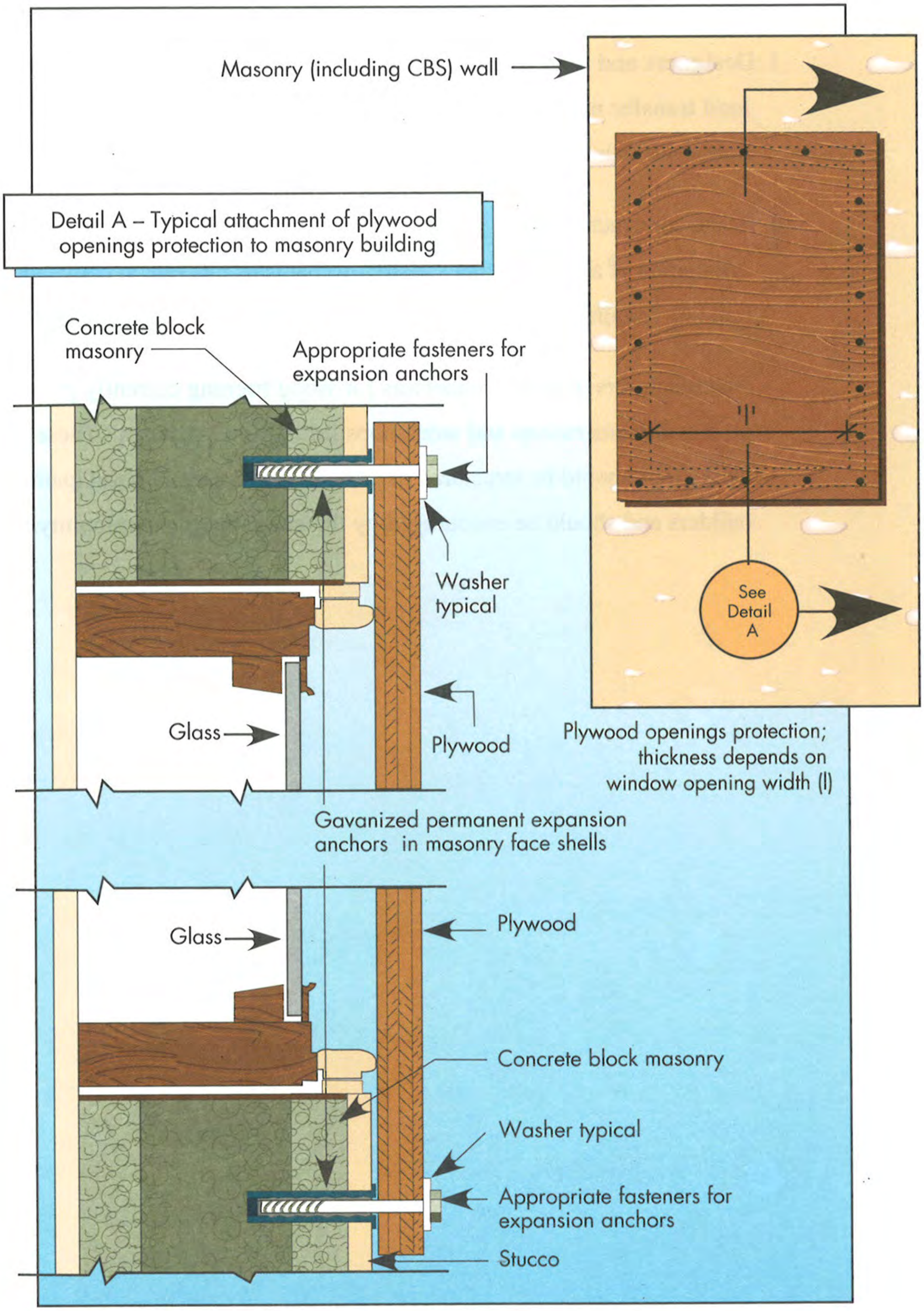


FIGURE 53. *Typical installation of plywood openings protection for masonry (including CBS) building.*

Light Wood-Frame Buildings

1. Designers and plan reviewers should pay greater attention to lateral load transfer mechanisms because of high lateral loads generated by hurricane winds (see Figures 9, 10, and 54-58).

2. At the construction stage, greater attention must be paid to the proper installation of all lateral load transfer mechanisms inherent in conventional building framing, especially hurricane straps and clips (see Figures 59-62).

— Manufacturers of metal connectors for wood framing currently provide on-site demonstrations and workshops for training purposes. These workshops should be structured to provide certificates of participation to builders and should be encouraged by the home-buying community.

