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HURRICANE
IKE
IN TEXAS
& LOUISIANA

3

Performance of Residential Buildings (Flood and Wind), One- to Two-Family and Multi-Family

Assessing the structural and building envelope performance of residential buildings was one of the main goals of the MAT.

3.1 Structural Performance

Assessing the structural and building envelope performance of residential buildings was one of the main goals of the MAT (the other being the assessment of critical facility performance—see Chapter 4). Making these assessments required location-specific information, gathered prior to and during the MAT's field investigations, and knowledge of the flood and wind loads and conditions to which the buildings were exposed during Hurricane Ike. In a few cases, additional data were gathered after field work was completed, but in most cases building performance judgments were based on information available to the MAT while in the field. Although the MAT believes its assessments of buildings described in this chapter are correct, statements made herein are not intended to represent final judgments as to the cause of damage to individual buildings—the MAT recognizes that further investigation by others may refine or alter judgments made by the MAT. Nevertheless, general damage patterns and trends observed by the MAT are valid and can be used as the basis for recommendations to improve residential design and construction.

3.1.1 Foundation Performance

Foundations in coastal areas must be able to perform several functions:

- Elevate the building above the surge and wave crest level
- Remain intact and functional despite scour and erosion effects
- Provide a continuous load path from the elevated building to the ground, and resist all vertical and lateral loads transferred from the elevated building to the foundation
- Resist flood loads—including storm surge, wave, and floodborne debris impacts—acting on the foundation and on any below-flood level obstructions that do not break away

Failure to perform any of these functions can result in building damage or loss. The MAT observed foundations that performed well (Figure 3-1), and foundations that failed to satisfy one or more of the requirements listed above.

Failures of the most common type of foundation observed by the MAT—the open (e.g., pile or column) foundation—were usually associated with one of two factors: insufficient embedment into the ground, or breakage of the piles or columns.

Embedment Failures. Embedment failures occur where a foundation is not deep enough in the ground to resist wind and flood loads pushing on the structure; a leaning foundation or overturned building results (Figure 3-2). Scour and erosion can exacerbate this mode of failure by reducing embedment.

Pile and Column Breakage. Pile and column breakage occur where the strength of the piles or columns is inadequate to resist the bending moments or shear forces caused by the flood and wind loads acting on the structure (Figures 3-3 and 3-4). Scour and erosion contribute to this mode of failure by increasing the un-braced pile/column length and by increasing the bending moments in the pile/column.

The methods used to secure an elevated building to the top of the foundation can affect the overall foundation strength. Connections at the tops of the piles or columns that do not provide fixity (i.e., resistance to rotation) allow greater stresses to develop in the piles or columns than would develop with connections that rigidly tie the structural elements together.

In most buildings the MAT evaluated, timber construction was used and the tops of the piles or columns were connected to the elevated buildings with bolted connections (Figure 3-5). This type of connection provides limited fixity; weakness in this type of connection can be overcome in some instances through the use of larger piles or columns and other design details that help to stiffen the foundation.

Figure 3-1.
Louisiana house sufficiently elevated on a foundation that withstood Ike flood loads

Figure 3-2.
A house on timber piles was pushed over by wind and flood loads and the load path failed at the connection between the floor beam and the piles. Embedment and elevation were also insufficient at this Bolivar Peninsula, TX, site.

Figure 3-3.
Broken timber piles (Galveston Island, TX)

Figure 3-4.
This concrete column failed due to lateral loads. Note limited overlap of reinforcing steel at the bottom of the column.

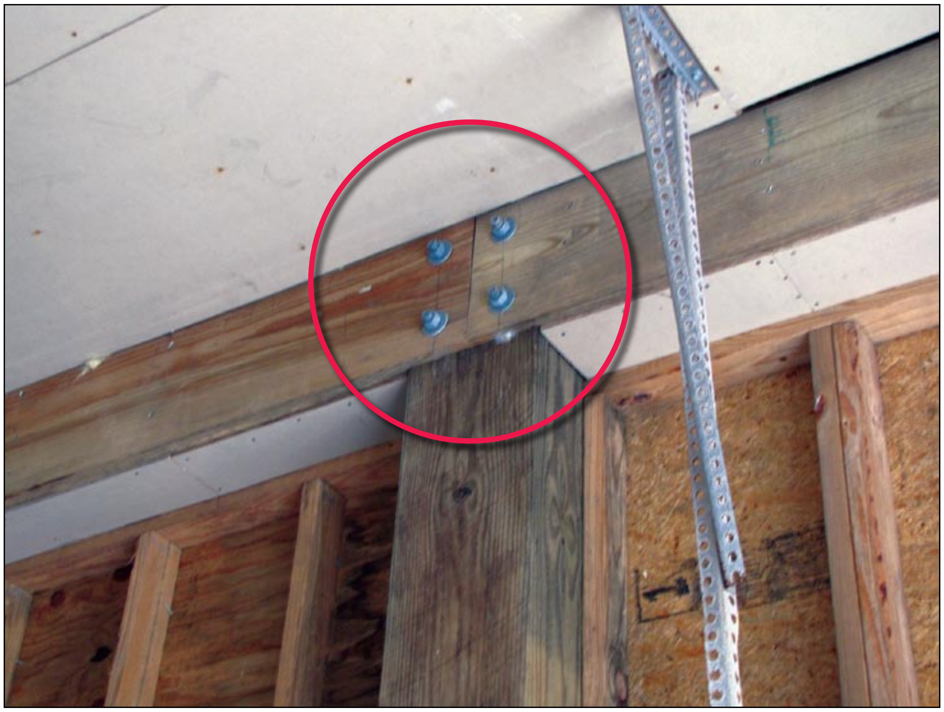


Figure 3-5.
Typical bolted connection between wood columns and wood beams

3.1.1.1 Foundation Function 1: Elevate the Building

Elevation is one of the most important keys to a successful coastal building. The MAT observed many residential buildings along the Gulf shoreline that were elevated above the effects of Ike's storm surge and waves, and sustained no significant damage; on the other hand, nearby buildings that were at lower elevations were heavily damaged or destroyed (Figure 3-6).

Figure 3-6.
Unlike the older and lower house on the right, the Zone V house on the left was elevated approximately 5 feet above the 16-foot National Geodetic Vertical Datum (NGVD) BFE and sustained no structural damage due to flooding (Crystal Beach, TX)

The MAT's observations of wave damage and analysis of building elevation data indicate that the wave crest elevation on much of the Bolivar Peninsula reached approximately 2 to 5 feet above the BFE.

It was difficult to obtain HWMs for flood levels on Bolivar Peninsula due to the magnitude of the destruction there. However, the MAT was able to supplement high water mark data collected by government agencies (see Section 1.2.3) with wave damage data in elevated houses that remained standing after Ike. For instance, houses such as the one shown in Figure 3-6 indicate that the wave crest elevation at that location was below the bottom of the elevated floor system (due to the fact that the floor system was intact). Damage such as that shown in Figure 3-7, where the shore-parallel floor joists were displaced landward, indicates the onset of wave damage to an elevated floor system. By carefully examining several such houses and by acquiring the corresponding lowest floor elevations from NFIP Elevation Certificates, the MAT concludes that the wave crest elevation reached approximately 18 to 20 feet NGVD, an elevation approximately 2 to 4 feet higher than the BFEs at these particular houses. Although it is possible that the wave crest reached higher elevations relative to the BFE, it is unlikely based on the lack of wave damage at some houses that were approximately 5 feet above the BFE (waves apparently passed beneath those elevated houses).

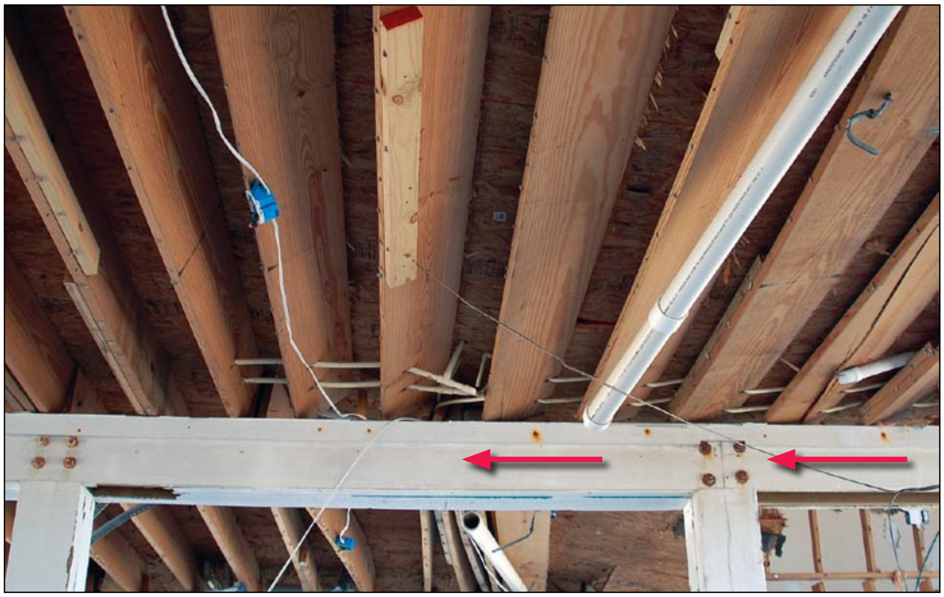


Figure 3-7.
The landward displacement of shore-parallel floor joists indicates the onset of wave damage to an elevated floor system (Bolivar Peninsula, TX)

The MAT also observed many bay shoreline and inland examples that demonstrate the importance of elevation. Houses situated at higher elevations, whether because of elevated foundations or because of being sited on high ground, sustained little or no damage, while adjacent houses with lower elevations were damaged or destroyed. In many cases, undamaged bay-front houses were elevated above the surge and wave elevation on pile foundations. Figure 3-8 shows a house elevated above the BFE and Ike wave effects that suffered no significant damage due to flooding. However, the nearby at-grade house shown in the inset was heavily damaged. On some bay-front shorelines (or inland areas) where storm wave heights were smaller and where erosion did not threaten a house, siting on natural high ground or fill provided the required elevation and support for the house (Figure 3-9).

The MAT observed many houses in more inland locations that were not elevated high enough to avoid Ike flooding, and were apparently subject to surge inundation, low-velocity storm surge flow, and, in some cases, minor wave action. These houses sustained varying degrees of flood damage depending on site-specific flood depths, flood loads, and construction details. Some

Figure 3-8.
This elevated house (Zone V, BFE = 15 feet) suffered no significant damage due to flooding. The nearby at-grade house in the background, shown in the inset, was heavily damaged (Baytown, TX).

Figure 3-9.
Adjacent houses south of Baytown, TX. The house on the left (Zone X) was above the surge and wave runup level and sustained no flood damage. The house on the right (Zone A, BFE = 13 feet) was at a lower elevation and was largely destroyed by surge, waves, and floating debris.

were inundated by several feet of flooding, as they had been during Hurricane Rita in 2005. The house shown in Figure 3-10 was not subject to wave action during Ike and suffered no apparent structural damage. However, flood damage to contents and finishings were likely severe. Other houses sustained significant structural damage due to storm surge flow (Figure 3-11). Some floated or were washed off their foundations (Figure 3-12).

Figure 3-10.
The Ike flood level reached approximately 3 feet above the floor slab (1 foot above the 6-foot BFE) of this Zone A house (see inset), which was reported to have been similarly inundated during Hurricane Rita. The MAT was told that the house will be elevated (Lake Charles, LA).

Figure 3-11.
This house sustained significant structural damage due to storm surge and small waves above the 9-foot BFE in Zone A (Bridge City, TX). Note flood debris line on the roof.

Figure 3-12. This house floated off its foundation due to insufficient elevation and inadequate connections between the foundation and the house (Golden Meadow, LA)

The tallest residential foundations the MAT observed were at *Fortified… for safer living*® houses (see text box and Section 2.4) on Bolivar Peninsula. The houses are elevated with their lowest floor at approximately 27 feet NGVD (21 feet above the ground), 10 feet above the BFE (Figure 3-13). These foundations are reinforced, cast-in-place concrete columns connected to concrete slabs and drilled concrete shafts (extending 10 feet below grade). Ten of the 13 houses survived Ike, and three were destroyed.

WARNING

Elevation alone is not adequate to ensure a building will perform well during a high wind and flood event. A building must be elevated on a well-designed and constructed foundation. Some of the tallest foundations the Ike MAT observed either failed or were in danger of failing.

The houses had substantial timber decks connected to the columns at or just above the BFE, approximately mid-way between the ground and the elevated houses. Although not designed as breakaway decks, the decks broke away during Ike, probably a result of both wave and flood-borne debris effects. The deck failures damaged some of the concrete columns where the decks were connected (Figure 3-14).

The concrete columns left standing between the slabs and the (destroyed) elevated decks were observed to have a series of horizontal cracks in the columns (Figure 3-15). These cracks likely resulted from the columns bending in response to a combination of wind loads on the elevated houses, flood loads (waves, currents, debris) on the columns, and transfer of flood loads from the decks to the columns.

FORTIFIED... FOR SAFER LIVING®

The *Fortified… for safer living*® designation is from the Institute for Business and Home Safety. The "Fortified®" program specifies design and construction guidelines to increase a house's resistance to natural disasters such as hurricanes. For more information: www.disastersafety.org/text.asp?id=fortified.

Figure 3-13.
Looking toward the Gulf, past Zone V houses on tall concrete column foundations (with the lowest floor 10 feet above the 17-foot BFE). Four of the five tall houses shown in this photograph survived Ike (red circle indicates destroyed house). The red arrow points to exposed geotextile tube (under former dune). Note other destroyed houses (not on tall foundations) seaward of the highway (Bolivar Peninsula, TX).

Figure 3-14.
Ground-level view of elevated houses with inset showing typical column damage where the timber deck broke away (Bolivar Peninsula, TX).

Figure 3-15.
Concrete column showing cracking that was likely caused by extreme column bending stresses due to lateral loads on the elevated house and foundation (Bolivar Peninsula, TX)

3.1.1.2 Foundation Function 2: Resist Scour and Erosion

Residential building performance in coastal areas often depends on the capability of the building foundation to accommodate a lowering of the ground elevation and loss of soil support. The lowering of the ground is often accompanied by high winds, storm surge, large waves, and debris propelled by wind or water, which further magnify any adverse effects of soil loss.

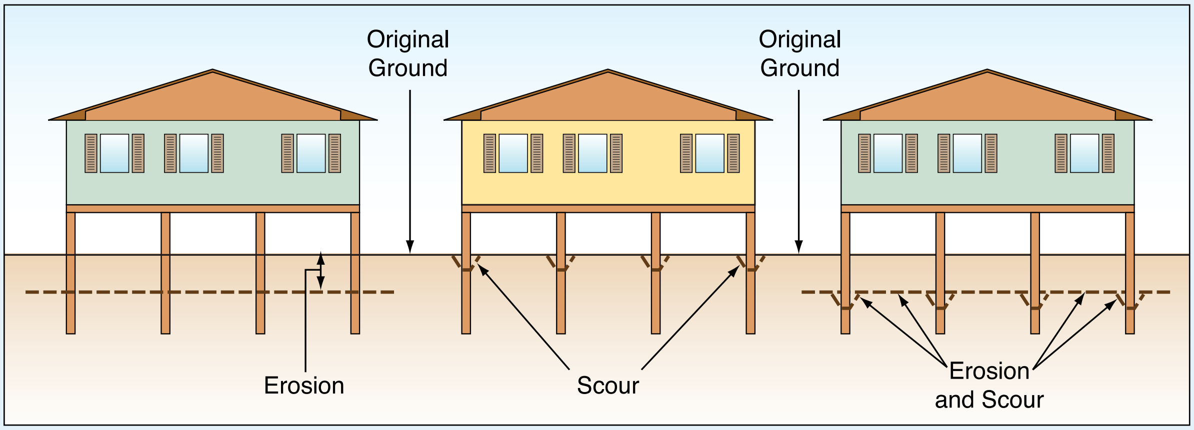
For foundation design purposes, it is important to distinguish the nature and extent of soil loss expected around a building, since these can affect the stillwater flood depth and the magnitude of the flood conditions at the site (see erosion and scour text box on next page).

The MAT observed significant levels of erosion and scour near buildings situated along the Gulf of Mexico. Erosion was widespread along the Gulf of Mexico shoreline of Follets Island, Galveston Island, and Bolivar Peninsula, TX, and portions of southwest Louisiana. Scour was particularly evident around building foundations on Bolivar Peninsula and at Holly Beach (Cameron Parish, LA). The MAT believes that erosion and scour were among the major contributors to structural failure of buildings close to the Gulf shoreline. Significant erosion and scour were not observed by the MAT along the bay shorelines, although there may have been some locations where such erosion and scour occurred.

EROSION AND SCOUR

Erosion is a lowering of the ground surface over a large area, usually brought on by a coastal storm or long-term shoreline recession. Erosion increases the unbraced length of vertical foundation elements and increases the stillwater depth at the building, allowing larger waves to reach the foundation.

Scour is a localized loss of soil immediately around an object or obstruction. Scour also increases the unbraced length of vertical foundation elements, but does not act to increase the stillwater flood depth across which waves propagate (thus, scour can be ignored for wave height calculation purposes). Walls, columns, pilings, pile caps, footings, slabs, and other objects found under a coastal building can contribute to localized scour.



Depending on the building location, soil characteristics, and flood conditions, a building may be subject to either coastal erosion or scour, or both. Refer to Hurricane Ike Recovery Advisory on *Erosion, Scour and Foundation Design* (Appendix D) for additional information.