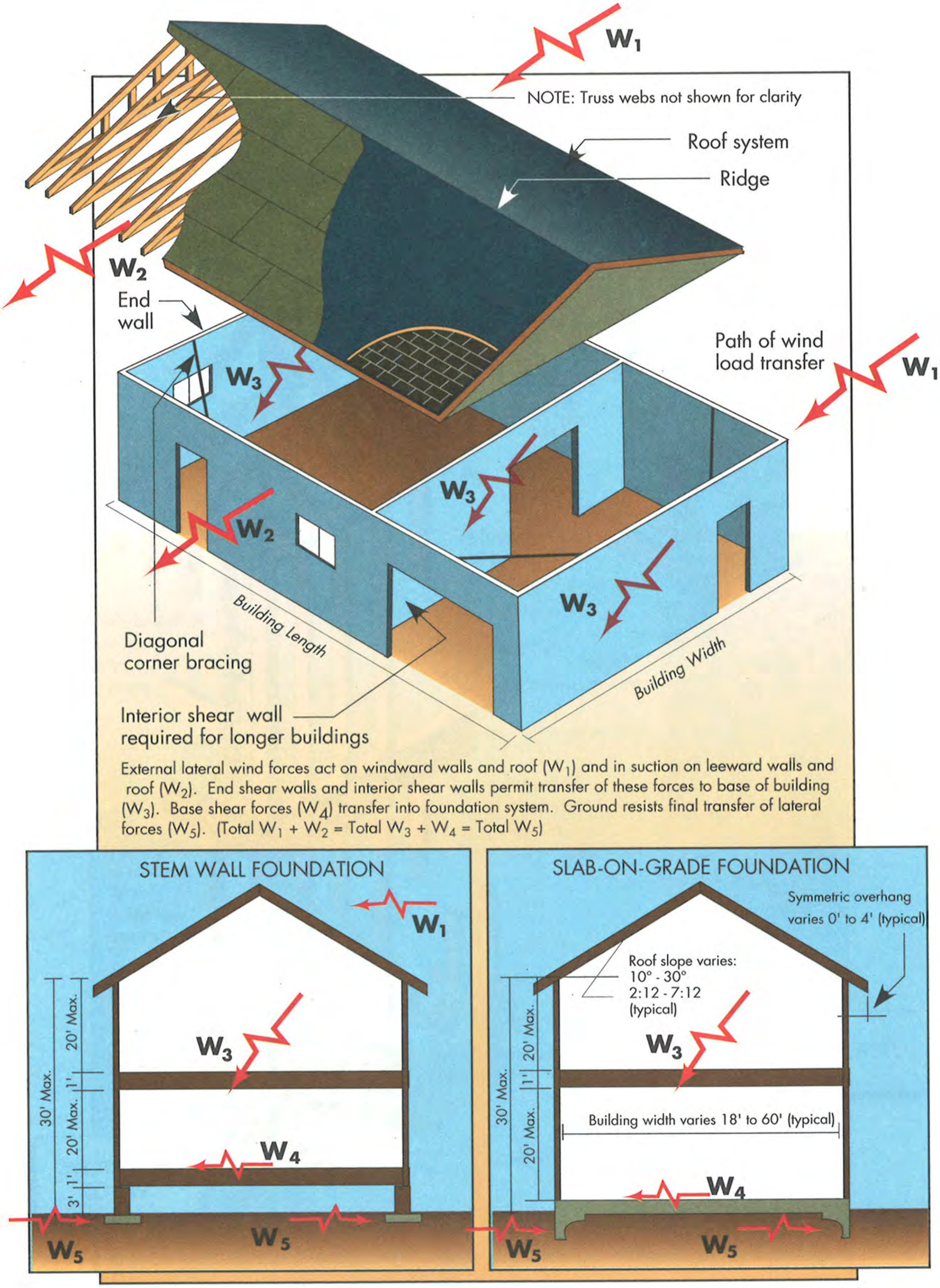


FIGURE 54. *Typical lateral load transfer for one- and two- story buildings.*

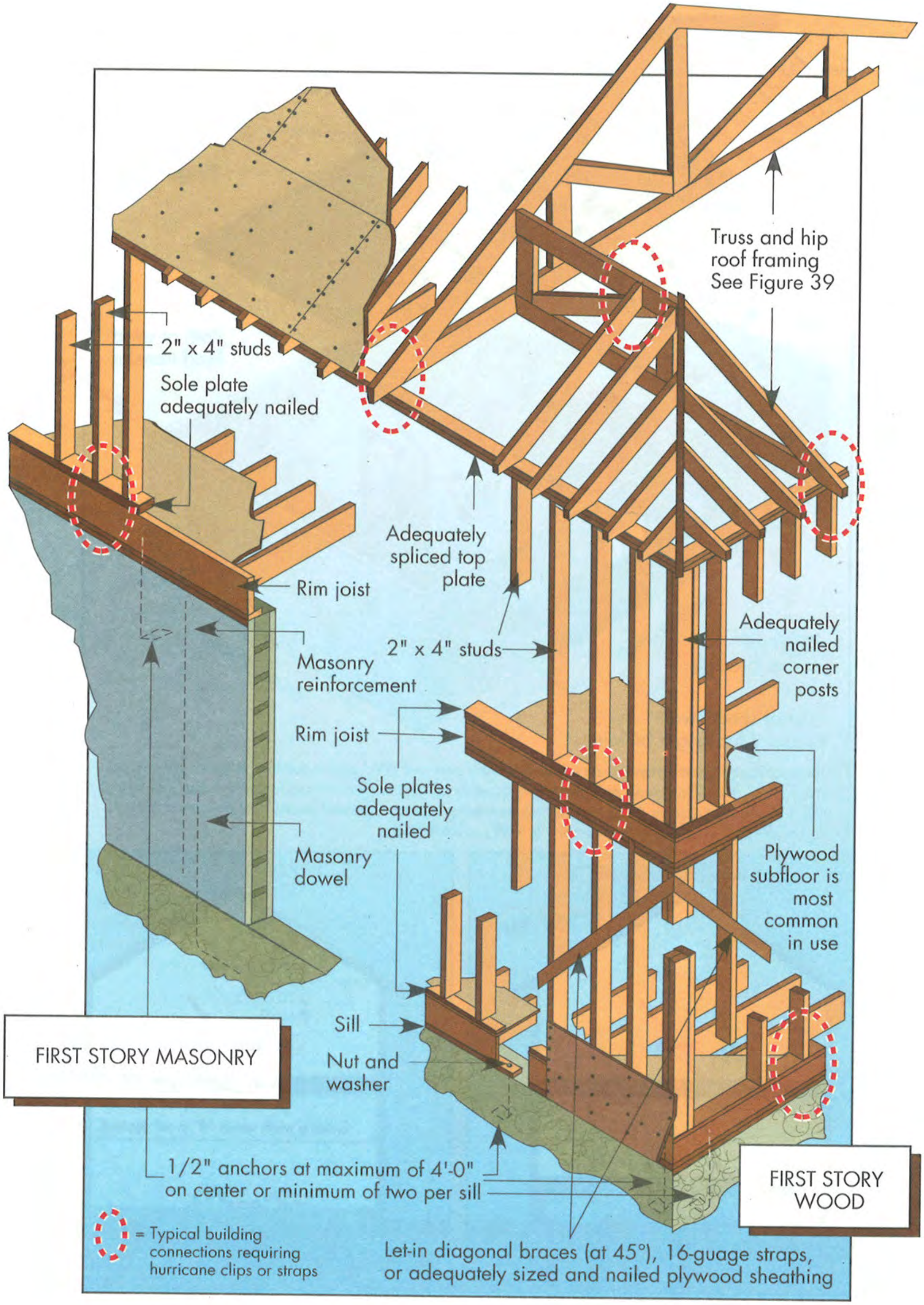


FIGURE 55. *Primary wood framing systems: walls, roof diaphragm, and floor diaphragm.*

FIGURE 56. *Properly placed hurricane straps from masonry tie-beams to roof trusses.*