A preliminary review of pre- and post-Ike aerial photographs suggests that between 100 and 200 feet of dunes and vegetation were lost during Ike along much of the Gulf shoreline (see Figure 3-16).

This loss occurred in areas with natural dunes and in areas where previously eroded dunes had been rebuilt and reinforced with geotextile tubes (see Figures 3-13 and 3-17). As of 2003, approximately 7.6 miles of geotextile tube dune reinforcement had been installed along the Texas shoreline, mostly along the Bolivar Peninsula and western Galveston Island shorelines (Gibeaut et al., 2003). Virtually all of these tubes were uncovered by Ike, and many were destroyed.

Figure 3-16.
Pre- and post-Ike aerial photographs of the east end of Galveston Island, TX, illustrating some of the most significant loss of dunes and vegetation during Ike

SOURCE: USGS, http://coastal.er.usgs.gov/hurricanes/ike/photo-comparisons/galveston.html

The Ike MAT noted that the amount of scour around pile foundations was far greater than that observed during previous post-storm investigations, both in terms of frequency of occurrence and depth of scour. Most of the scour was observed at foundations with concrete slabs at ground level, but this is likely due to the prevalence of this type of construction; significant scour was also observed around some pile foundations before the slabs had been constructed. Significant scour (several feet deep, tens of feet in diameter) was observed after Ike at hundreds of the buildings that were still standing near the Gulf shoreline.

Figure 3-17.
Exposed geotextile tubes formerly covered by sand and dune vegetation. Note erosion behind the tubes and under Zone V (BFE = 18 feet) buildings (yellow arrow at left).

Figures 3-18 and 3-19 show buildings at Holly Beach, LA, both of which sustained significant scour around foundations. Of the approximately 20 pile-elevated houses in existence at Holly Beach prior to Hurricane Ike, nearly half experienced significant foundation scour (virtually all of buildings at Holly Beach were destroyed by Hurricane Rita in 2005, and the houses observed by the Ike MAT had been built since 2005).

The amount of scour around pile foundations observed by the Ike MAT far exceeded what current design guidance predicts.

Figure 3-18.
Foundation scour observed at Holly Beach, LA

Figure 3-19. Foundation scour observed at Holly Beach, LA (Zone V, ABFE = 16 feet)

Figure 3-20 shows a case of extreme foundation scour at a house on Bolivar Peninsula. The scour depression shown was reported by a local contractor to have been as much as 10 feet deep. The house was able to withstand the scour and the wind and flood loads acting on the structure, but lack of soil support allowed the bottoms of some of the piles supporting the deck on the right side of the house to be shifted toward the left.

Figure 3-20. Foundation scour was reported to be 10 feet deep—note the bottoms of the piles on the right side of building that have been pushed toward the building (Bolivar Peninsula, TX; Zone V)

In some cases, pile foundations subject to erosion and/or scour were not embedded deeply enough to resist the loads and conditions that were present during Ike. Figure 3-21 shows such a case where a pile foundation shifted under an elevated house. Scour and erosion contributed to the failure. The presence of the attached, but broken, concrete slab could also have contributed to the foundation failure by reducing the lateral support formerly provided by the intact slab, and by causing eccentric loading of the piles (see Section 3.3.3).

Figure 3-21.
Failure of a timber pile foundation undermined by scour and erosion. Inset shows close-up of concrete slab failure and rotation of some of the foundation piles (Galveston Island, TX; Zone V).

One other aspect of scour was noted by the MAT—linear scour features that result in the loss of soil around or under buildings when storm surge flow is channeled or directed across a building site. This process usually takes place where storm surge flow is constrained between large buildings or gaps in shore protection, or when storm surge return flow to the sea follows paths of least resistance, such as along canals and roads (Figure 3-22). Some of the many buildings lost during Ike were likely lost as a result of this process.

Figure 3-22.
Linear scour features tend to align with canals and roads as storm surge returns to the Gulf. Houses such as this one were fortunate not to be undermined and lost during Ike, as many homes undoubtedly were (Bolivar Peninsula, TX).

3.1.1.3 Foundation Function 3: Provide a Continuous Load Path to the Ground

Loads acting on a building follow many paths through the building and must eventually be resisted by the ground, or the building will fail. Loads accumulate as they are routed through key connections in a building (connections between members are usually the weak links in a load path). Load paths must be continuous, from the top of the building, through the foundation, and into the ground; failed or missed connections cause the loads to be rerouted through unintended load paths, potentially overloading those paths and resulting in structural failure. A graphic illustrating vertical and horizontal load paths from an elevated building to the foundation and into the ground is shown in Figure 3-23.

Connections between structural members are often the weak point in a load path, and the MAT observed many load path failures at the floor system-pile connection. The MAT also observed instances where this connection was adequate to prevent structural failure during Ike. Figure 3-24 shows an example of a wood-frame house elevated on concrete columns. The house survived with no structural damage even though the owner reported a flood level above the lowest floor. The attachment of the timber floor beams to the concrete columns provided load path continuity and prevented the house from floating or washing off its foundation (Figure 3-25). Although this house survived Hurricane Ike, this type of connection only provides limited resistance to lateral loads and applied moments—had the house experienced a higher surge or stronger winds, it may not have survived. The MAT estimated the 3-second gust wind speed (Exposure C) during Ike was approximately 85 mph at this site, but if wind speeds or lateral flood loads had been higher, this house could have sustained structural damage.

Figure 3-23.
Example load path through a pile foundation (note: some building components are not shown)

SOURCE: FEMA P-762, *LOCAL OFFICIALS GUIDE FOR COASTAL CONSTRUCTION*

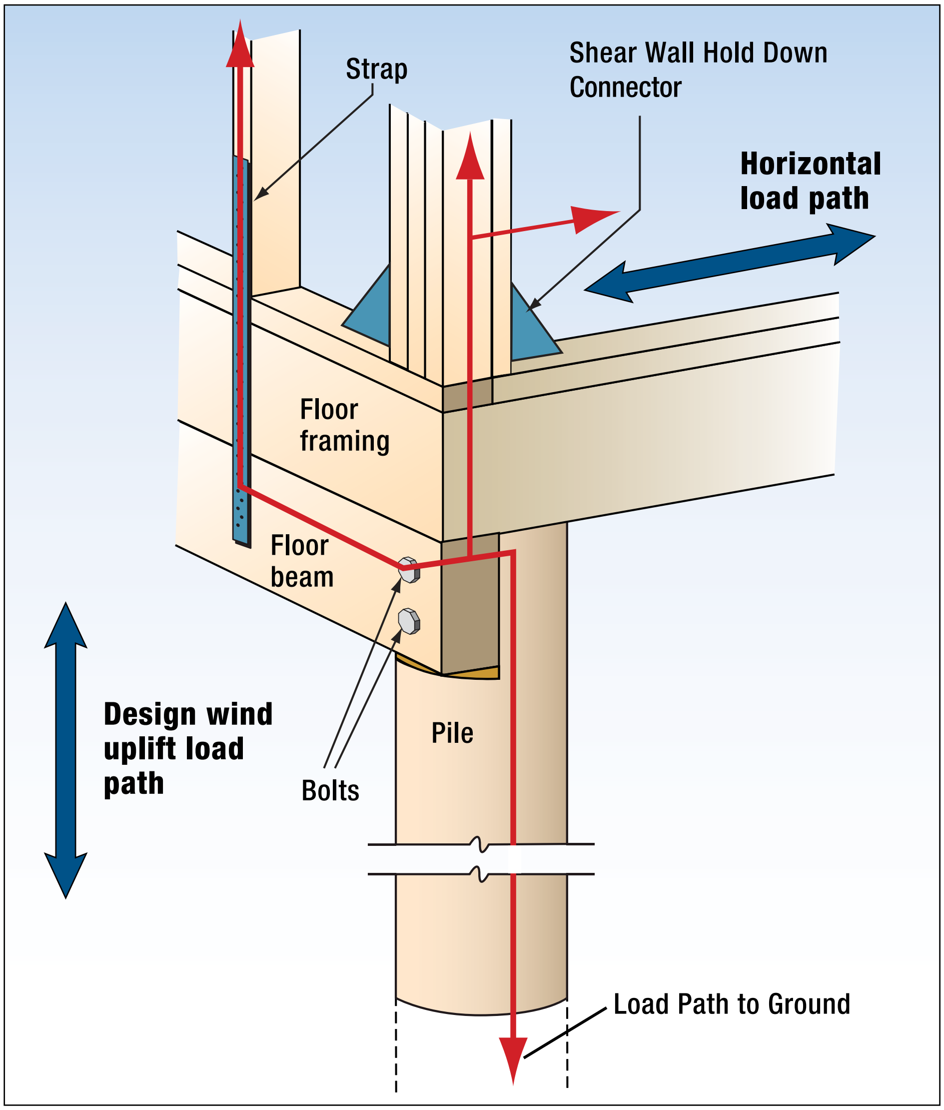


Figure 3-24.
This Bridge City, TX, house sustained no structural damage, despite the fact that the owner reported that Ike flood levels rose above the lowest floor

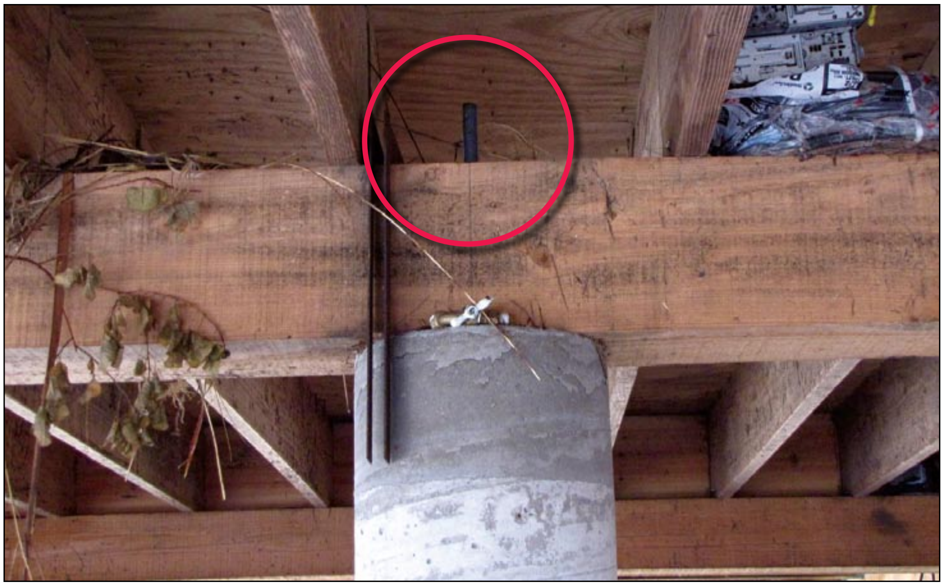


Figure 3-25.
A ⅝-inch diameter galvanized steel anchor bolt in red circle (with washer and nut, not visible in this photograph) provided connections between beam and column for the house shown in Figure 3-24. This does not appear to be an engineered connection.

Some designs rely on connections between columns and beams to provide fixity (resistance to rotation), particularly in commercial or multi-family buildings of concrete construction. Figure 3-26 shows one such example—reinforcing steel that will extend into a concrete beam (under construction) and connect columns and beams. The cast-in-place concrete connection will provide resistance to rotation.

Figure 3-26.
Reinforcing steel extending from the top of a concrete column (building under construction) (Galveston Island, TX)

The MAT noted instances of other types of foundation load path failures, including those at the point where a column attached to a pile cap, slab, or grade beam. Deterioration of timber piles contributed to load path failures in some foundations (Figure 3-27). The deterioration could have been the result of inadequate preservative treatment or poor design/construction practice. In other cases, deterioration was observed that did not result in foundation failure during Ike; however, such a weakened foundation would be more susceptible to failure in the future (Figure 3-28).

Figure 3-27.
Deterioration in the wood piling likely contributed to the foundation failure (Bolivar Peninsula, TX)

Figure 3-28.
Deterioration in wood piling. The foundation did not fail during Ike, but it was weakened and will be more susceptible to failure in the future (Galveston Island, TX).

The MAT also noted cases where houses survived Ike, but must not have been exposed to high winds or large flood loads; otherwise the lack of load path continuity would have resulted in foundation failure. The house shown in Figure 3-29 is resting on top of precast concrete piers, stacked concrete masonry units (CMUs), and shallow footing pads—the necessary structural connections are missing. This design will not provide a continuous load path from the elevated house to the ground, and does not comply with minimum NFIP or building code requirements. This foundation will likely fail if it is subject to high winds and/or waves, velocity flow, or scour. Additional discussion of load paths is provided in Section 3.1.2.3.

Figure 3-29.
House resting (i.e., with no structural connection) on top of precast concrete piers, stacked CMUs, and shallow footing pads (New Iberia, LA)

3.1.1.4 Foundation Function 4: Resist Flood Loads

Flood loads acting on a coastal building can include:

- Hydrostatic loads (pressure from standing or slowly moving water). Vertical hydrostatic forces are known as buoyant forces, and cause objects to float, including houses that are poorly attached to their foundations. Lateral hydrostatic forces will not harm pile or column (open) foundations, but can cause damage to foundation walls and enclosure walls that do not have the flood openings required to allow inside and outside water levels to equalize.

- Hydrodynamic loads (forces caused by fast-moving water, the up-rush of broken waves, etc.). Storm surge flowing past or around a foundation or building will lead to hydrodynamic loads.

- Wave loads (caused by waves breaking on or striking a building foundation). Wave loads are high magnitude, short duration loads that can cause rapid destruction of inadequately elevated or constructed buildings. Hundreds of waves can strike a building during an episode of hurricane flooding.

- Floodborne debris impacts (parts of broken structures striking a building, or becoming lodged in a building foundation and transferring other flood loads to the foundation). Large numbers of buildings destroyed by flood forces contributed to large quantities of floodborne debris, and undoubtedly led to additional building failures during Ike.

Flood damages to residential buildings observed by the MAT were consistent with the nature and magnitudes of the flood loads described above.

- In locations where waves were small and flood velocities were low, there was little damage to houses elevated above the flood level on NFIP-compliant foundations. Houses constructed at grade, or not elevated high enough above the ground to escape the flooding, were inundated and sometimes dislodged from their foundations.
- In locations where waves were larger, flow velocities were greater, and floodborne debris generation was significant. Houses not elevated high enough were severely damaged or destroyed. Houses elevated above the wave crest level were still subject to damage or destruction if their foundations could not withstand the flood loads and failed.

The typical wave damage patterns described above are illustrated in Figure 3-30. Damage to properly designed and constructed elevated houses is generally minor until the waves reach the elevated floor system, at which point the damage increases dramatically with increasing water level and wave height. The importance of adding freeboard—elevating above the wave crest level—is apparent (see Section 3.1.3 and the Ike Recovery Advisory, *Designing for Flood Levels above the BFE).*

Typical, low-rise residential buildings near the shoreline can be designed and constructed to resist wind loads, but must be elevated high enough on a pile or column (open) foundation to avoid flood loads.

Wind pressures acting on walls of low-rise buildings are almost always less than 100 pounds per square foot (psf), and these loads can be resisted easily by proper design and construction. However, fast-moving storm surge and floodborne debris can exert pressures several times higher than wind pressures against a building wall. Wave pressures against walls can reach several hundred, or in extreme cases, thousands of psf.

Even lateral flood loads acting on pile or column foundations can reach 1,000 pounds or more against each pile or column. These loads can be resisted, but only by properly designed and constructed open foundations.

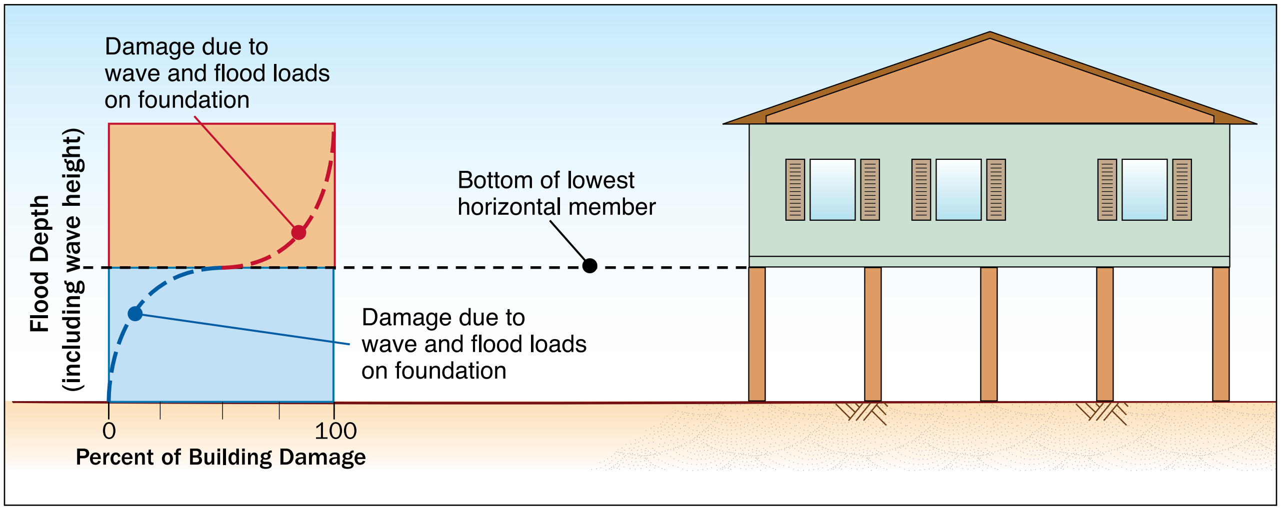


Figure 3-30. Idealized depth-damage relationship for an elevated building subject to waves

An estimated 3,600 buildings, (approximately 61 percent of the pre-Ike buildings) on Bolivar Peninsula were destroyed by Hurricane Ike, and approximately 2,200 (37 percent) more were damaged (Halff Associates, 2008). Much of the Peninsula was inundated by an estimated 6 to 10 feet of stillwater, and experienced wave effects above that level—meaning that Ike flood levels exceeded the BFE for virtually all of the Peninsula. This would explain the widespread loss of elevated houses on the Peninsula, and the survival of only those houses elevated the highest, with deep foundations resistant to waves, debris, storm surge, erosion, and scour.