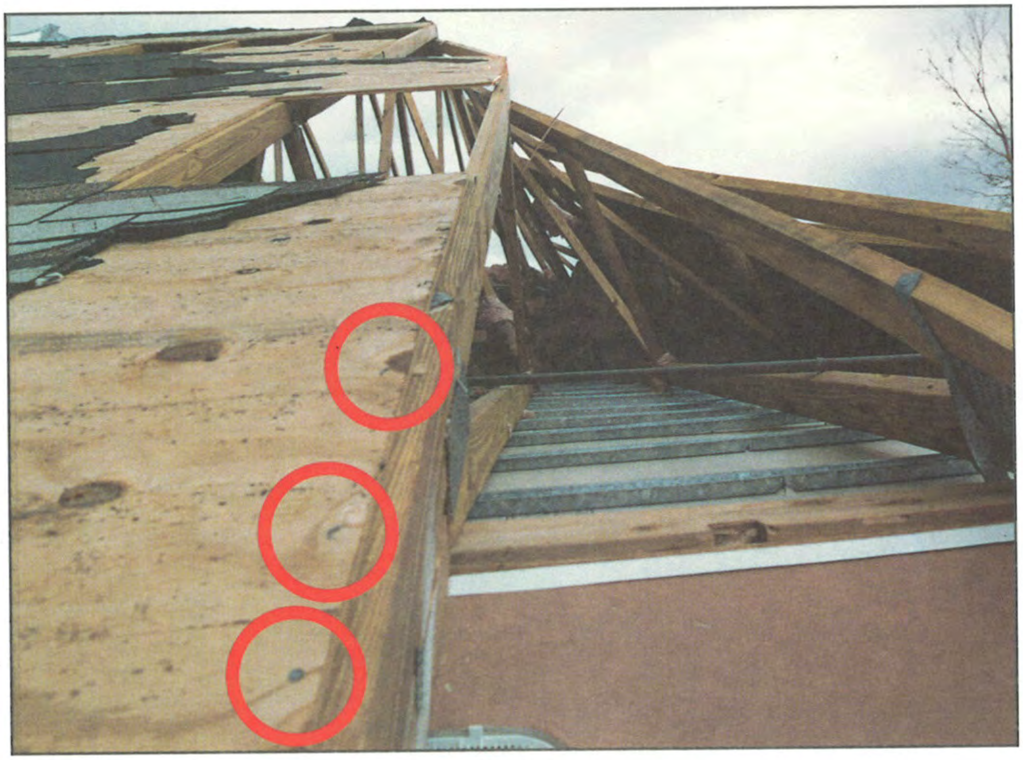


FIGURE 57. *Sheathing only tack-nailed.*

FIGURE 58. *End wall failure. Example of lack of load transfer capacity after separation.*

FIGURE 59.
End column/corner post missing from wall.

FIGURE 60.
Side wall failure. Side wall has no lateral load transfer capacity due to inadequately built-up corner post.

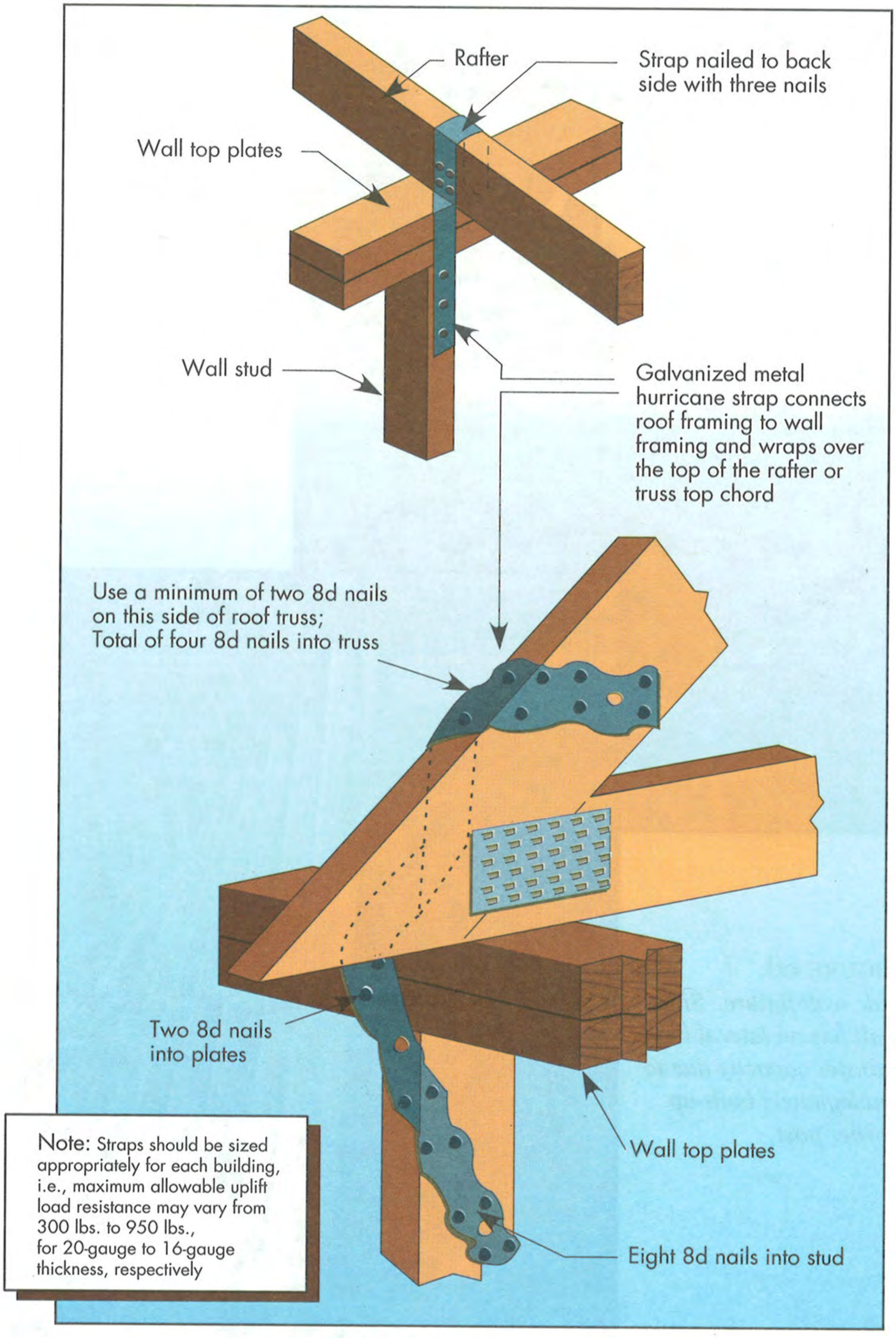


FIGURE 61. *Typical hurricane strap to roof framing detail. Rafter or prefabricated roof truss.*

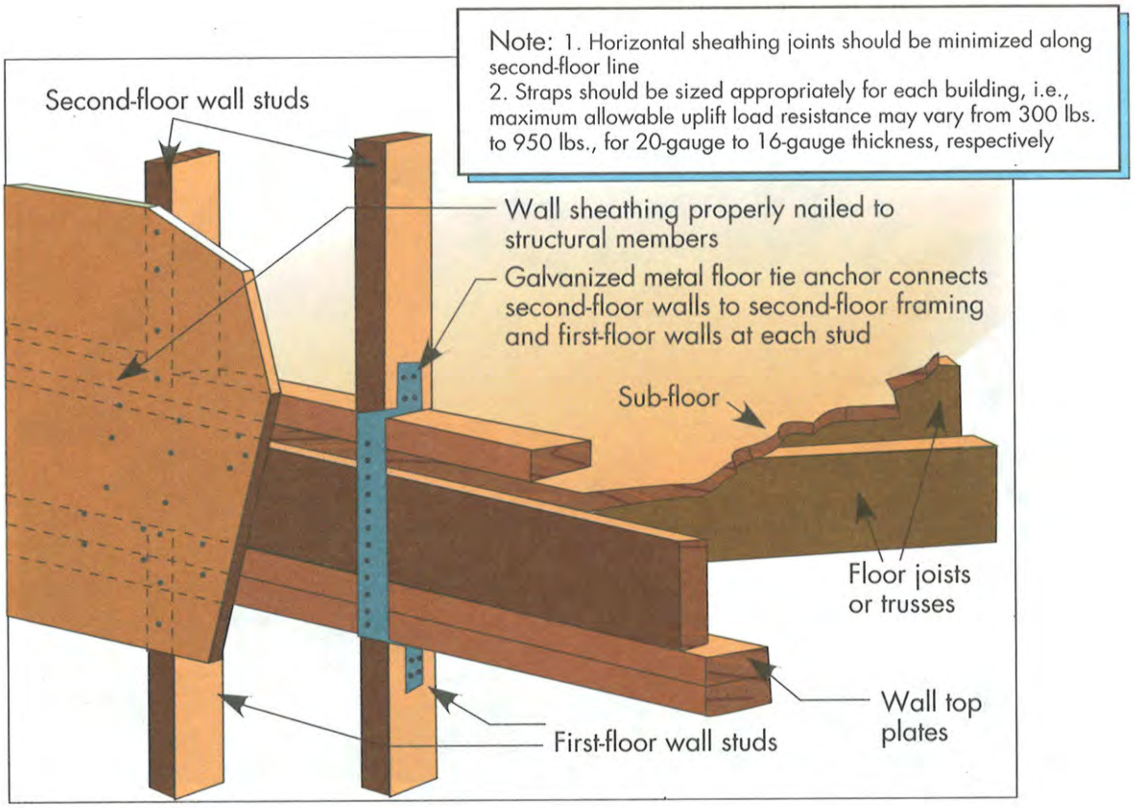


FIGURE 62. *Upper-floor tie to lower floor for two-story building. Floor tie anchor and nailed wall sheathing.*

MASONRY BUILDINGS

1. Adequately designed and constructed masonry walls must be ensured through compliance with the provisions of the Code.

— The Code requirements for tie-beams/tie-columns, or alternative reinforced masonry construction, should be reviewed and enforced (SEE FIGURES 63 AND 64).

FIGURE 63. *Example of masonry construction. Wall separated from building envelope due to inadequate vertical wall reinforcing in connection to horizontal tie-beam.*

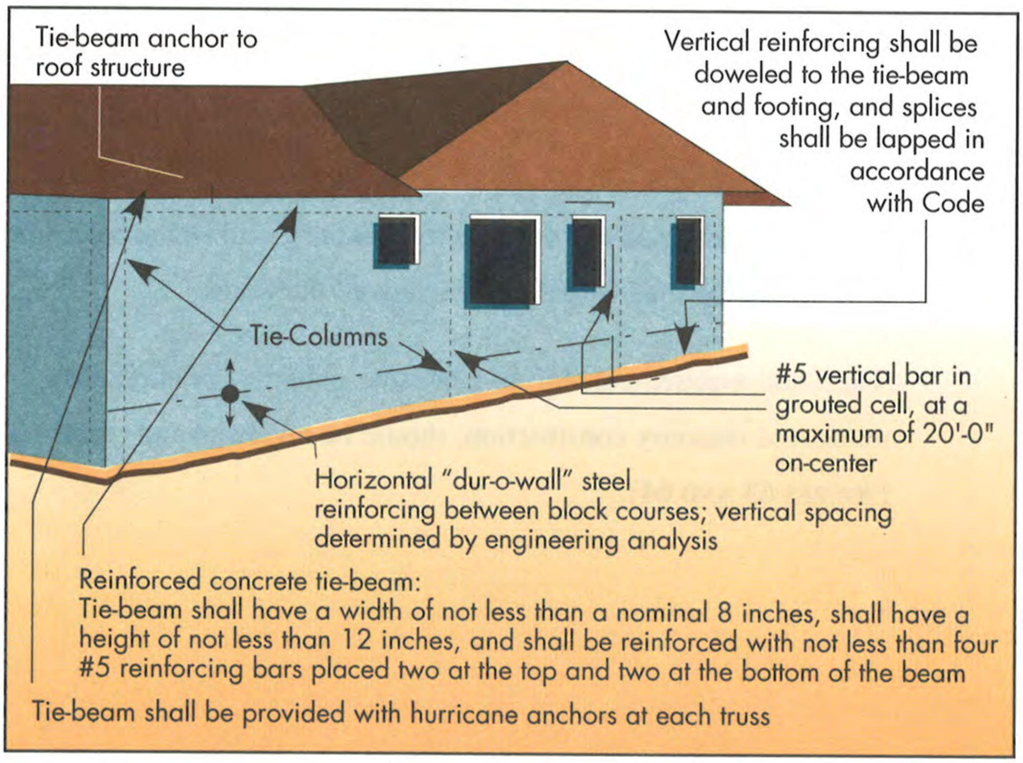


FIGURE 64. *Adequately designed and constructed tie-beam/tie-column masonry wall.*

— A tie-beam of reinforced concrete should be placed in all walls of unit masonry, at each floor or roof level, and at such intermediate levels as may be required to limit the vertical heights of the masonry units to 16 feet.

— The use of concrete tie-columns at all corners, and at intervals not to exceed 20 feet on center of columns, should be reviewed as a Code improvement. The maximum area of wall panels of 8-inch-thick unit masonry as measured between concrete members which frame the panel, such as the tie-beams and tie-columns, should not exceed 256 square feet.

2. Masonry walls with continuous tie-beams should be engineered and constructed to support the specific architecture of the building. This includes consideration of freestanding cantilevered wall systems for elements such as firewalls that have discontinuous tie-beams. (SEE FIGURES 65-68).