Wave effects and floodborne debris impacts were a major cause of building structural failure during Hurricane Ike, both on lands near the Gulf of Mexico and immediately adjacent to many bay-front shorelines. Damage was more severe and widespread along the Gulf shoreline, as would be expected, since the wave heights were larger there. Also, the loss of many buildings along the Gulf shoreline added greatly to the debris stream available to strike and damage other buildings farther inland.

It is not always possible to separate damages caused by waves alone from that caused by floodborne debris, especially since the debris is carried by the surge and waves. However, the direct and indirect effects of waves should be considered one of the two most damaging aspects of coastal flooding for coastal residential buildings (erosion and scour being the other).

Figure 3-31 shows a comparison of pre- and post-Ike photographs for the Crystal Beach area of the Bolivar Peninsula. The Peninsula is the region where Hurricane Ike storm surge levels and wave heights appear to have reached maximums along the Gulf shoreline. Buildings along the Gulf shoreline of the Peninsula were likely subject to the greatest flood forces during Ike, and sustained the worst damage. Damage in this area has been compared to the Mississippi coast following Hurricane Katrina.

Figures 3-32 and 3-33 show examples of houses affected by waves and the inland penetration of large debris fields. The combination of waves and debris led to the destruction of many houses on Bolivar Peninsula.

Figure 3-31.
Pre- and post-Ike aerial photographs of the Crystal Beach area of Bolivar Peninsula, TX
SOURCE: USGS[1]

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[1] http://coastal.er.usgs.gov/hurricanes/ike/photo-comparisons/bolivar.html

Figure 3-32.
Seaward side of Zone V house struck by waves. The deck, the elevated floor system, and the seaward walls were destroyed or heavily damaged (Bolivar Peninsula, TX).

Figure 3-33.
Roofs, walls, and other parts of destroyed houses washed landward to and inland of this location, approximately ½ mile from the Gulf shoreline of Bolivar Peninsula, TX

Although flood levels and wave conditions were not as severe on Galveston Island as on the Bolivar Peninsula, many houses were also lost there, largely as a result of waves and erosion. Figure 3-34 shows one example, approximately 3 miles west of the seawall, where two Gulf-front houses were lost.

Figure 3-34.
Broken piles beneath destroyed Gulf-front houses, Galveston Island, TX (west of the seawall)

Figures 3-35 and 3-36 show examples of Ike wave damage typical for Galveston Bay, where wave heights were less than those on the Gulf shoreline. These at-grade buildings were gutted or destroyed by storm surge, waves, and floodborne debris. In both cases, nearby buildings elevated on pile foundations survived, with damage only to breakaway walls and access stairs.

Figure 3-35.
Damage to at-grade house in Zone V likely caused by wave and surge along the northern Galveston Bay shoreline in Baytown, TX

Figure 3-36.
Likely wave and debris damage to townhouse building along the western Galveston Bay in Seabrook, TX. The building was supported on shore-parallel masonry walls, and is landward of another building that was destroyed by Ike.

3.1.2 Main Wind Force Resisting System

According to ASCE 7-05, the MWFRS is an assemblage of structural elements that provide support and stability for the overall structure. The MWFRS can be thought of as the portion of a building's structural frame that collects wind loads from the building envelope and transfers those loads to the ground via the building's foundation. Elements of the building envelope that do not qualify as a part of the MWFRS are identified as C&C. While some may consider the foundation to be part of the MWFRS, the following discussion will focus on that portion of the structural system above the foundation.

3.1.2.1 High Winds

High winds can originate from a number of events—tornadoes, hurricanes, extra-tropical cyclones, and other coastal storms. The most current design wind speeds are given by the national load standard, ASCE 7-05. Figure 3-37, taken from ASCE 7-05, shows the geographic distribution of design wind speeds for Gulf of Mexico and Atlantic Ocean portions of the United States.

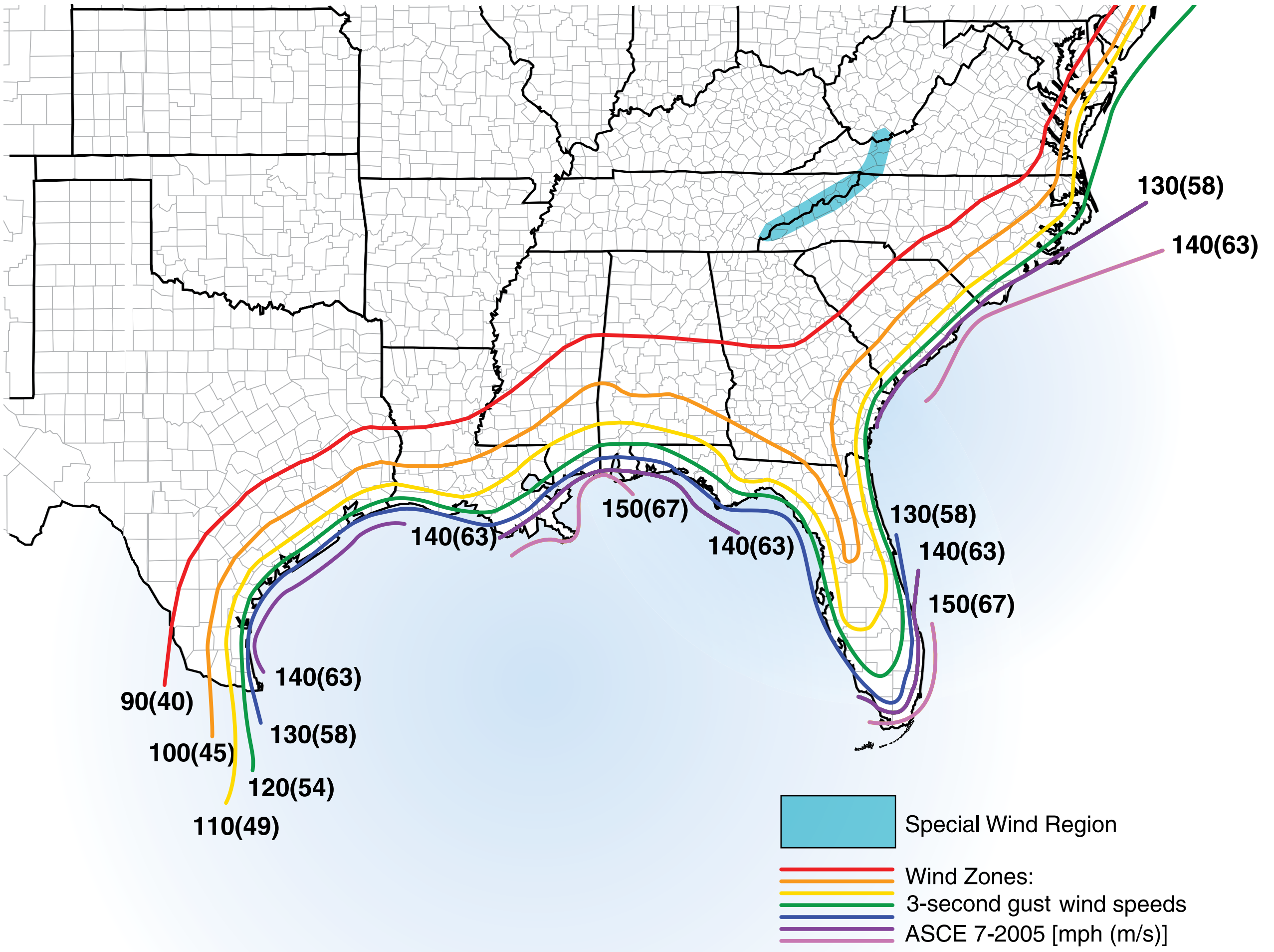


Figure 3-37. ASCE wind speed map (ASCE 7-05)

High winds are capable of imposing large lateral (horizontal) and uplift (vertical) forces on buildings (see Figure 3-38). Residential buildings can suffer extensive wind damage when they are improperly designed and constructed and when wind speeds exceed design levels. The damages shown in Figures 3-39, 3-40, and 3-41 exemplify poor design and construction, since Ike's winds were less than design levels.

The effects of high winds on a building will depend on several factors:

- Maximum wind speeds, gustiness of the winds, wind directions, and duration of high winds
- Height of building above ground
- Exposure or shielding of the building (by topography, vegetation, or other buildings) relative to wind direction
- Topographic effects (hills and escarpments) that create wind speedup
- Strength of the structural frame, connections, and envelope (walls and roof)
- Shape of building and building components

- Number, size, location, and resistance to damage of openings (e.g., windows, doors, and vents)
- Presence and strength of shutters or opening protection
- Type, quantity, and velocity of windborne debris

Proper design and construction of residential structures, particularly those close to open water or near the coast, demand that every factor mentioned above be investigated and addressed carefully. Failure to do so may ultimately result in building damage or destruction by wind. Hurricane Ike winds removed the roof structure on the house shown in Figure 3-41. Hurricane straps could have been added, thereby greatly increasing the resistance to wind. Refer to IBHS 2005 Standards for proper connection of roof structural elements.

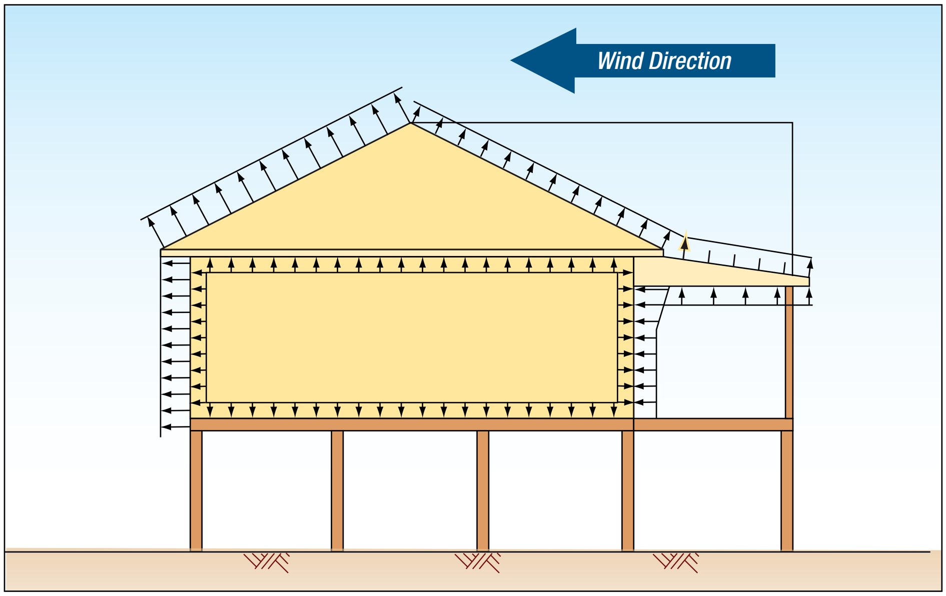


Figure 3-38.
Code-defined MWFRS wind loads on an elevated residential structure
SOURCE: FEMA 55

Figure 3-39.
Galveston, TX, West End Beach house with roof structure removed by Hurricane Ike.
The cause of the failure is unknown, but Ike wind speeds in this area were below design speeds (Hurricane Ike estimated wind speed in this area: 93 mph, Exposure C).

Figure 3-40.
This West Bay, Galveston Island, TX, apartment experienced gable-end wind damage as a result of sheathing failure and poor connection of the brick veneer to the stud walls (Hurricane Ike estimated wind speed in this area: 90 mph, Exposure B)

Figure 3-41.
The roof structure was poorly connected to this house in Grand Isle (Jefferson Parish, LA) and was blown off by 50-mph Ike winds (Exposure B)

3.1.2.2 Combination of Loads – MWFRS and C&C

Some elements of low-rise buildings are considered to be part of the C&C or part of the MWFRS, depending upon the wind load being considered. Using the example of the exterior walls of a masonry building, the MWFRS provisions are used to determine the in-plane shear forces in the design of these masonry walls, and the C&C provisions are used to determine the out-of-plane design bending loads.

The pressure (positive/inward or negative/outward suction) exerted by wind flowing over and around a building varies with time and location on the building. The highest pressures occur over small areas for a very short time in the regions of a building where the wind flow separation is quite significant (such as at corners of roofs and walls, ridges, hips, and overhangs). This flow separation can cause small vortices to form that can cause much higher pressures in small localized areas. These flow separation regions generally occur along the edges of the roof and corners of exterior walls (see Figures 3-42 and 3-43). Therefore, the design wind pressures for the design of the C&C element can be nearly three times the pressure used to design the structural framing of the building. Proper assessment of the design wind pressures is critical to developing the design of a building's structural frame and the selection of appropriate exterior cladding.

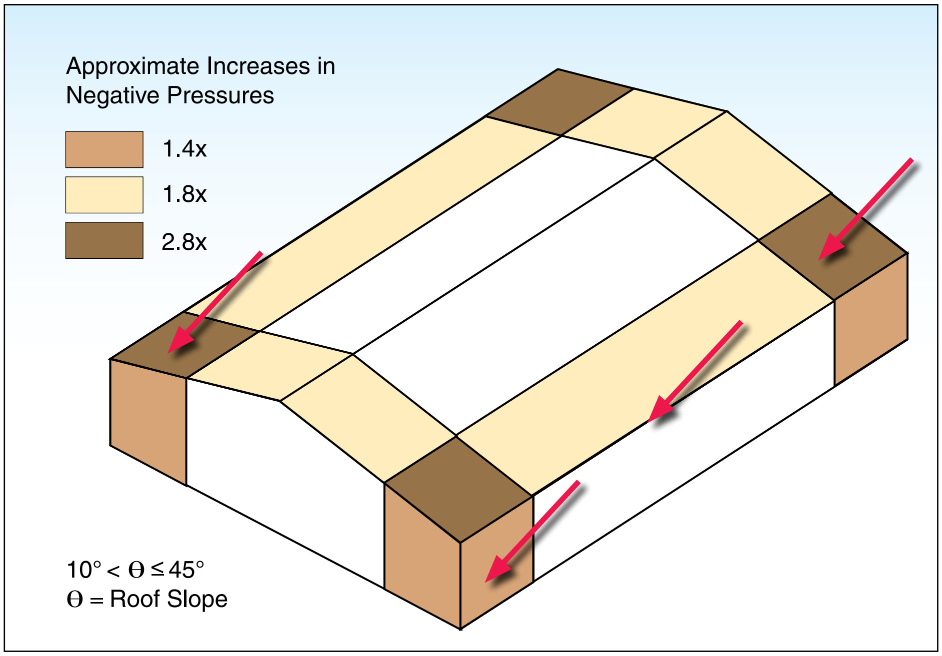


Figure 3-42.
Areas of roof covering loss (red arrows) indicate zones of higher wind pressure on a roof

Figure 3-43.
Galveston, TX, West End Beach house with roof damage in high pressure zones (Hurricane Ike estimated wind speed in this area: 95 mph, Exposure C)

In addition to these external pressures, openings and the natural porosity of the building components contribute to internal pressures. As seen in Figure 3-44, internal pressures introduced by building openings are additive to (or subtractive from) the external pressures. The magnitude of the internal pressures depends on whether the building is “enclosed,” “partially enclosed,” or “open” as defined by ASCE 7-05. In hurricane-prone regions as defined by ASCE 7-05, in order for a building to be considered “enclosed” for design purposes, glazing must either be impact-resistant or protected with shutters or other devices that are impact-resistant. This requirement also applies to indoor glazing and skylights. Refer to Section 3.2.4 for the discussion on windows and shutters and their performance in Hurricane Ike. As previously stated, Hurricane Ike was not a wind design event and therefore the MAT did not observe any notable examples of building failures resulting from internal pressurization.