— Bracing with struts or pilaster columns in walls perpendicular to the free-standing walls, or adequate reinforcing in the walls sufficiently anchored in the foundation or story below, must be engineered and installed.

3. Greater emphasis should be given to the transfer of loads to concrete slabs and masonry walls from wood framing (SEE FIGURES 8, 69, AND 70). For example, the use of cut nails in lieu of bolted masonry-to-wood connections must be eliminated. Also masonry-to-wood-frame straps must be properly located.

MANUFACTURED HOMES AND MODULAR BUILDINGS

1. Re-examination of State and Federal regulations concerning the wind safety design standards for manufactured homes is recommended.

2. The issue of providing safe, affordable housing in high-wind areas needs to be further examined.

FIGURE 65. *End wall failure. Freestanding concrete masonry wall has discontinuous tie-beam.*

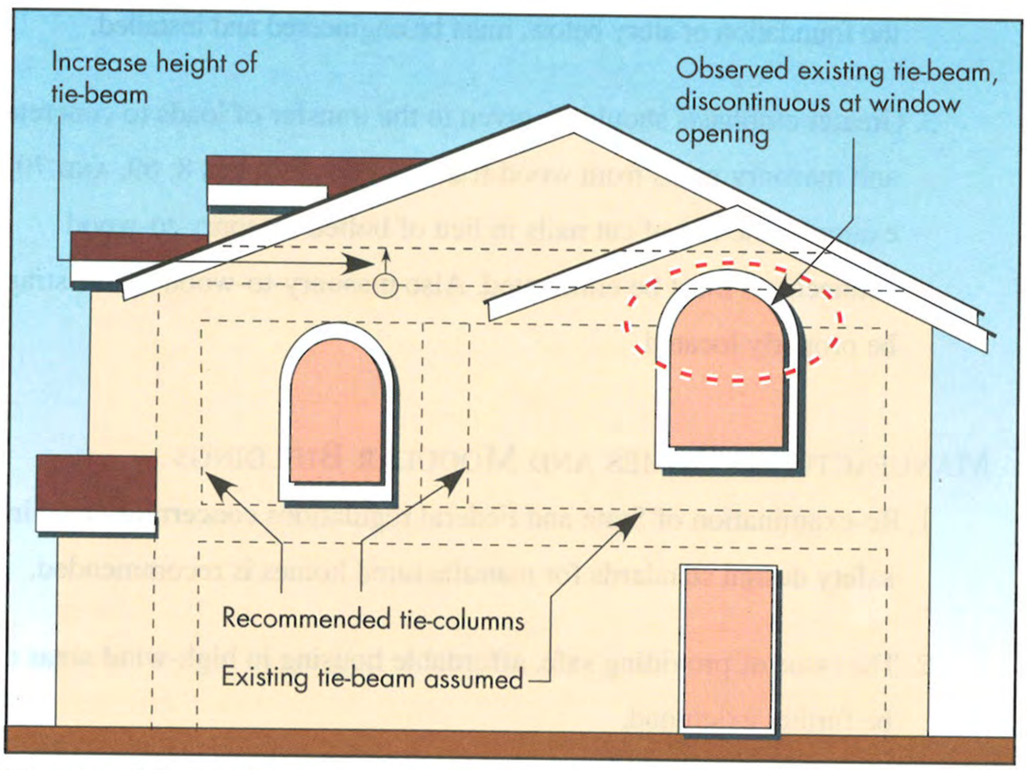


FIGURE 66. *Individualized architectural systems require designs for structural support.*

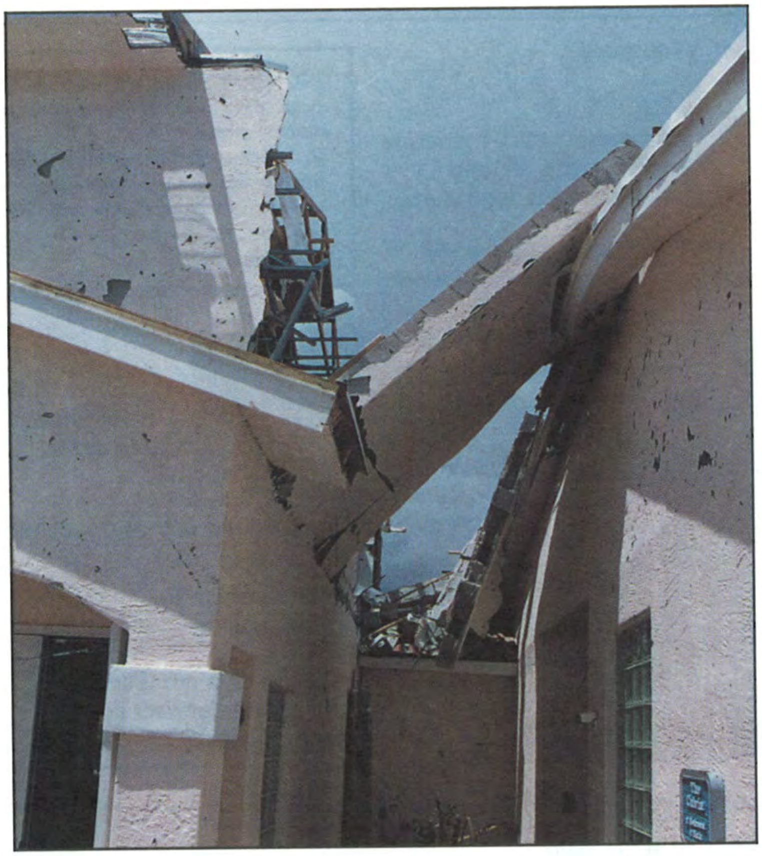


FIGURE 67. *Firewall separation . Results from building corners being discontinuous with tie-beams. (See Figure 68 for side view)*

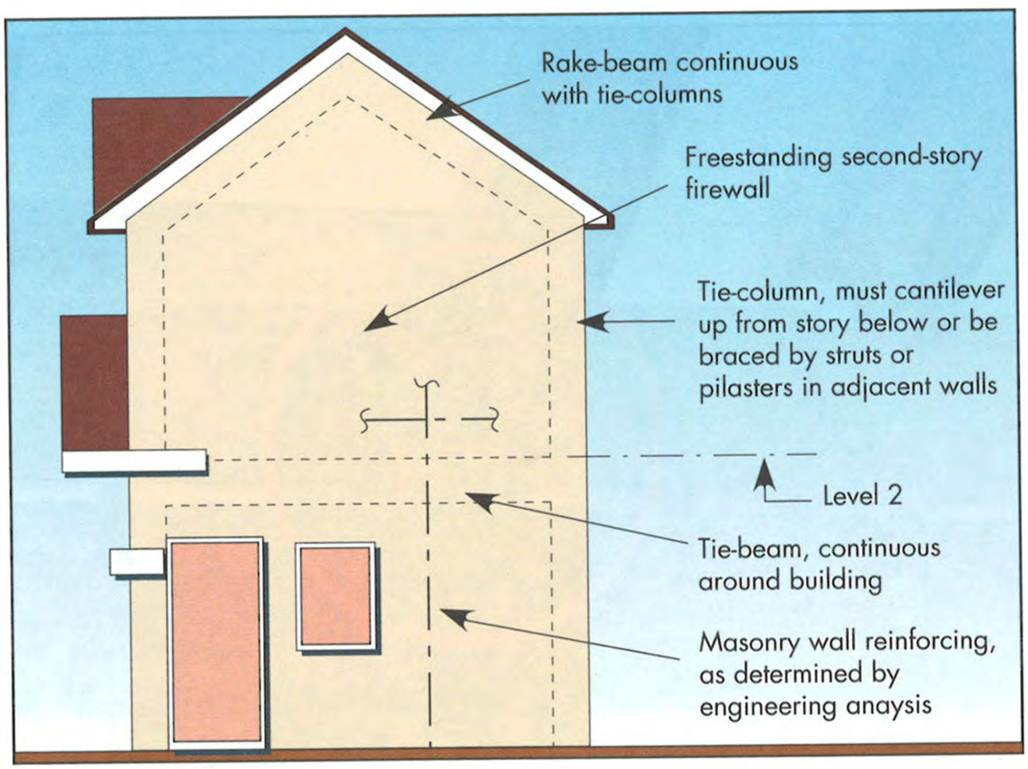


FIGURE 68. *Adequately designed and constructed freestanding cantilevered wall system.*

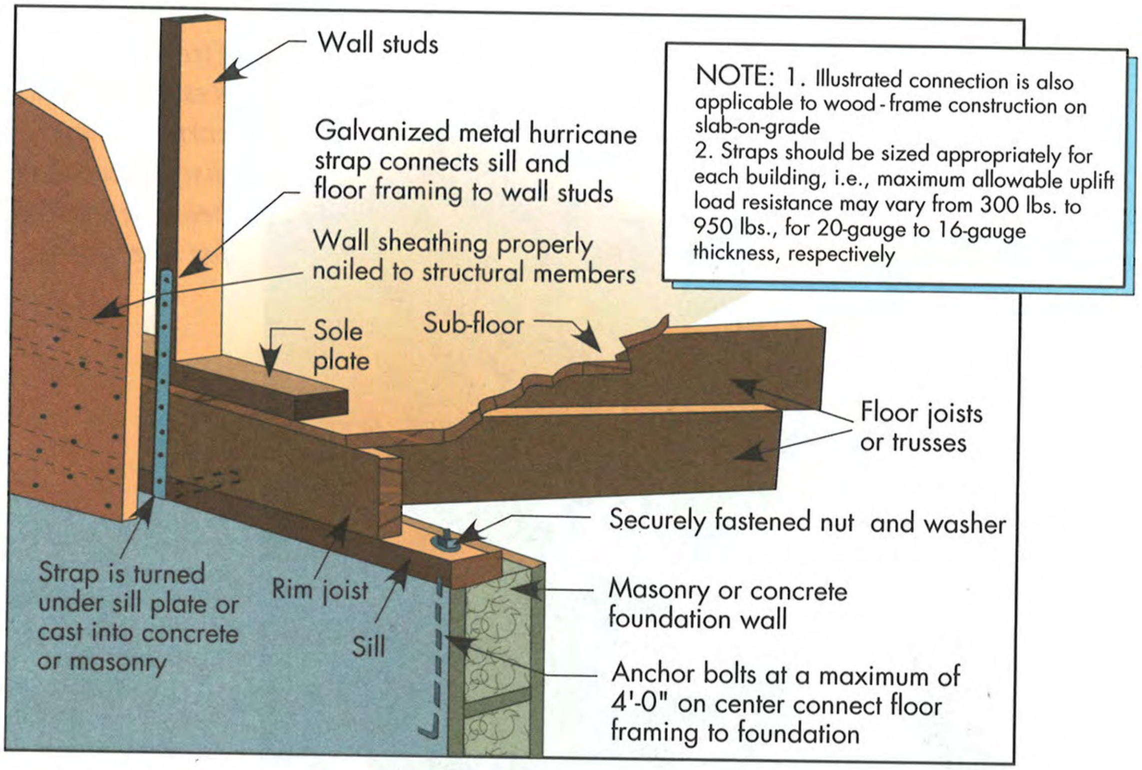


FIGURE 69. *Lower-story wall anchorage to masonry (or concrete) base. Straps properly nailed at wall studs.*

FIGURE 70. *Improperly located masonry-wall-to-wood-frame straps.*

3. Although the modular systems (SEE FIGURE 18) generally performed well, possible alternatives to the detailing and construction of weaker components of the systems should be reviewed. Most notably, the end-panel connections of end units, and roof sheathing should be reevaluated (SEE FIGURE 71).