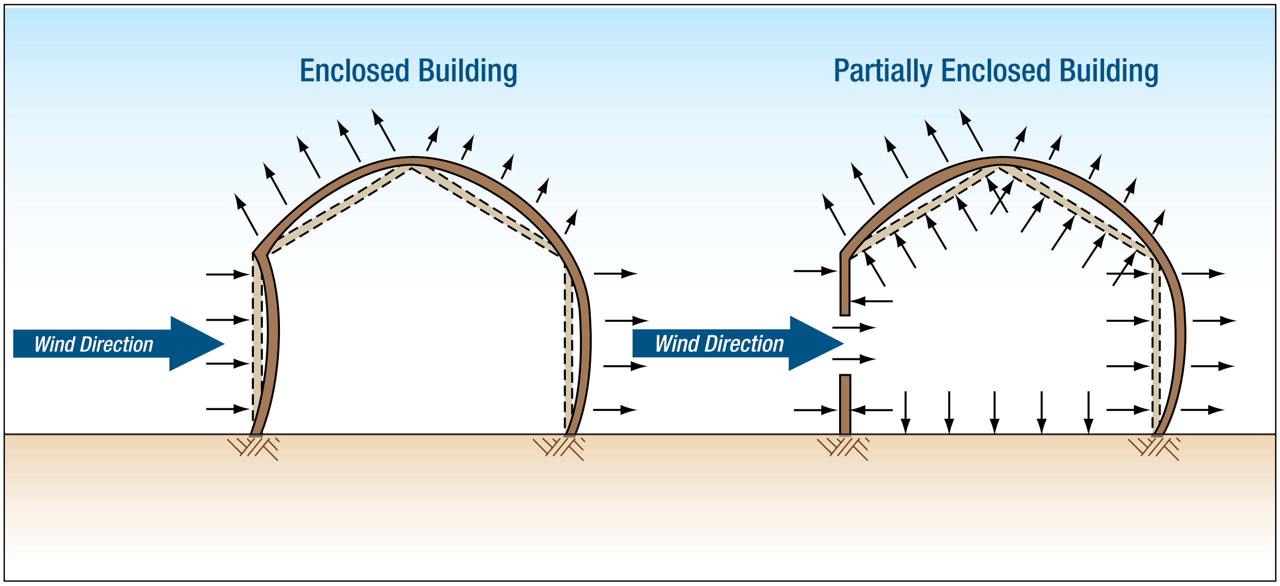


Figure 3-44.
Effect of wind on an enclosed building and a building with a wall opening producing a partially enclosed building by allowing internal pressurization of the structure

3.1.2.3 Load Paths

Figures 3-45 and 3-46 illustrate the load path concept for the elevated portion of a building. Wind loads collected and concentrated as shown in these figures must be passed through the foundation to the ground (see Figure 3-23).

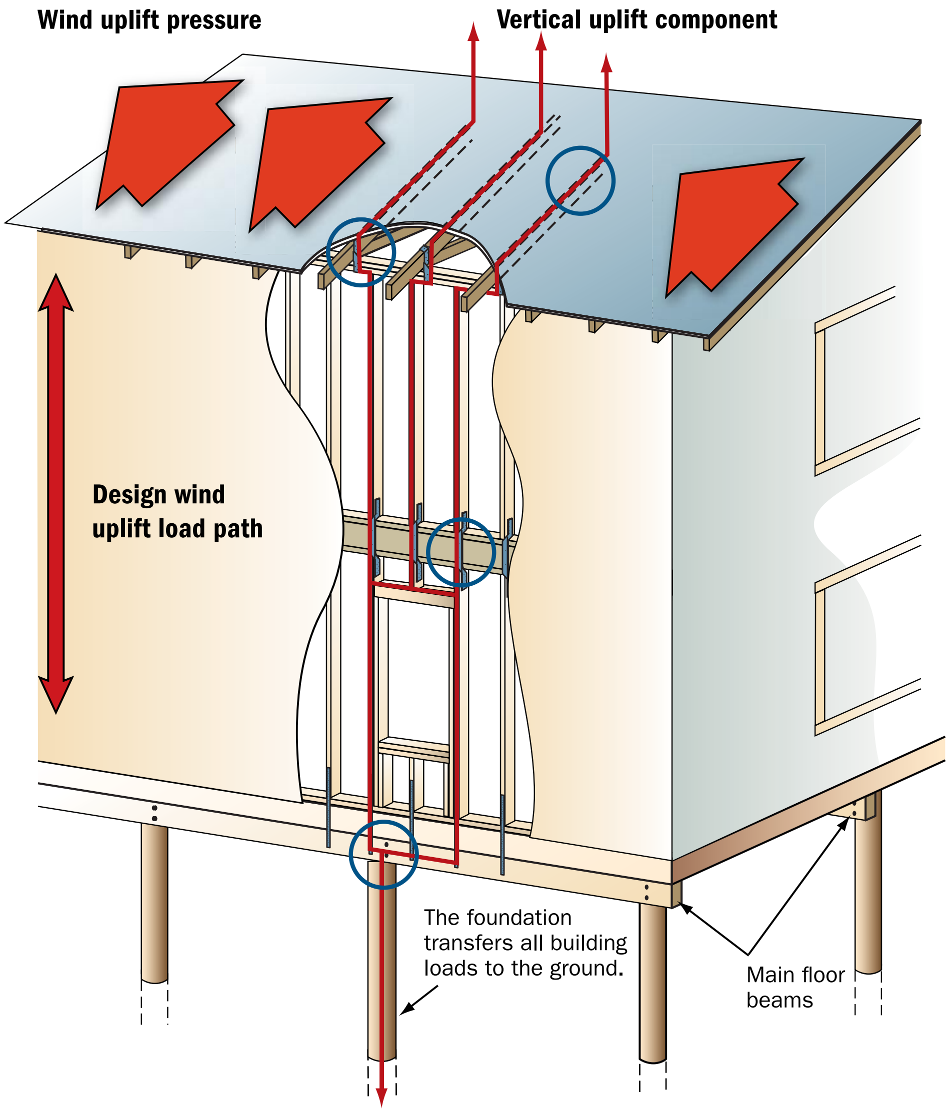


Figure 3-45. Depiction of a building load path

SOURCE: FEMA 489

Figure 3-46.
Load path around openings and connection to foundation pile
SOURCE: FEMA 499

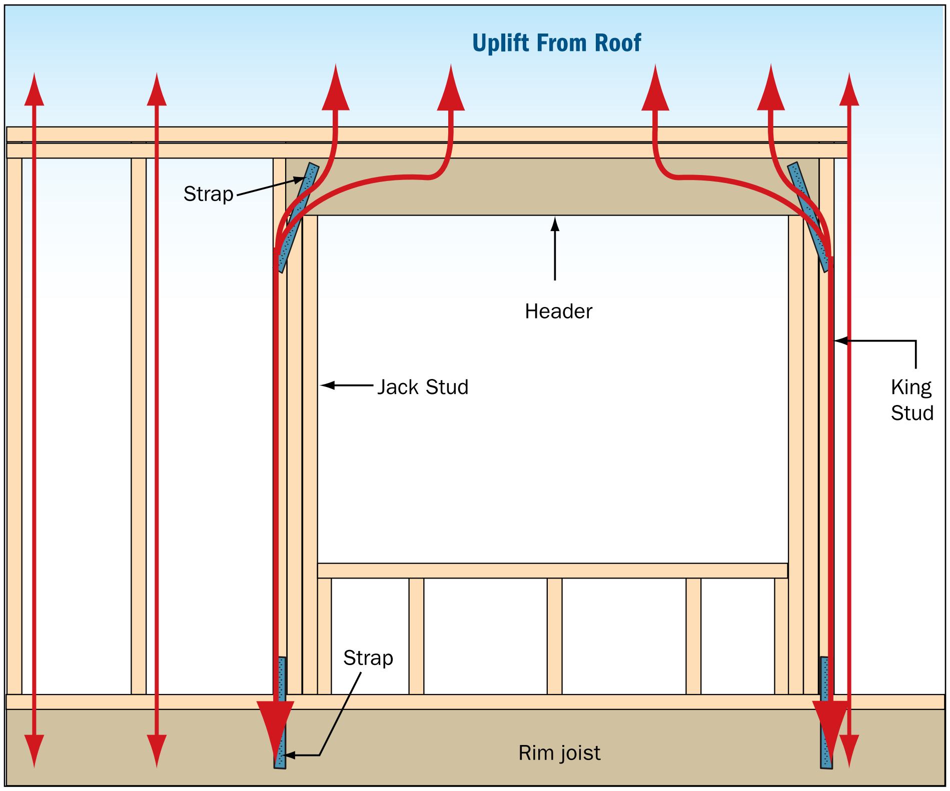


Figure 3-47 shows a house on western Galveston Island that collapsed during Ike. High water levels and waves acted on the foundation while winds (blowing from land toward the Gulf of Mexico) pushed the house seaward. The result was a foundation failure—the foundation could not provide the required load path continuity to the ground without breaking.

Figure 3-47.
Collapse of a West Galveston Island, TX, house due to foundation failure

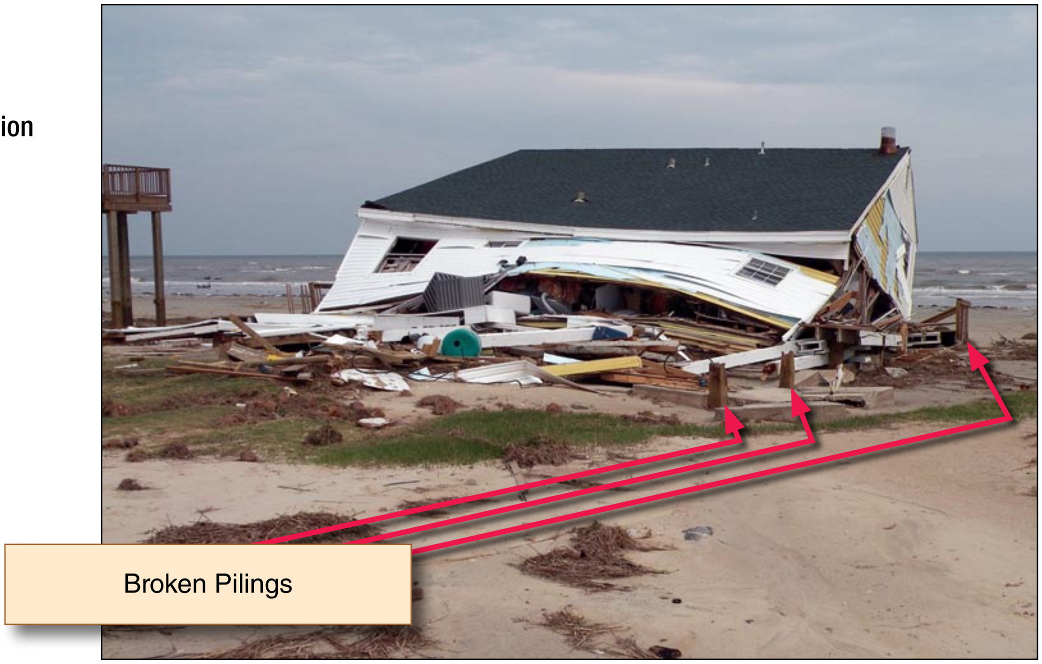


Figure 3-48 shows a house on Bolivar Peninsula that remained standing although severely damaged by surge, waves, and wind. The house survived because its MWFRS and foundation load paths remained intact.

**Figure 3-48.
Though much of the cladding and structural sheathing was destroyed by Ike's surge, the MWFRS of this Bolivar Peninsula, TX, beach house remained intact and connected**

Piling connections to floor beams of elevated structures were routinely observed by the MAT. However, unless the building was substantially damaged or under construction, most load path connections of wall and roof structural elements were covered by building finishes and not visible for inspection. Some beam-to-piling connections were found to be strong and robust as seen in Figures 3-49 and 3-50. Many others were weakly connected with nails, too few bolts, or columns weakened by deep mortises (Figures 3-51).

**Figure 3-49.
Strong concrete column-to-beam steel saddle connector**

Figure 3-50.
Strong interior wood column-to-beam connector with building shear wall connector

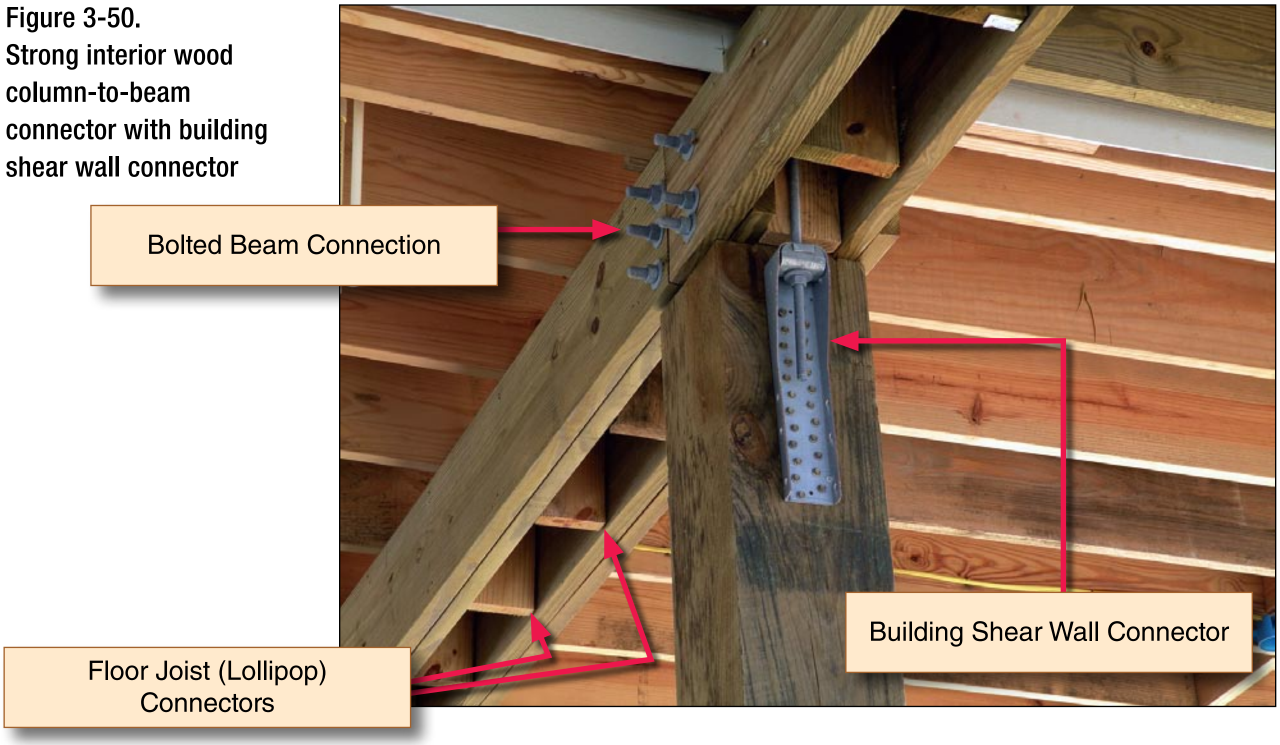


Figure 3-51.
Poor beam connection to corner column

New construction was frequently observed with robust construction such as sill plates bolted to slabs-on-grade, studs clipped to double top plates, and wall-to-roof construction (Figures 3-52, 3-53, and 3-54).

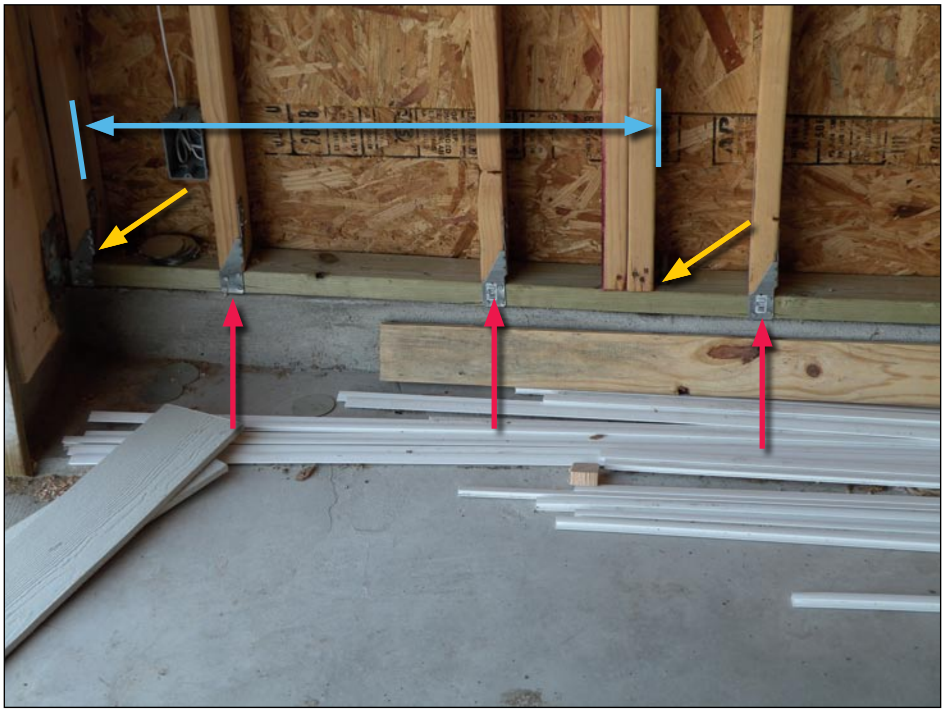


Figure 3-52.
Studs and sill plate connected in new house (sill bolts yellow arrows and clips red arrows). However, sill bolts are spaced too far apart (2 feet is the maximum spacing allowed) and did not have 3-inch by 3-inch by 1/8-inch washers per 2003 IRC and TDI-adopted IBHS guidelines. Blue line shows 3-foot spacing (Webster, TX).

Figure 3-53.
Studs clipped to double top plate; rafter-to-top-plate connector has yet to be installed. Better framing practices could have avoided some of the problems shown in this photo. Ceiling joists are not well nailed to the rafter and may twist in the future. The builder did not take advantage of aligning wall framing and rafter framing to simplify connections for wind loads.

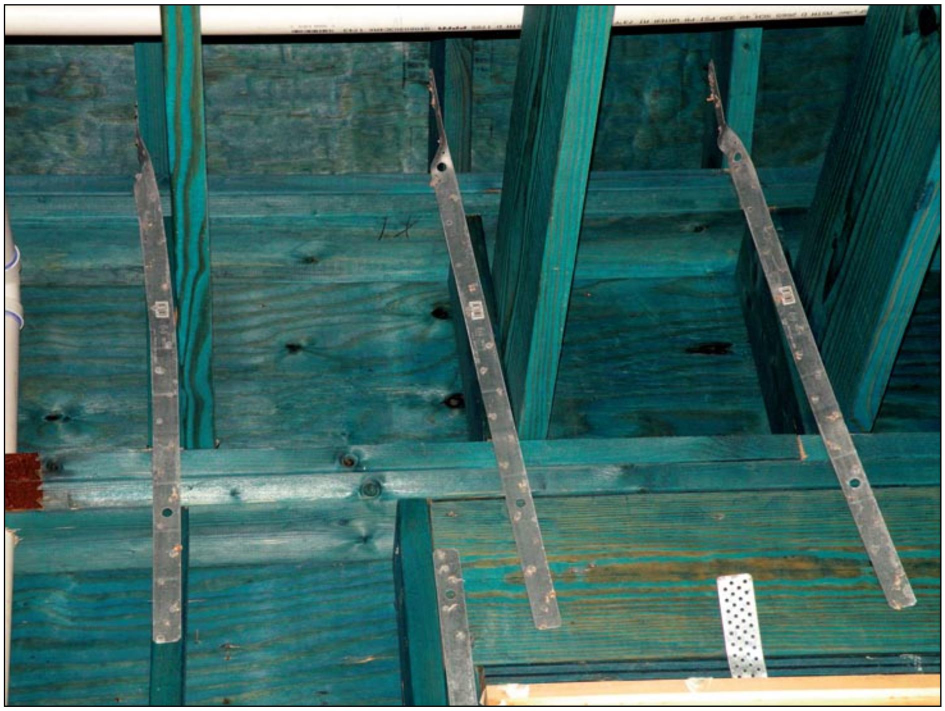


Figure 3-54.
Wall-to-roof strapping. Details for uncommon framing details should be specifically provided by the designer on building plans, including specifying the specific connection and application to ensure a continuous load path.

Numerous new and older houses, however, were observed without proper hurricane connections or improperly installed connections (Figures 3-55 and 3-56).

Figure 3-55.
Toe-nailed connection of floor joists on band beam on house under construction. Floor joist should be installed using either galvanized metal joist hangers or ledger beams (LaPorte, TX).

Figure 3-56.
Existing house shear wall connector incorrectly located (red arrow). Connector should be located on column line or the beam and beam-to-column connection should be designed to resist the uplift load, which is carried by a nailed connection in the absence of bolts (Sunset Crystal Beach, Bolivar Island, TX).

3.1.3 Elevation and Freeboard

The observations of the Ike MAT investigation clearly demonstrate the importance of elevating buildings above the flood level, including any effects of waves and floodborne debris. Elevating only to the BFE does not guarantee a house will remain free of flood damage during a specific hurricane or coastal flood event. As was stated in Section 2.1.1, FISs and FIRMs may not depict the true lateral and vertical extents of actual flooding during the base flood event (100-year flood event) for a variety of reasons. Nor will construction to the 100-year flood event shown on the maps offer protection against floods that exceed the true base flood.

The key to successful coastal buildings is to construct them higher than the BFE by adding freeboard. The desired amount of freeboard will depend on a number of factors, but the age of the FIRM and the nature of the building being constructed are the most important factors. Old FIRMs tend to be less accurate than newer FIRMs in showing the contemporary 1-percent-annual-chance flood level. Critical facilities should be constructed with higher freeboard than typical residential and commercial structures.

The MAT recommends any post-Ike reconstruction and new construction in Ike-flooded areas be carried out with a minimum of 3 feet of freeboard above the BFEs shown on the Effective FIRMs at the time of Ike (refer to Section 3.1.1.1 for additional information). Freeboard is necessary to compensate for out-of-date flood hazard maps and to provide an additional degree of flood protection not afforded by the Effective FIRMs.

3.1.4 Siting Effects on Structural Performance

While many people recognize that how buildings are constructed will affect flood damage to that building (e.g., building floor elevation and foundation design), they may not appreciate the importance of where buildings are constructed in determining flood damage. Post-hurricane inspections typically observe the greatest flood damage, loss of coastal buildings, and loss of roads and infrastructure in the area closest to the shoreline. This was also the case with Hurricane Ike.

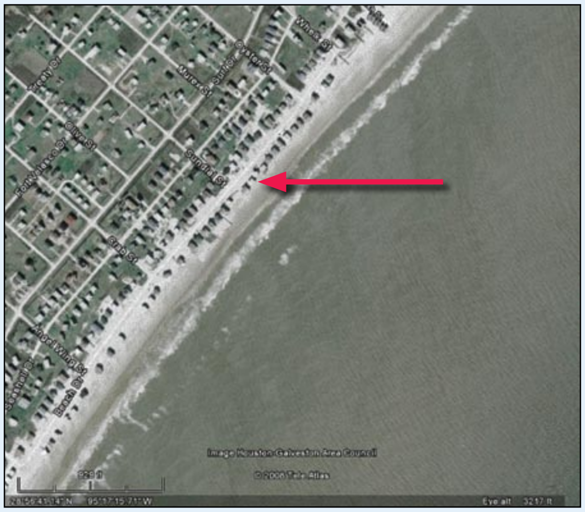
The greatest damage occurs in the area closest to the water since buildings and infrastructure situated there are subject to the most extreme flood forces and conditions during a hurricane, i.e., the highest waves and the greatest erosion (Figures 3-57 and 3-58). Buildings situated closest to the shoreline are also at greatest risk for the effects of long-term erosion, sea level rise, and other long-term changes affecting the shoreline (see Surfside Beach text box).

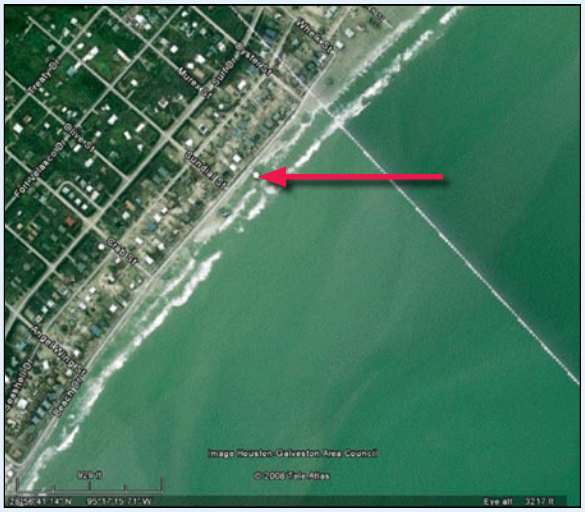
Figure 3-57.
Post-Ike photograph of West Galveston Island, TX, illustrating increased severity of flood damage near the shoreline

Figure 3-58.
Post-Ike photograph of Bolivar Peninsula, TX, illustrating increased severity of flood damage near the shoreline

SURFSIDE BEACH, TX

The closer a building is located to the shoreline, the more vulnerable it becomes. This is not only due to the increasing flood forces close to the shoreline, but also because a building's foundation designed for a given location and set of conditions (ground elevation, stillwater flood depth, wave height, etc.) will find itself exposed to a different set of conditions (lower ground, higher wave height, etc.) as the shoreline erodes over time, and the building may not be able to withstand those new conditions. A classic case is Surfside Beach, TX, where long-term erosion had resulted in dozens of houses standing on the beach, seaward of the line of vegetation. Many of these houses were ordered removed by the State of Texas; some were removed, but others remained and litigation resulted. Hurricane Ike destroyed most of the houses standing on the beach (see photos below).





The presence of reinforced dunes and revetments and seawalls can reduce damage slightly in areas close to the shoreline when those dunes and erosion control structures remain intact during a storm event. However, when they fail they offer little protection to upland buildings. Of the structures observed by the MAT, only the Galveston Seawall provided significant protection to buildings against wave attack and erosion. The recently completed Surfside Beach revetment appears to have survived Ike with minor damage, and undoubtedly offered some protection to upland buildings, but this revetment was not subject to the extreme forces that the Galveston seawall and shorelines farther east were.

Although wave and erosion effects in the bays were not as severe as on the Gulf coast, buildings sited close to the bay shoreline were at increased risk to flood damage, relative to buildings farther from the bay shoreline.

3.2 Envelope Damage

The MAT observed building envelope damage as far west as the west end of Galveston Island, TX, and as far east as Terrebonne Parish, LA, a distance of approximately 150 miles. The MAT also observed building envelope damage as far inland as the north side of the City of Houston, approximately 45 miles from the coast (see Figure 1-16). Sections 3.2.1 through 3.2.6 describe building envelope performance, including roof systems, non-load-bearing walls and wall coverings, doors, windows and shutters, soffits and roof ventilation, and exterior-mounted equipment.

Blow-off of building envelope components frequently results in damage to adjacent buildings and vehicles, as well as the building itself. The most notable building envelope issues during Hurricane Ike, and the most common windborne building envelope debris, were roof coverings and vinyl siding. Figure 3-59 illustrates the magnitude of building envelope debris that occurred in some areas.

As expected, the building envelope on older houses did not perform as well as on new houses. Specifically, houses constructed prior to 1985 in Texas and prior to the adoption of the IRC in 2005 in Louisiana exhibited the poorest envelope performance. Post-1985 Texas home construction in the counties affected by Hurricane Ike were governed by the Texas Windstorm Program (refer to Section 2.3), and all post-2005 houses in Louisiana were governed by the newly adopted IRC.

The extent and magnitude of envelope damage observed by the MAT was greater than would be anticipated given that the estimated actual wind speeds of Hurricane Ike were less than the design speeds given by ASCE 7-05 and IRC 2006. The poor performance of the newer houses is therefore related to the lack of contractor knowledge of proper hurricane construction, material installations not conforming to manufacturer's requirements for hurricane zones, and poor code enforcement.

Figure 3-59.
A substantial amount of siding (the white lines scattered around the ground), along with roofing materials, blew off these West Galveston, TX, houses (Hurricane Ike estimated wind speed in this area: 90 mph)

3.2.1 Roof Systems

Historically, damage to roof coverings is the leading cause of building performance problems during hurricanes. In the rains accompanying a hurricane, rainwater entering a building through damaged roofs can cause major damage to the interior finishes and contents. Unless quick action is taken to dry a building, mold bloom can quickly occur in the hot, humid southern climate. Drying of buildings was hampered after Hurricane Ike by the lack of electrical power to run fans and dehumidifiers.

LIQUID-APPLIED ROOF COVERING

The MAT observed one residence that had a liquid-applied roof covering over a concrete deck. FEMA investigations after Hurricane Marilyn (1995) in the U.S. Virgin Islands found that this type of roof covering has excellent wind performance.

The MAT observed a variety of roof coverings, including asphalt shingles, metal panels, metal tiles, and tile. In the areas observed by the MAT, roof covering damage was common, and quite variable as shown in Figure 3-60. This type of variability is consistent with what was observed by the Hurricane Charley, Ivan, and Katrina MATs (see FEMA 488, *Hurricane Charley in Florida: Observations, Recommendations, and Technical Guidance* [April 2005a]; FEMA 489, *Hurricane Ivan in Alabama and Florida: Observations, Recommendations, and Technical Guidance* [August 2005e]; and FEMA 549, *Hurricane Katrina in the Gulf Coast: Building Performance Observations, Recommendations, and Technical Guidance* [July 2006b]).

Figure 3-60.
Some of the roofs on these Jamaica Beach, TX, houses had no roof covering damage, while one had moderate damage (blue arrow) and one had extensive damage, including loss of underlayment (red arrow) (Hurricane Ike estimated wind speed in this area: 90 mph)

At several residences, a large amount of roof covering was blown away, as shown in Figures 3-60, 3-66, 3-67, and 3-69. However, more commonly, roof covering damage was limited to a small area such as at corners, eaves, rakes, or ridges. In the case of asphalt shingled roofs, sometimes a few shingles in the field of the roof were blown away. Had Hurricane Ike's winds been closer to current design wind speeds, the roof covering damage would likely have been greater. The following subsections present asphalt shingle, metal panel, and tile roof observations.

3.2.1.1 Asphalt Shingles

Most of the residences observed by the MAT had asphalt shingle roof coverings. There were two notable observations, as discussed below: 1) use of shingles that had been tested and labeled in accordance with relatively new criteria, and 2) the use of roof tape at deck sheathing joints.

New Shingle Labels. Asphalt shingles are now available with Class D, G, or H labels (see text box). At the time of Hurricane Katrina (2005), only a limited number of shingles were available with the new ratings. However, several products are now available with the new classifications.[2]

ASPHALT SHINGLE CLASS RATINGS

Testing and labeling is prescribed in ASTM D 7158.* The following classes of shingles are specified in this standard:

Class D: Suitable for use up to 90 mph

Class G: Suitable for use up to 120 mph

Class H: Suitable up to 150 mph

Class F: Shingles with this classification are tested in accordance with the old test method prescribed in ASTM D 3161, a test method widely recognized as antiquated for evaluating the wind resistance of self-sealing shingles

* Wind speeds cited are design wind speeds in IBC/IRC/ASCE 7 (based on Exposure C, and a maximum mean roof height of 60 feet).

Figure 3-61 shows a shingle bundle wrapper at a house under construction at the inset in Figure 3-61. The shingle bundle wrappers indicate the shingles meet Class H (i.e., suitable for up to 150 mph). The IRC/ASCE 7 design wind speed for this locaton is 120 mph, hence use of a Class G shingle would have been sufficient. This is the first and only house observed by a MAT wherein it was known that shingles meeting one of the new Class ratings was installed. There was no apparent wind damage to this house.

The MAT observed several other newly installed roofs, but was unable to determine if the shingles met any of the new classifications. Even if the shingles did meet Class G or H, failure could have initiated along the rake, eave, or hip/ridge unless there was special securement (such as that shown in Technical Fact Sheet 20, *Asphalt Shingle Roofing for High-Wind Regions*, in FEMA 499), as described below.

The newly constructed house shown in Figure 3-62 is on the same block as the one shown in Figure 3-61. Bleeder strips were installed along the rake; however, as discussed in Section 5.4.1.3 of the Katrina MAT report (FEMA 549), unless the shingles are hand-tabbed as described in Technical Fact Sheet 20, bleeders do not provide reliable securement.

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[2] See the following TDI Web site for product listings: http://www.tdi.state.tx.us/wind/documents/ashglcnf08ibcircrev031009b.pdf

Figure 3-61.
View of a shingle bundle wrapper at the Webster, TX, house shown in the inset. This shingle has a Class H rating (red arrow) (Hurricane Ike estimated wind speed in this area: 104 mph).

Figure 3-62.
Shingle damage at a house near the one shown in Figure 3-61 (Webster, TX)

Figure 3-63 shows a house under construction on Bolivar Peninsula that lost shingles along the eave (it is also shown on the front cover of this report). Failure along eaves commonly occurs because of incorrect application of the starter course and lack of hand-tabbing (as recommended in Technical Fact Sheet 20). For further discussion of eave issues, see Section 5.4.1.2 in FEMA 549.

Figure 3-63.
Loss of shingles along the eave in Bolivar Peninsula, TX (Hurricane Ike estimated wind speed in this area: 110 mph)

Figure 3-64 shows a house that was reportedly constructed in 2005 on Bolivar Peninsula. It lost shingles and underlayment at a corner area (red circle at the inset) and shingles in the field of the roof near the exhaust fan (blue arrow). Loss of shingles was likely due to lack of hand-tabbing. These shingles reportedly met Class F.

Figure 3-64.
Loss of shingles and underlayment in a corner area, and loss of shingles from the field of this roof in Bolivar Peninsula, TX (Hurricane Ike estimated wind speed in this area: 110 mph)

Figure 3-65 shows a house under construction on Bolivar Peninsula. It lost shingles along the hip. Also, at areas along the exposed hip, either the underlayment did not completely lap over the hip line, or if it did, portions of the underlayment blew away. Water could leak into the building in the vicinity of the two red arrows. Unless hip and ridge shingles are hand-tabbed, as recommended in Technical Fact Sheet 20, they are very susceptible to blow-off (for further discussion, see Section 5.4.1.1 in FEMA 549).

Taping of Sheathing Joints. Figure 3-66 shows some relatively new *Fortified…for safer living®* houses in the Audubon Village area of Bolivar Peninsula (refer to Section 3.1.1.1 text box for more information on *Fortified…for safer living®* homes).

As shown in Figure 3-66, some of the roof coverings had no apparent damage, but the shingles and underlayment were blown off of one roof (red arrow). Also, a portion of the roof overhang blew off of one of the houses (blue arrow). When the MAT observed blow-off of roof framing and/or sheathing, it typically occurred on older buildings, rather than new construction.

Figure 3-65.
Loss of hip shingles and portions of the underlayment in Bolivar Peninsula, TX (Hurricane Ike estimated wind speed in this area: 110 mph)

Figure 3-66.
Roof covering and roof structure damage at *Fortified... for safer living*® houses in the Audubon Village area on Bolivar Peninsula, TX (Hurricane Ike estimated wind speed in this area: 110 mph)

The *Fortified...for safer living*® requirements include special provisions pertaining to attachment of roof underlayment in order to make them more wind-resistant in the event the shingles are blown off. The MAT was unable to determine whether or not the failed underlayments complied with the *Fortified...for safer living*® requirements. However, according to IBHS investigators deployed after Hurricane Ike, two layers of #15 felt were installed. (Use of two layers of #15 is one of the underlayment options in the current *Fortified...for safer living*®.) The underlayment was attached with plastic capped-head nails, spaced at 6 inches on center along the laps and 12 inches on center in the field (this spacing is consistent with the original *Fortified...for safer living*® spacing guidance). This underlayment and attachment spacing is consistent with underlayment Option 2 in Technical Fact Sheet 19, *Roof Underlayment for Asphalt Shingle Roofs*, in FEMA 499.