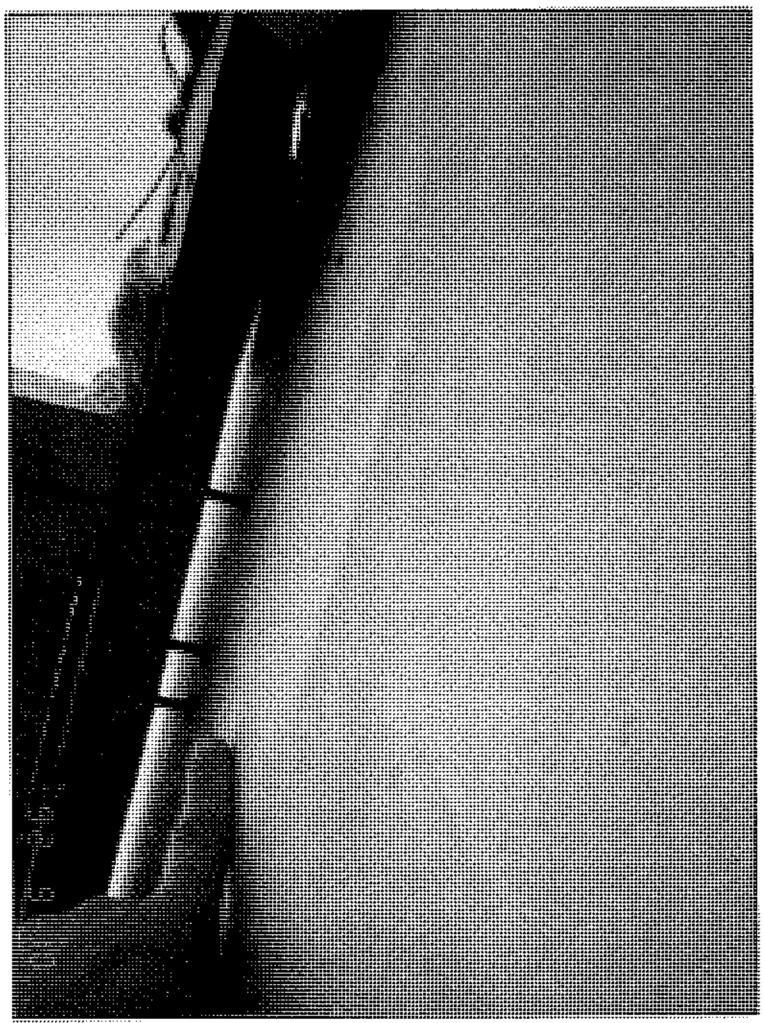


FIGURE 71. *Modular home. Partial separation of end panel (right) from roof structure (left). Evidence of failure due to nail withdrawal.*

Accessory Structures

1. Accessory structures should be appropriately designed, manufactured, and installed to minimize the creation of airborne debris. To meet this goal, the community may want to further regulate these structures to ensure Code compliance.

Repair/Retrofit of Partially Damaged and Undamaged Buildings

1. The NFIP requirements concerning "substantial damage" provisions contained in the county Code must be enforced. The lowest floors of all substantially damaged buildings must be located at or above the BFE. This form of mitigation will reduce damages from future flood events.

2. During the Hurricane Andrew rebuilding period, building departments within Dade County should explore all available resources for expanding the pool of qualified building inspectors.

3. Although southern Dade County experienced extensive damage, many buildings are repairable. Repairs should be carried out with attention to the recommendations made in this report.

4. Technically feasible methods of retrofitting damaged and undamaged buildings for compliance with current Code requirements should be identified and promoted.

5. An audit program for existing undamaged buildings for retrofit needs should be developed and promoted. Undamaged portions of damaged buildings must be evaluated during the repair process.

6. A program that offsets retrofit burdens should be explored. This may be done through public funding of a building assessment program and/or by financial assistance through such vehicles as loan supports, tax credits, and insurance incentives.

7. A public awareness program that focuses on the maintenance of critical building components should be developed. This program could be undertaken by existing educational institutions such as community colleges.

8. A program to gain the fullest participation of the citizens in the building code process should be established.

9. Community outreach programs promoting hurricane-resistant construction should be developed and institutionalized using available local resources such as State and local colleges, trade organizations, and trade schools. If homebuyers had a greater understanding of hurricane-resistant construction, they could demand better built homes. Because market forces may well dictate future design and construction trends, this may be one of the most effective ways of promoting sound design and construction practices in Dade County.

Exhibit 1

Building Performance Assessment Team Members

John Gambel	Federal Emergency Management Agency, Federal Insurance Administration, Washington, D.C., Team Leader
Clifford E. Oliver	Federal Emergency Management Agency, Federal Insurance Administration, Washington, D.C., Team Coordinator
Michael G. Mahoney	Federal Emergency Management Agency, Office of Earthquakes and Natural Hazards, Washington, D.C.
Mark A. Vieira	Federal Emergency Management Agency, Region IV, Atlanta, GA
Charles Danger	Metro-Dade County Office of the County Manager, Miami, FL
Christopher S. Hanson	Greenhorne & O'Mara, Inc., Consulting Engineers, Greenbelt, MD
John C. Pistorino	Pistorino & Alam, Consulting Engineers, Inc., Miami, FL
Douglas B. Timmons	Riva, Klein & Timmons, Structural Engineers, Miami, FL

Building Performance Assessment Team Advisor

Rodney Cross	National Flood Insurance Program, General Adjustor, Landover, MD, Technical Advisor on Insurance and Claims

Appendix A

Building Performance Assessment, Damage Assessment, and Hazard Mitigation Reports

The following is a summary of the reports that FIA has issued, or that FIA staff have participated in preparing, to date to document damages and propose mitigation measures to reduce future damages.

Building Performance Assessment Team Report: Hurricane Andrew, 12/92

Building Performance Assessment Team Report: Hurricane Iniki, 12/92

Building Performance Assessment Team Report: Noreaster, Delaware and Maryland, 1/92

Flood Damage Assessment Report: Noreaster, New York and Massachusetts, 10/91

Flood Damage Assessment Report: Hurricane Bob, 8/91

Guidance Document on Post-Disaster Assessment of Building Flood Damage

Damage Assessment of Flooded Buildings 1985-1990, 6/91

Flood Damage Assessment Report: Hurricane Hugo, 8/91

Hazard Mitigation Team Report: Hurricane Hugo, 10/89

Follow-Up Investigation Report: 9 Months After Hurricane Hugo, 8/91

Flood Damage Assessment Report: Tropical Storm Allison, 6/90

Flood Damage Assessment Report: Noreaster of April 1990, 6/90

Flood Damage Assessment Report: Riverine Flooding in Central Kentucky, 2/90

Flood Damage Assessment Report: Texas, 6/89

Flood Damage Assessment Report: Noreaster, Mid-Atlantic Coast, 3/89

Flood Damage Assessment Report: Noreaster, Mid-Atlantic Coast, 4/88

Flood Damage Assessment Report: Riverine Flooding in the Minneapolis Area

Flood Damage Assessment Report: Riverine Flooding in Maine, 6/88

Flood Damage Assessment Report: Riverine Flooding in Clive, Iowa, 9/86

Flood Damage Assessment Report: Riverine Flooding in Allegheny County, Pennsylvania, 1/87

Flood Damage Assessment Report: Riverine Flooding in Central Michigan, 5/87

Flood Damage Assessment Report: Hurricane Gloria, 2/86

Improving Resistance of Buildings to Wind Damage: Hurricane Elena, 9/85

Hazard Mitigation Team: Hurricane Diana, 1984

Proposed Changes to Building Codes in Response to Hurricane Alica, 8/83

Hazard Mitigation Report: Noreaster, Outer Banks, North Carolina, 10/82

Hazard Mitigation Team Report: Hurricane Frederick, 9/79

APPENDIX B

MANUFACTURED HOUSING

A nationwide standard for manufactured home construction was established when Congress passed the Manufactured Home Construction and Safety Standards Act of 1974. This Act directed the Department of Housing and Urban Development (HUD) to develop and administer standards for all components of manufactured home construction, including body and frame construction requirements, and support and anchoring systems to resist specific design wind loads.