The *Fortified...for safer living*® requirements also include a requirement to tape the sheathing joints with a minimum 4-inch-wide modified bitumen roof tape. The tape is intended to provide an additional line of defense against water infiltration in the event the shingles and underlayment blow off. The use of roof tape was recommended in the 2000 edition of FEMA 55 and it is recommended in Technical Fact Sheet 19 in FEMA 499.

The IBHS is preparing a report on Audubon Village. This report is expected to be available on the IBHS Web site by the end of 2009. Refer to: www.ibhs.org

Several of the *Fortified...for safer living*® houses that lost underlayment had taped joints, including the one shown in Figure 3-67. However, as shown in Figure 3-68, the taping was not effective. Observations by IBHS investigators revealed application problems with the tape. Staples were used to attach the tape because bonding problems were experienced during application. Apparently the applicator did not realize the tape was intended to prevent water from leaking through the sheathing joints. With the tape in an un-bonded and wrinkled condition, it was incapable of fulfilling its intended purpose. Self-adhering modified bitumen roof tape normally bonds quite well to sheathing. Bonding problems are commonly attributed to dust on the sheathing, wet sheathing, a surfacing on the sheathing that interfered with the bonding, or using inappropriate tape. According to IBHS, problems with bonding self-adhering modified bitumen to oriented strand board (OSB) had been previously experienced at a demonstration project. In evaluating that demonstration project, IBHS discovered that although the OSB manufacturer had recommended application of a primer before installation of the self-adhering modified bitumen because of the presence of a wax on the OSB, a primer had not been installed.

According to IBHS, the shingles at the *Fortified…for safer living*® houses at Audubon Village met Class H (i.e., suitable for use up to 150 mph).

Figure 3-67.
This *Fortified...for safer living*® house had taped sheathing joints (red arrow)

Figure 3-68.
This tape did not provide a watertight seal. Note the wrinkles (which allow water migration) and the staples (blue arrow) that were used to attach the tape (Audubon Village, TX).
CREDIT: IBHS

3.2.1.2 Metal Panels

Metal panels were the second most common type of residential roof covering observed by the MAT. However, there were substantially fewer metal roofs than asphalt shingle roofs. Their performance was quite varied, as illustrated by a new housing area near the west end of the Galveston seawall. All of the houses in that area (around a dozen) had metal panel roofs. Three of the houses experienced panel blow off. Two of these failures are shown in Figures 3-69 and 3-70. Fortunately, as shown in the figures, the underlayment did not blow away, so it provided leakage protection. The panels shown in Figure 3-69 have snap-lock seams. One side of the seam was attached with concealed fasteners. The seam unlatched, but lack of roof access prevented MAT investigation of the cause of the unlatching.

Several metal panel roofs performed exceptionally well during Hurricane Charley (2004), even though they were exposed to very high winds. For further discussion, see FEMA 488.

For guidance on metal roofs, see Hurricane Ike Recovery Advisory, *Metal Roof Systems in High-Wind Regions* (Appendix D).

Figure 3-69.
These snap-lock seam panels were attached with fasteners through one side of the seam (Galveston Island, TX; Hurricane Ike estimated wind speed in this area: 110 mph)

The panels shown in Figure 3-70 were attached with concealed clips, which unlatched from the panels. The first row of clips (just above the red line) was several inches from the end of panels; this first row should have been within a few inches from the eave.

Figure 3-70.
These architectural metal panels unlatched from the concealed clips. The red line shows location of the first row of clips (Galveston Island, TX; Hurricane Ike estimated wind speed in this area: 110 mph).

3.2.1.3 Tile

The MAT observed very few tile roofs. As with asphalt shingles and metal panels, the performance was quite varied. Figures 3-71 and 3-72 show two houses along the coast of Galveston Island. The roof shown in Figure 3-71 was observed from the air and ground. No tile damage (including hips) was observed. Figure 3-72 shows damage at hips, the eave, and the field (which was likely caused by windblown eave and/or hip tiles.

For further information on tile roof performance, see the MAT reports for Hurricane Charley and Hurricane Ivan (FEMA 488 and 489, respectively), wherein a large number of tile roofs were observed. For guidance on design and installation of tile, see Technical Fact Sheet 21, *Tile Roofing for High-Wind Areas,* in FEMA 499.

Figure 3-71.
This tile roof on Galveston Island, TX, did not experience any wind damage (Hurricane Ike estimated wind speed in this area: 106 mph)

Figure 3-72.
This tile roof on Galveston Island, TX, experienced hip, eave, and field damage (Hurricane Ike estimated wind speed in this area: 106 mph)

3.2.2 Non-Load-Bearing Walls and Wall Coverings

This section covers exterior wall coverings (also known as cladding or siding) including brick veneer (Section 3.2.2.1), vinyl siding (Section 3.2.2.2), fiber-cement siding (Section 3.2.2.3), and wood and hardboard siding (Section 3.2.2.4). In the area visited by the MAT, the most common exterior wall coverings were fiber-cement lap siding; vinyl siding; and panels of wood, hardboard, or fiber cement. Although not a prevalent residential cladding, Exterior Insulation Finish System (EIFS) was observed in a few locations. Because most of the houses surveyed were elevated, brick was predominantly observed on a few commercial or institutional buildings, and on one multi-family residential complex.

In Louisiana, the MAT observed a variety of siding and cladding failures, despite the fact that wind speeds were less than current code-specified values. The damage observed was mostly, but not always, on older buildings, which (presumably) had been designed and constructed without full consideration of wind resistance (Figures 3-73 and 3-74).

Figure 3-73.
Loss of siding due to winds, Chauvin, LA (Terrebonne Parish; Hurricane Ike estimated wind speed in this area: 50 to 60 mph, Exposure B)

Figure 3-74.
Loss of siding at Holly Beach, LA, home (Cameron Parish; Hurricane Ike estimated wind speed in this area 80 mph, Exposure C)

Gable end walls are frequently covered with a non-structural sheathing, such as foam plastic or thin fiberboard and gypsum sheets. Because there is no interior wall covering, the sheathing and cladding assembly is exposed to the full force of the wind pressure differential between the attic and outside. Where this pressure is negative (that is, the side of the house is downwind or parallel to the wind direction), substantial suction pressure is exerted against the sheathing, which can transfer the load to the cladding and thereby produce cladding failure. The MAT observed several cases where both sheathing and cladding over the gable end were blown out (Figures 3-75 and 3-76).

Figure 3-75.
Complete loss of thin gypsum sheathing and brick veneer from gable end (West Bay, Galveston Island, TX; Hurricane Ike estimated wind speed in this area: 90 mph, Exposure B)

Figure 3-76.
Loss of fiberboard sheathing and fiber cement siding from gable end wall of an apartment complex (West Bay, Galveston Island, TX; Hurricane Ike estimated wind speed in this area: 90 mph, Exposure B)

3.2.2.1 Brick Veneer

Numerous brick veneer failures were observed at one Galveston apartment complex. Figure 3-77 shows failed brick veneer at one complex. The brick ties were randomly spaced with the horizontal spacing ranging from 32 inches to 16 inches on-center and the vertical spacing ranging from 48 inches to 24 inches on-center. Many of the corrugated ties were rusted and broken, were not embedded in the masonry, or had minimal embedment. Figure 3-78 illustrates common problems with brick veneer installations and Figure 3-79 illustrates proper methods of installation.

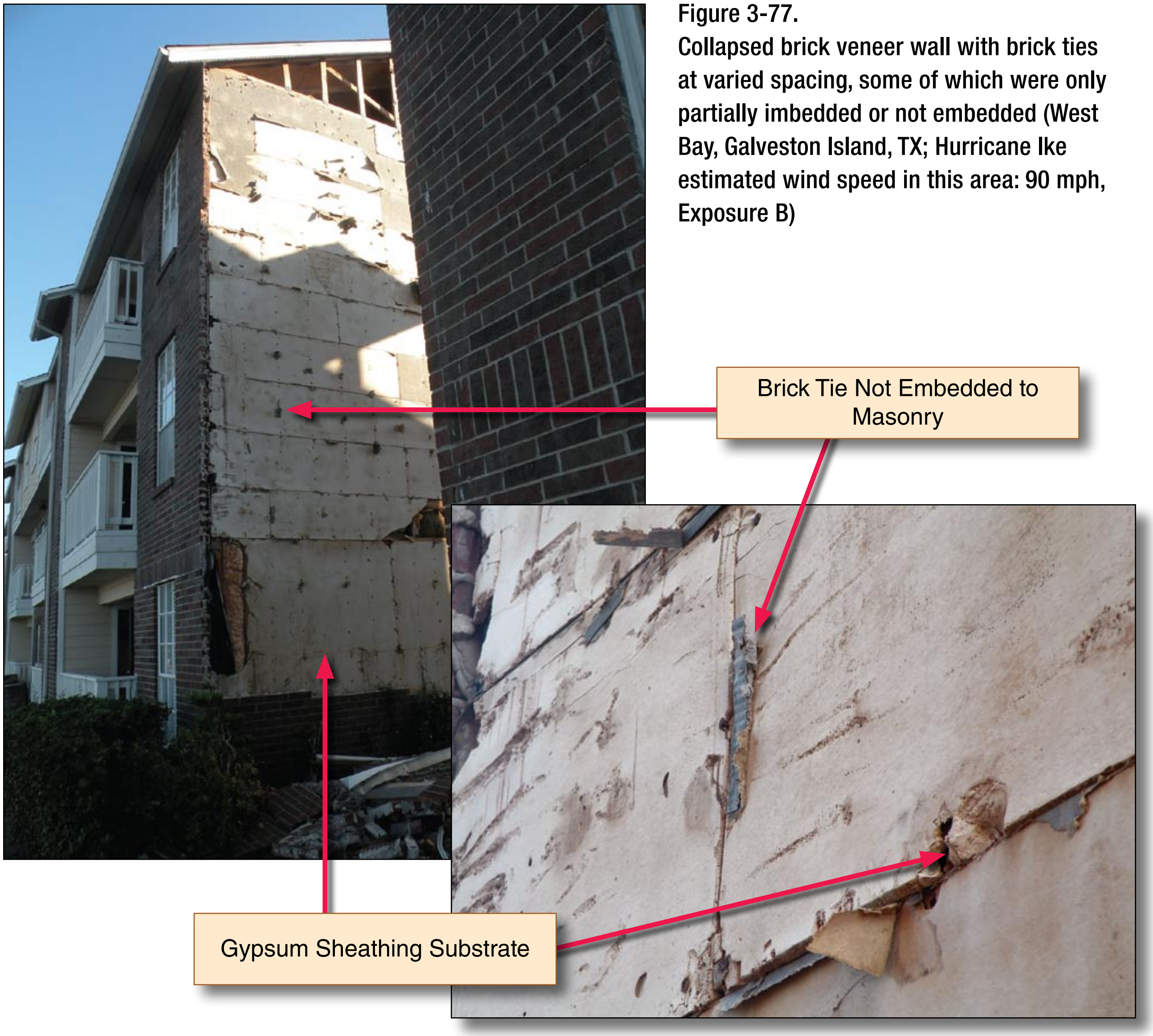


Figure 3-77.
Collapsed brick veneer wall with brick ties at varied spacing, some of which were only partially imbedded or not embedded (West Bay, Galveston Island, TX; Hurricane Ike estimated wind speed in this area: 90 mph, Exposure B)

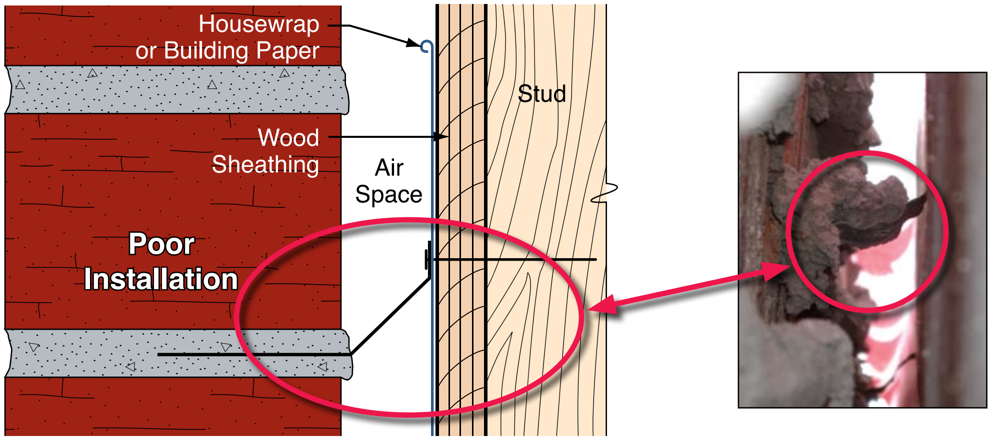


Figure 3-78. Misalignment of the tie reduces the embedment and promotes veneer failure

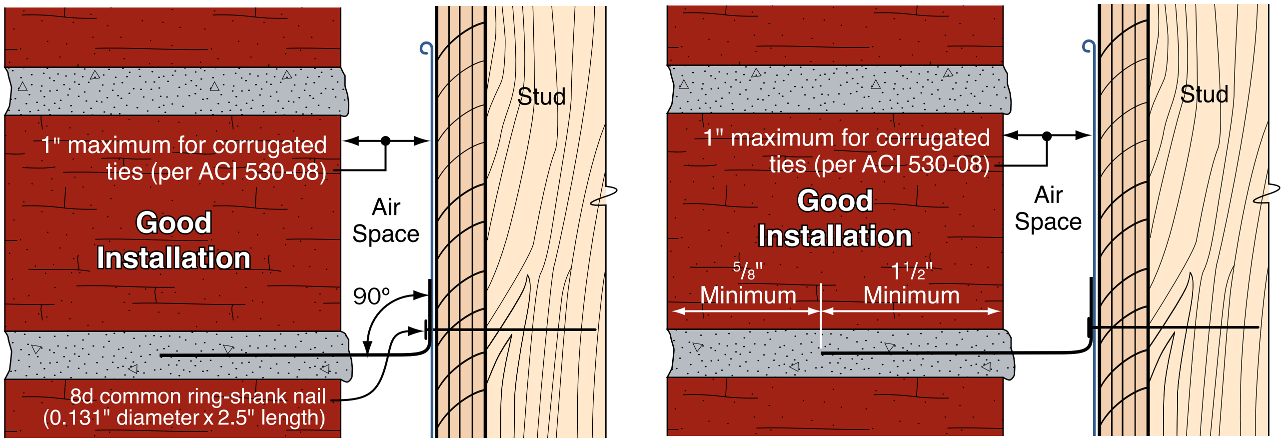


Figure 3-79. Proper installation and embedment of corrugated brick ties

The Brick Industry Association's (BIA's) Technical Notes 28 *Anchored Brick Veneer, Wood Frame Construction* (2002) specifies a maximum tie spacing of 24 inches in each direction for 16-inch stud spacing for buildings in standard 90-mph wind zones. Table 3-1 indicates the required tie spacing for high wind zones. Though Galveston experienced less than design wind speeds, the proximity of the adjacent complex shown in Figure 3-77 may have produced increased wind pressures, thereby producing the catastrophic failure of the poorly anchored brick veneer. However, the installed tie spacing was not suitable for this back bay Galveston location with a design wind speed of 120 mph.

FEMA Hurricane Ike Recovery Advisory, *Attachment of Brick Veneer in High-Wind Regions* (Appendix D), provides recommended practices for brick veneer attachment. The advisory is based on observations from Hurricanes Ivan, Katrina, and Ike.

Table 3-1. Brick Veneer Tie Spacing

Wind Speed (mph) (3-Second Peak Gust)	Wind Pressure (psf)	Maximum Vertical Spacing for Ties (inches)	
		16-inch stud spacing	24-inch stud spacing
90	-19.5	24[a,b]	16[a]
100	-24.1	24[a,b]	16[a]
110	-29.1	20½ [b]	13½
120	-34.7	17	NA[c]
130	-40.7	15	NA[c]
140	-47.2	13	NA[c]
150	-54.2	11	NA[c]

Notes:

1. The tie spacing is based on wind loads derived from Method 1 of ASCE 7-05, for the corner area of buildings up to 30 feet high, located in Exposure B with an importance factor (I) of 1.0 and no topographic influence. For other heights, exposures, or importance factors, engineered designs are recommended.
2. Spacing is for 2 ½-inch long 8d common (0.131-inch diameter) ring-shank fasteners embedded 2 inches into framing. Fastener strength is for wall framing with a Specific Gravity G=0.55 with moisture contents less than 19 percent and the following adjustment factors, C_t=0.8; and C_D, C_M, C_{eg}, and C_{tn}=1.0. Factored withdrawal strength W'=65.6#.
3. The brick veneer tie spacing table is based on fastener loads only and does not take into account the adequacy of wall framing, sheathing, and other building elements to resist wind pressures and control deflections from a high-wind event. Prior to repairing damaged brick veneer, the adequacy of wall framing, wall sheathing, and connections should be verified by an engineer.

a Maximum spacing allowed by the American Concrete Institute (ACI) 530-08.

b In locales that have adopted the 2006 IBC/IRC, the maximum vertical spacing allowed by ACI 530-05 is 18 inches.

c 24-inch stud spacing exceeds the maximum horizontal tie spacing of ACI 530-08 prescribed for wind speeds over 110 mph.

3.2.2.2 Vinyl Siding

Vinyl siding was the most frequently used exterior cladding and was found in all the areas observed by the MAT, on both newer and older buildings. Vinyl siding was observed to be commonly used to re-cover older wood cladding (Figure 3-80). Panel widths observed were typically between 8 and 12 inches, with double-four (two 4-inch) faces, double-five, and triple 3 ½-inch profiles being the most common. Siding was most commonly installed over plywood or OSB sheathing, and usually, with a water-resistant barrier (house wrap) over the sheathing. Where the siding was covering older wood plank or panel siding, a layer of foam sheathing was frequently applied. The foam sheathing, typically ½-inch to 1-inch extruded polystyrene sheets, served as both additional thermal insulation and flat substrate against which to place the siding.

Figure 3-80.
Typical vinyl siding failure. Vinyl was installed over older wood cladding (red arrows) (Sea Isle, TX; Hurricane Ike estimated wind speed in this area: 95+ mph, Exposure C).

Vinyl siding failure was frequently initiated at the building corners and along the bottom edges of elevated houses. The higher wind corner pressures produced unlatching along the bottom strip that resulted in the unzipping of the entire wall (Figure 3-81). When vinyl siding was blown off, the water-resistant barrier (either asphalt-saturated felt or housewrap) was often blown away. Though not witnessed by the MAT, this loss of the siding and underlayment could have allowed wind-driven rainwater to enter the wall cavity and the house, thereby causing water damage to interior finishes and contents. Vinyl siding and soffits that become windborne debris can potentially break unprotected glazing.

The most important factors influencing whether vinyl siding will remain on the wall during a high wind event are: (1) selection of siding appropriate for the basic wind speed at the location, and (2) the use of proper application techniques and installation details. The latter category includes use of proper accessories such as starter strips, receivers and utility trim; nail selection and placement; and locking of successive panel courses to each other.

Detachment of vinyl siding attributed to application deficiencies is frequently seen after high wind events (e.g., excessive spacing between fasteners and improper nail head size of the fasteners). In other cases, while proper fastening may have been used, the type of vinyl siding used may not have been appropriate for use in high wind locations.

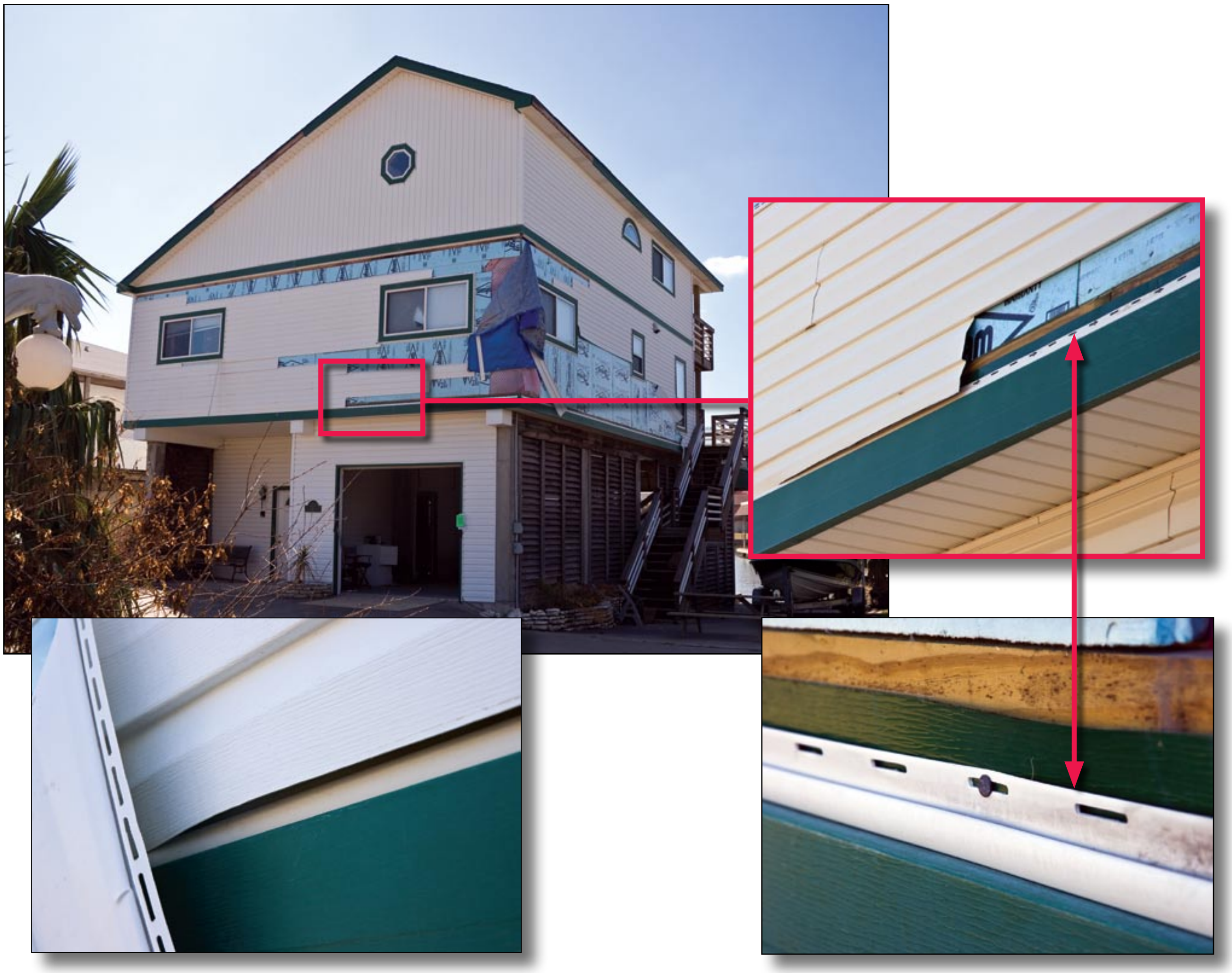


Figure 3-81. Improper installation led to extensive loss of siding up the house wall. The bottom lock of the lowest course of siding was cut off, and utility trim substituted for the correct starter strip. The poorly retained bottom edge pulled out under wind pressure, leading to extensive loss of siding up the house wall (Tiki Island, TX; Hurricane Ike estimated wind speed in this area: 88 mph, Exposure B).

Siding that is intended for locations with a basic wind speed greater the 110 mph usually has a double-layer nail hem (Figure 3-82). This double layer strengthens the vinyl at the point where the nail attaches so the siding better resists tearing or pull-through of the nail head. Conventional vinyl siding has a single-layer nail hem. Most of the siding that was removed from the wall (and therefore exposed for inspection by the MAT) had a single nail hem and was thus not likely to have been rated for high wind locations. Although it is possible that the siding that stayed on the wall (and therefore wasn't inspected) was predominantly high-wind rated, it seems likely that a significant percentage of the siding installed in the high wind zones of this area of the Texas coast is not intended for that application. This conclusion would appear reasonable, since winds produced by Ike varied from maximum 3-second gusts of 90 mph on the west end of Galveston to 110 mph on the east end of Bolivar Peninsula, and the ASCE 7-05 assigned wind speeds for these locations is 130 mph.

Figure 3-82.
Vinyl siding rated for high wind has a double-layer nail hem

As with any building system, even high-wind rated siding needs to be properly installed in order to function as designed. The MAT observed several common installation methods that tended to allow siding to be blown from the building by Hurricane Ike, including:

1. Starter strip attachment along the first (lowest) course of siding

Starter strips consist of a nail hem and locking profile that matches the shape of the lock on the lower edge of the siding panel (called the buttlock). The starter strip is fastened to the lowest part of the wall and the first course of siding is locked into it. If this lock is not strong, wind can get under the first course and detach it from the starter strip. The loose piece of siding will place stress on the lock of the course above, as well as its own nail hem, leading to successive loss of courses up the wall. In order to protect against this, the starter strip should be designed for use with the particular profile (shape) of siding being used, and the siding should be firmly locked into the starter strip.

Proper use of the starter strip is particularly important with elevated structures, where the wind passes at high velocity underneath the structure as well as against the walls. On Galveston Island, Bolivar Peninsula, and Tiki Island, where elevated houses were predominant, a large percentage of siding loss originated at the lowest course and led to loss of the courses above. The MAT saw numerous instances where a "generic" starter strip (having just a bulge, rather than a lock shaped to match the siding) was used. In other cases, J-channels, which do not lock into the panel at all, or field-fabricated substitutes for starter strips were used. Elevated structures with poorly implemented starter strips were most vulnerable to siding loss starting at the lowest edge of the elevated wall (Figure 3-83).

Vinyl siding installers should be advised to use starter strips that are specifically designed for the brand and model or profile of the siding that will be used and generic starter strips should be avoided. Installers should consult the manufacturer's instructions to identify the starter strip to be used. Installers should also test the fit of the starter strip to the siding to make sure it locks securely before installing. On elevated structures, the starter strip should not extend below the lowest edge of the vertical wall or the exposed edge may catch the wind blowing under the house.

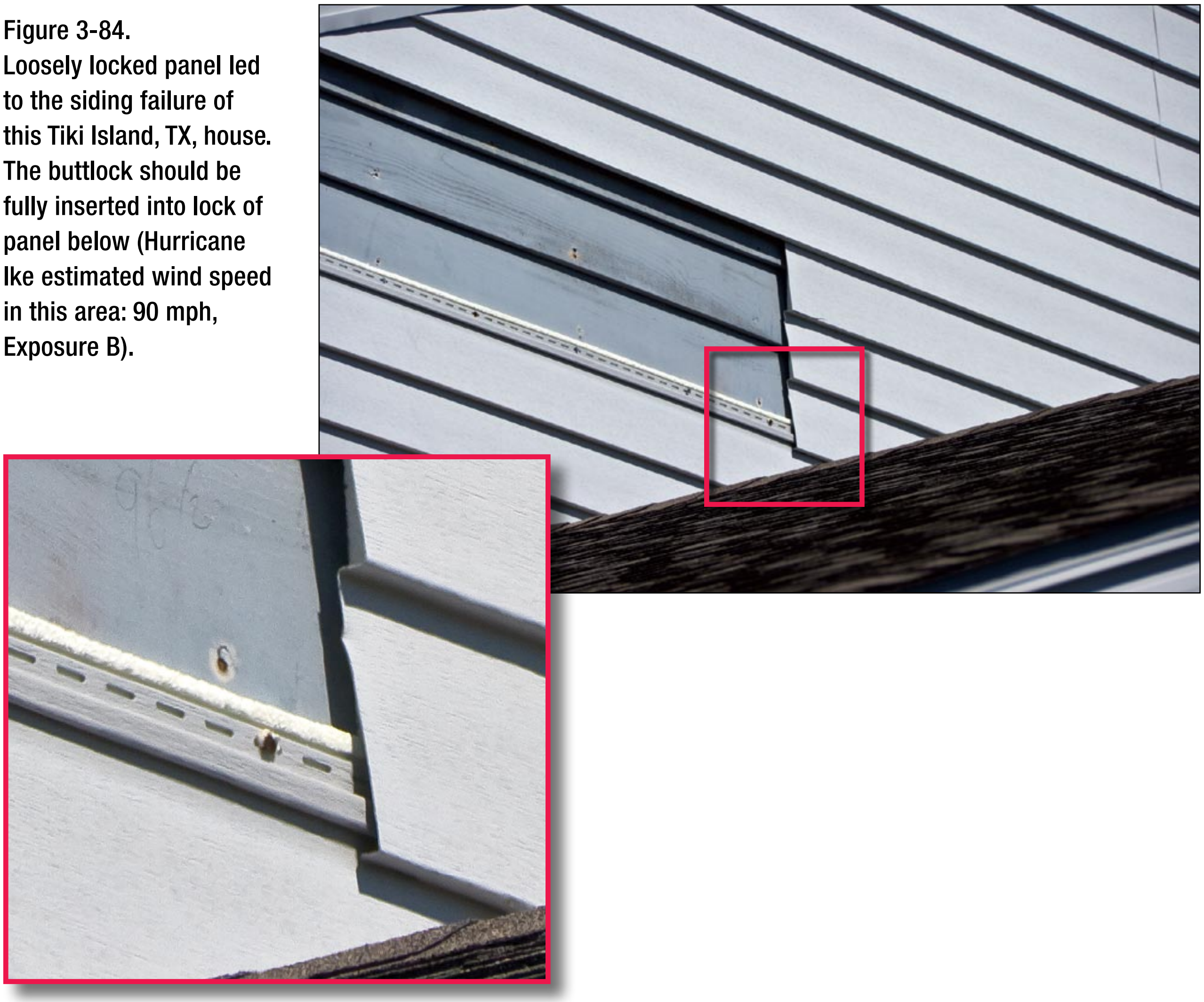
Figure 3-83.
Use of a generic starter strip contributed to loss of siding on this house. The shape of the starter strip did not properly match the shape of the siding, and the relatively weak strip bent up at the end and released the siding lock (blue inset). The edge of the starter strip also extended slightly below the edge of the building, which further contributed to the failure (red inset) (Tiki Island, TX; Hurricane Ike estimated wind speed in this area: 88 mph, Exposure B).

2. Locking of mid-wall siding courses

Siding loss frequently begins midway up the wall rather than at the bottom course. Many of these instances are the result of failure to fully and securely lock the buttlock of the siding into the locking shape of the siding course below. This can happen when the siding is pulled up too tightly before being nailed, thereby placing it under tension when the siding is not fully pushed into the lock (Figure 3-84), or when the siding is allowed to sag before nailing. These modes of failures frequently occur when installers try to align the horizontal course lines on one wall with those of an adjacent wall by installing several courses loosely.

Each course of siding should be installed by pushing the buttlock firmly upward into the lock of the course below until it snaps into place and goes no further. The siding should be held in the lock by pushing up from the bottom while the first several fasteners are placed to hold it in position. Siding should never be pulled up from the nail hem. When properly installed, siding should be able to slide back and forth without undue force; neither tight fasteners at the nail hem nor friction in the buttlock should prevent the siding from sliding. Installers should properly locate the starting points for siding on adjacent walls and check alignment of horizontal lines every course or two to avoid needing to make adjustments further up the wall.

Figure 3-84.
Loosely locked panel led to the siding failure of this Tiki Island, TX, house. The buttlock should be fully inserted into lock of panel below (Hurricane Ike estimated wind speed in this area: 90 mph, Exposure B).



3. Using utility trim at windows and other locations where the top edge of siding must be removed

When a course of siding intersects the bottom of a window or other large opening, a section of the top portion of the panel must be removed to fit around the window. With the nail hem removed, special techniques must be used to stabilize and secure the cut edge of siding. An accessory called utility trim must be installed beneath the window. The cut edge of the siding panel is notched with a snap lock punch. The edge of the siding is inserted into the utility trim, which grabs and holds the punched notches (Figure 3-85). A furring strip may need to be used underneath the utility trim to place it at the right level to match the angle of the siding. An overlap between adjacent siding panels should never be located directly beneath a window or similar opening (Figure 3-86). The same technique must be used to finish the top course of siding where the nail hem is cut off to match the location of the eave line.

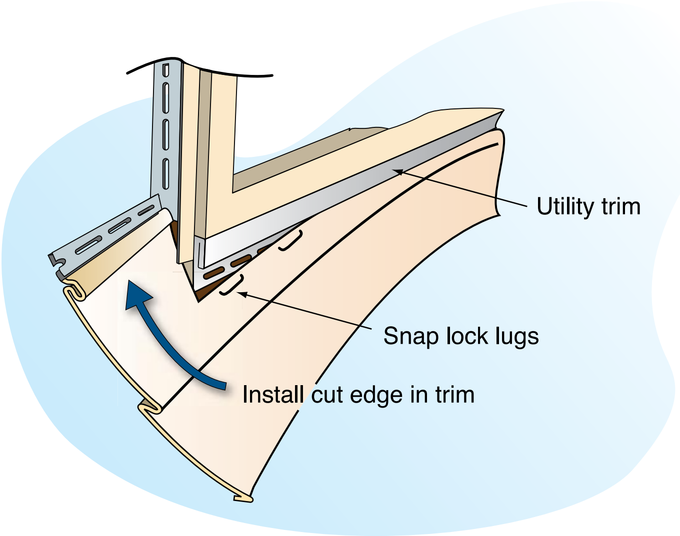


Figure 3-85.
Use of utility trim under window to securely attach cut and notched siding section
SOURCE: VSI INSTALLATION MANUAL

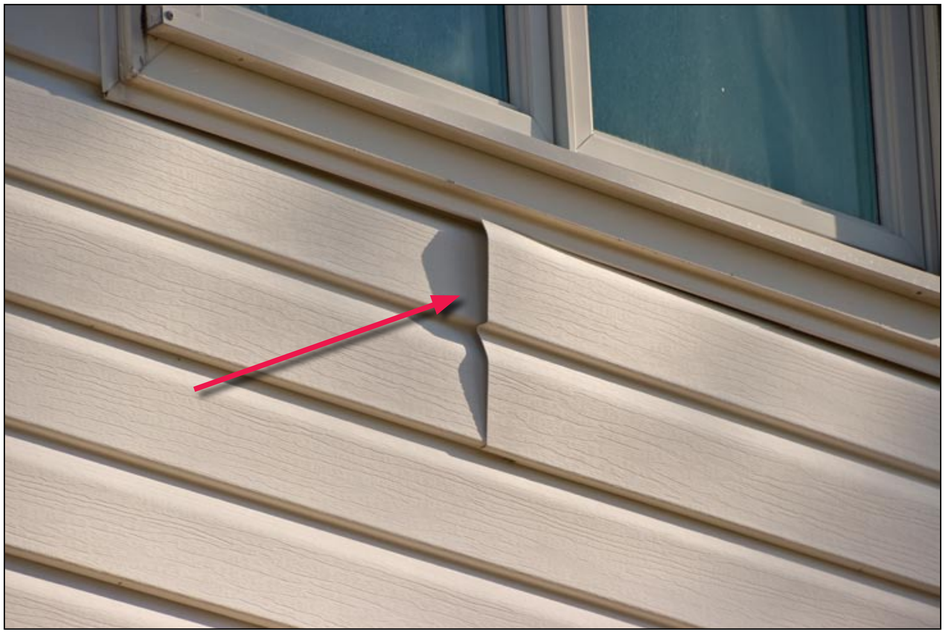


Figure 3-86.
Siding partially detached by wind as a result of improper placement of joint directly under window. Factory-notched end is not held by utility trim (Tiki Island, TX; Hurricane Ike estimated wind speed in this area: 88 mph).