HUD's regulation of the manufactured housing industry is based on an enforcement program that consists of three principal components: pre-production design approval, production inspection, and post-production consumer protection.

Manufacturers are required to hire a HUD-approved independent third party Design Approval Primary Inspection Agency to review and approve the manufacturer's design, calculations, and testing for compliance with HUD standards. The manufacturers are also required to hire a HUD-approved Production Inspection Primary Inspection Agency to inspect homes for adherence to the approved design specification and HUD standards. Post-production enforcement processes focus on correcting nonconformances with HUD standards that are usually identified through consumer complaints. These activities are carried out through State Administrative Agencies or directly by HUD.

Under the auspices of the NFIP, localities must require that manufactured homes be elevated and anchored so that they are able to withstand flotation, collapse, and lateral movement as a result of wind and flood forces. Specifically, the NFIP requires manufactured homes to be elevated and secured to an adequately anchored foundation system so that the home itself is not displaced due to flood forces. It is expected that in addition to meeting NFIP requirements, manufactured homes are anchored against wind forces in accordance with State or local regulations.

An exception is manufactured homes in existing manufactured home parks that have been substantially damaged by wind. Here, the NFIP requires that all new replacement homes either be elevated so that their lowest floors are at or above the BFE or be elevated on reinforced piers or other foundation elements of equivalent strength that are at least 36 inches above grade, whichever is lower. In addition, the replacement homes must be securely anchored to withstand floatation, collapse, and lateral movement that could be caused by both flood and wind forces. An existing manufactured home park is defined as a park for which construction of the facilities for servicing the lots on which the homes are installed was completed prior to the effective date of the floodplain management regulations adopted by the community.

Appendix C

Comments From Reviewers

Numerous solicited and unsolicited comments were received concerning both the preliminary and the draft versions of the report.

Comments were solicited from the following:

- Building Performance Assessment Team Members
- FIA
- FEMA Region IV, Atlanta, Georgia
  - Natural Hazards Branch staff
  - Hazard Mitigation Officer
- FEMA State and Local Programs and Support Directorate
  - Office of Earthquakes and Natural Hazards
  - Office of Disaster Assistance Programs
- Florida Department of Community Affairs

Unsolicited comments were received from the following:

- National Roofing Contractors Association, Rosemont, Illinois
- Glazing Consultants, Inc., North Palm Beach, Florida

Following is a list of the substantive comments received and their disposition:

COMMENT: The Dade County GIS played a major role in supporting the assessment team's efforts to identify areas that were damaged. It has shown to be an effective tool in the mitigation and reconstruction effort after the storm. Therfore, the use of GIS should be further discussed in the report.

DISPOSITION: A discussion of the role of GIS and a recommendation concerning its future role in mitigation were added.

COMMENT: The discussion of the actual wind speeds needs to be clarified and expanded.

DISPOSITION: The intent of the report is not to focus on the actual wind speeds. Rather, the focus is based on the premise that buildings built in compliance with the Code should have performed better during Hurricane Andrew. The National Weather Service is producing a document that will identify "official wind speeds" for Hurricane Andrew.

COMMENT: The discussion of the methods used to measure wind speeds, and their differences, should be expanded.

DISPOSITION: Wind speeds are measured differently for meteorological and building code purposes. While the National Weather Service uses terms such as "sustained gust" and "highest gust," building codes prescribe the use of the "fastest mile" wind standard. Though it is possible to convert between the two, the issue is confusing to the general public. This report addresses the differences between the various terms. However, it is beyond the scope of the report to resolve the this complex, long-standing issue.

COMMENT: The report states that wood-frame gable ends failed because of a lack of a defined load transfer path. Instead, failure was due to an over-reliance on plywood roof sheathing, rather than gable and roof truss bracing, to act a load transfer mechanism.

DISPOSITION: The report language was revised to address this issue.

COMMENT: Why is the widespread failure of manufactured homes not discussed in greater detail?

DISPOSITION: The team did not focus on the failure mode of manufactured homes. HUD is the Federal agency responsible for oversight of the manufacured housing industry and is the more appropriate group to address this issue. HUD staff are knowledgeable about the design, construction, and installation practices of the manufactured housing industry. HUD has the resident capability to identify future improvements needed in this technology.

COMMENT: The discussion of the failure mode of composition roof shingles needs further explanation.

DISPOSITION: The report language was revised to address this issue.

COMMENT: The report language implies that the team observed universally poor-quality workmanship.

DISPOSITION: The report language was revised to remove this implication. The team observed numerous examples of quality workmanship that resulted in successful performance of buildings during the storm.

COMMENT: Due to the importance of roof system failure, roofs should be discussed in a separate subsection within the "Observations" section of the report.

DISPOSITION: The revised report includes a separate section on roofing systems.

COMMENT: The limited extent of storm surge damage was a result not only of the forward speed of the storm but also the compact size of the storm.

DISPOSITION: The report language was revised to address this issue.

COMMENT: The recommendation for a "hot-mopped" layer of tar underneath composition shingles may be overly conservative. Investing in better methods of shingle and roofing paper attachment may be more cost-effective.

DISPOSITION: The failure mode of composition roof shingles is complex. Even if the attachment mode were to be improved, material failure will continue to pose problems during high winds. Furthermore, accelerated deterioration of roof shingles in the subtropical climate of southern Florida is a problem. The recommendation for a tar layer, secondary roof membrane beneath composition roof shingles was therefore retained.

COMMENT: Though improved workmanship in the installation of roof tiles will improve the survivability of these roofs, continued debris impact will still result in damages.

DISPOSITION: The report language was revised to address this issue

COMMENT: Proper venting of buildings may act to relieve induced internal air pressure. However, vents can also provide access for uncontrolled air flow if not designed and installed properly.

DISPOSITION: The report language was revised to address this issue.

COMMENT: The failure mode of composition shingles is a complex problem. Further discussion of the team's observations is needed to justify the recommendation concerning composition shingles contained in the report.

DISPOSITION: The report language was revised to address this issue.

COMMENT: Further explanation of the failure mode of concrete and clay roof tiles is needed to support the recommendations contained in the report.

DISPOSITION: The report language was revised to address this issue.

COMMENT: Is there evidence to support the observation that flat roof tiles performed better than roof tiles of other shapes?

DISPOSITION: Changes have been made to the report text to clarify that this was an interpretation based on the team's observations.