Although most cases of vinyl siding loss can be traced to improper installation techniques or use of incorrect products and accessories, there is room for improvement in product testing and documentation. It is recommended that the vinyl siding industry reevaluate the test standards used for validating the strength of the siding material and its installation. ASTM D 3679, *Standard Specification for Rigid Poly (Vinyl Chloride) (PVC) Siding*, specifies a 1.5 product safety factor. Given the MAT observations, this safety factor appears to be too low. ASTM D 5206, *Standard Test Method for Windload Resistance of Rigid Poly (Vinyl Chloride) (PVC) Siding*, tests the product installations using a static load. Considering the flexible nature of vinyl siding and the dynamic nature of wind loading, a dynamic test appears to be prudent for vinyl siding. Manufacturers should provide clearer and more explicit information in the product literature (including Web sites) and installation instructions on high-wind applications, including explicit information on:

- Windload ratings for specific products and profiles, and any limitations or conditions needed to achieve the rated performance
- Specific accessories (e.g., starter strips, trim pieces) needed to provide the rated performance
- Any applicable fastener specifications, spacing frequency, and installation details needed for high-wind applications

3.2.2.3 Fiber Cement Siding

The MAT observed fiber cement siding on many residential structures, primarily as a reside cladding (Figure 3-87).[3] The observations included lap (plank) siding of varying exposures, perforated soffit material, and siding panels and sheathing material below elevated structures.

Figure 3-87.
Fiber cement plank siding, installed as a reside over the original plywood siding, was torn from this West Bay, Galveston Island, TX, house (Hurricane Ike estimated wind speed in this area: 100 mph, Exposure C)

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[3] Reside cladding relates to the installation of a cladding material over an original cladding, usually sandwiched between foam board insulation and house wrap.

Lap siding damage varied from the loss of a few planks to entire walls (Figure 3-88). In most cases, the siding had been blind nailed at each stud (Figure 3-89), which is standard for non-high wind zones. Published ratings and ICC Evaluation Reports for the application of fiber cement lap siding in high wind zones require that the siding be face nailed through both layers of siding at the lap joint, shown in Figure 3-90. The spacing of the nails (16-inch or 24-inch) and permitted material exposure is dependent upon the thickness and width of the siding boards and wind zone.

Figure 3-88.
Fiber cement lap siding was blown off this West Bay, Galveston Island, TX, house (Hurricane Ike estimated wind speed in this area: 100 mph, Exposure B)

Figure 3-89.
Damaged fiber cement plank siding. Note that blind nailing alone (red arrows) is recommended only for 90-mph or less installation. Higher wind zone installations should include both blind and face nailing (Hurricane Ike estimated wind speed in this area: 93 mph, Exposure B).

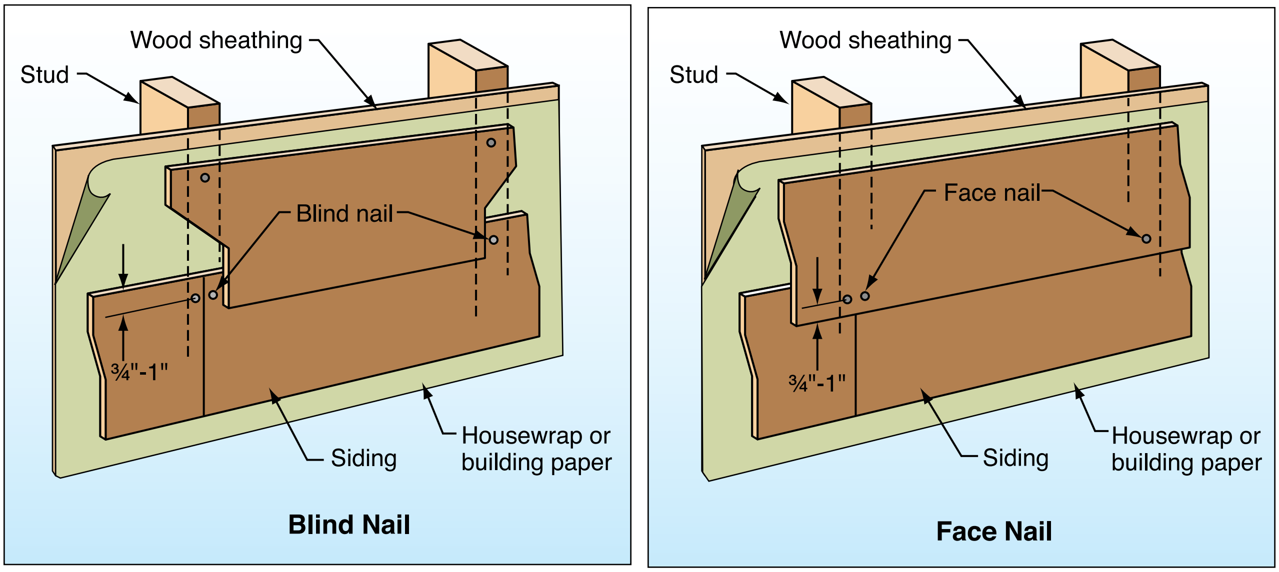
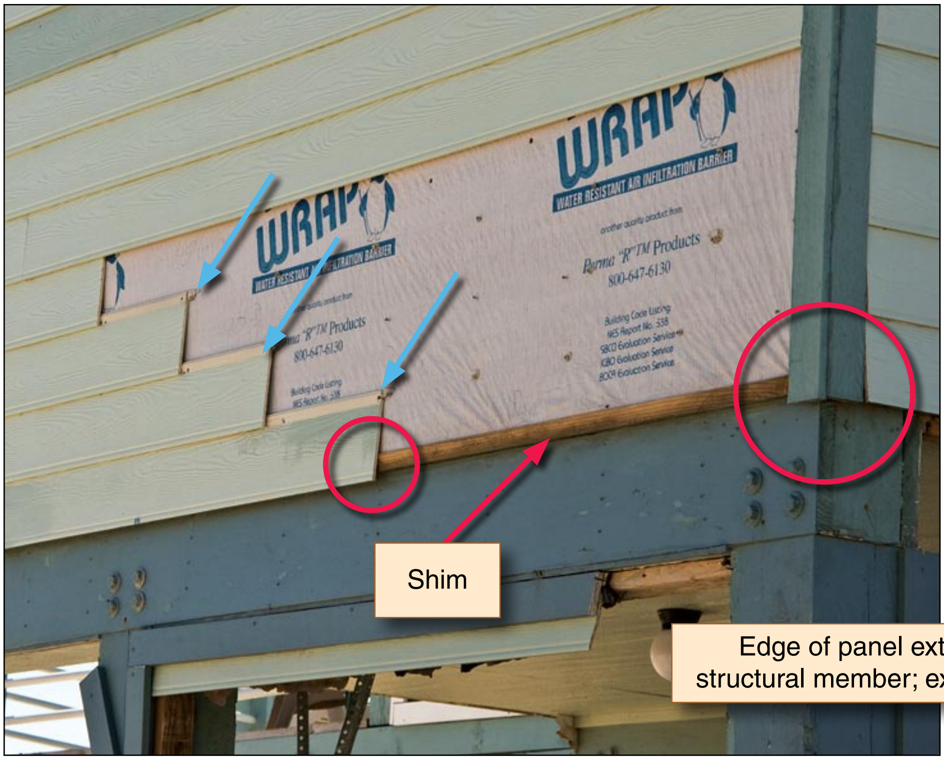


Figure 3-90. Standard wind zone installation High wind zone installation

Another area of vulnerability for fiber cement siding is the exposure of the underside of the first course of lap siding, or the bottom edge of panel siding. In setting the first (lowest) course of lap siding, a shim is used to place the board at the proper angle. If the shim is not flush with the bottom of the board, a lip is formed that can catch wind pressure, and force this board up. The first board acts as a lever under the second, and loss of siding progresses up the wall. This is a particular issue with elevated structures, where the wind accelerates under the building. The MAT observed numerous cases where a projecting lip of the first course on an elevated structure led to significant loss of siding (Figure 3-91). If the bottom edge of the panel extends below the lowest edge of the elevated structure, or there is a gap between the panel and the lowest structural member, wind pressure can catch the edge and pry the panel off.

Shims under lap siding should be placed flush with the bottom of the first course, and panel siding should be fastened tightly to the substrate so that no gap is created at the lowest edge. Consideration should be given to placing a trim piece below the lower edge of the siding to fully close off the edge. Neither lap siding nor panel siding should extend below the lowest structural member of an elevated building, where it would be exposed to the full force of the wind (Figure 3-92).



Shim

Edge of panel extends below structural member; exposed to wind.

Figure 3-91.
Shim placement (red arrow) allowed the lower edge (red circles) of siding to be exposed, resulting in loss of siding at several locations around this elevated structure on Bolivar Peninsula, TX. Note the blind nailing shown by blue arrows (Hurricane Ike estimated wind speed in this area: 110 mph, Exposure C).

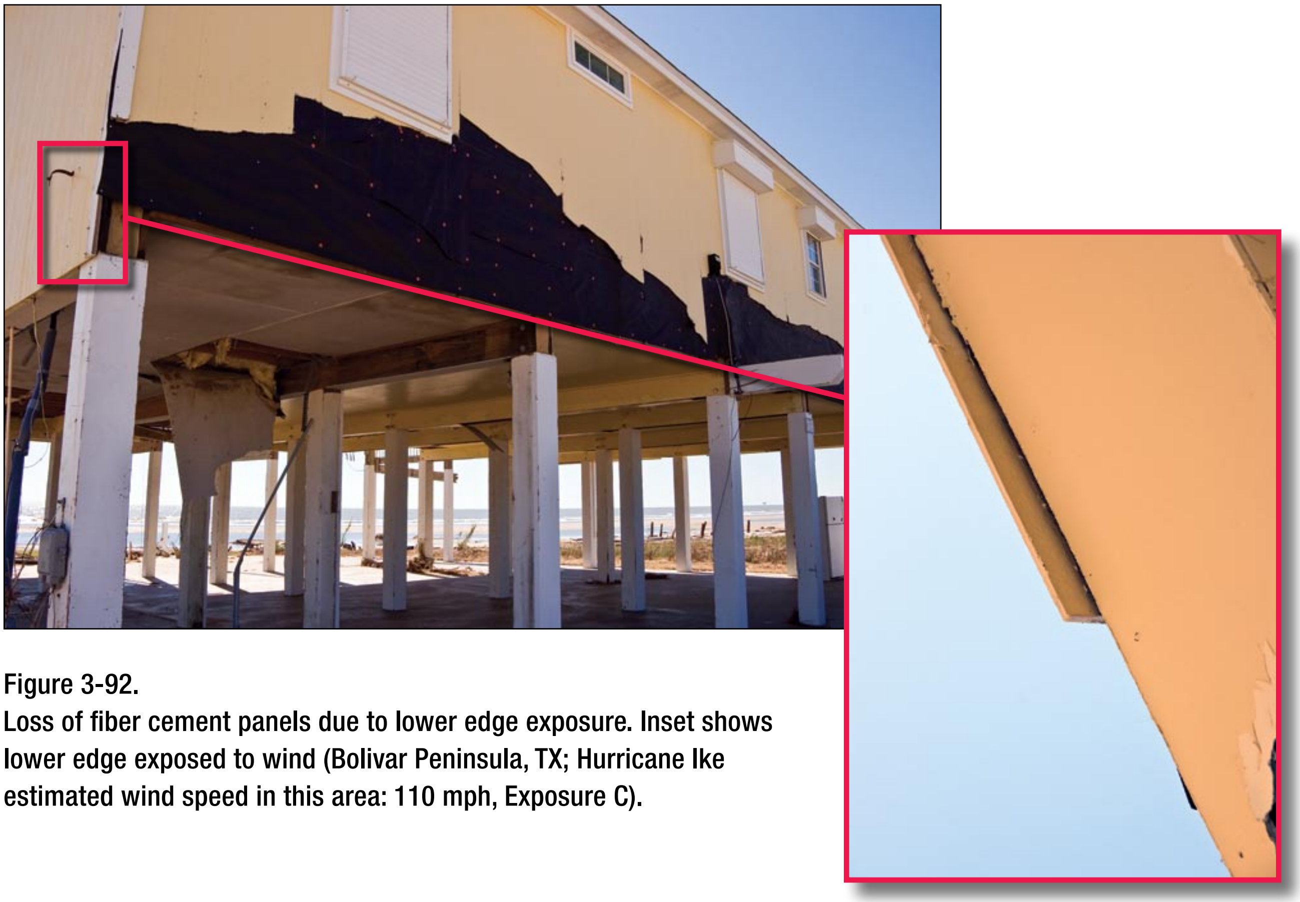


Figure 3-92.
Loss of fiber cement panels due to lower edge exposure. Inset shows lower edge exposed to wind (Bolivar Peninsula, TX; Hurricane Ike estimated wind speed in this area: 110 mph, Exposure C).

3.2.2.4 Wood and Hardboard Siding

Most of the older houses on Galveston Island, Tiki Island, and Bolivar Peninsula that were originally constructed with plywood or hardboard siding had been re-sided with either vinyl or fiber cement siding. The performance of the remaining plywood and hardboard siding was basically a function of maintenance. The clapboard-sided house shown in Figure 3-93 was well maintained and performed well, though the second floor failure was produced when a non-breakaway wall was destroyed by surge. Failure of the plywood siding shown in Figure 3-94 appeared to be the result of decayed plywood removed by the wind pressures.

Figure 3-93. Clapboard-sided house with siding that performed well; damage resulted from failure of a non-breakaway wall (Tiki Island, TX; Hurricane Ike estimated wind speed in this area: 103 mph, Exposure C).

Figure 3-94. Decayed plywood siding removed by wind pressures (Tiki Island, TX; Hurricane Ike estimated wind speed in this area: 103 mph, Exposure C)

3.2.3 Doors

Failure of an exterior door has two important consequences. First, the failure can cause a rapid increase in internal pressure, which may lead to exterior wall, roof, interior partition, ceiling, or structural failure. Second, wind can drive rainwater through the opening, causing damage to interior contents and finishes, and leading to the development of mold. The essential elements of good high-wind door performance include product testing to ensure sufficient factored strength to resist design wind loads (both static and cyclic loading); suitable anchoring of the door frame to the building; proper flashing, sealants, tracks, and drainage to minimize water intrusion into wall cavities or into occupied space; and, for glazed openings, the use of laminated glass or shutters to protect against windborne debris damage, as discussed in Section 3.2.4.

Many door failures observed by the MAT were the result of flood loads, which doors are not designed for. Personnel door failures in slab-on-grade houses and houses elevated below the BFE were commonly seen, along with catastrophic failure of the entire house. Garages with garage doors are frequently installed below elevated homes, and are designed to fail due to flood loads in conjunction with breakaway walls.

3.2.4 Windows and Shutters

Most building codes incorporate the wind provisions from ASCE 7-05 and require that buildings within the most hazardous portion of the hurricane-prone region, called the windborne debris region, be equipped with shutters or impact-resistant glazing and designed as enclosed structures. The 2003 IRC allows a residence without either protection to be designed as a partially enclosed structure (as if the windows and doors are broken out). Designing a partially enclosed structure typically requires upgrading structural components and connections. In Texas, the TDI requires opening protection for both Seaward and Inland I zones (refer to Figure 3-69 for wind zone locations). Few impact-resistant glazed window units were observed by the MAT, with homeowners and builders generally opting to use shutters to provide debris impact protection. However, the MAT observed four new houses being constructed on the east beach of Galveston Island that were installing impact-resistant glazing (Figure 3-95).

Figure 3-95.
Impact-resistant door and window glazing in new East Galveston, TX, house. Inset shows manufacturer's label indicating glazing is impact resistant.

The MAT observed that glazing at most houses was protected by some form of shutter. The shutter types varied from simple plywood to roll-down shutters. Figures 3-96 to 3-101 show a variety of shutters seen by the MAT.

Figure 3-96.
Clear Lake, TX, house with plywood shutters installed on the accessible first floor and roll-down shutters installed on the less accessible second floor (Hurricane Ike estimated wind speed in this area: 90 mph, Exposure B)

Figure 3-97.
Tiki Island, TX, house with adjustable shutters (Hurricane Ike estimated wind speed in this area: 103 mph, Exposure C)

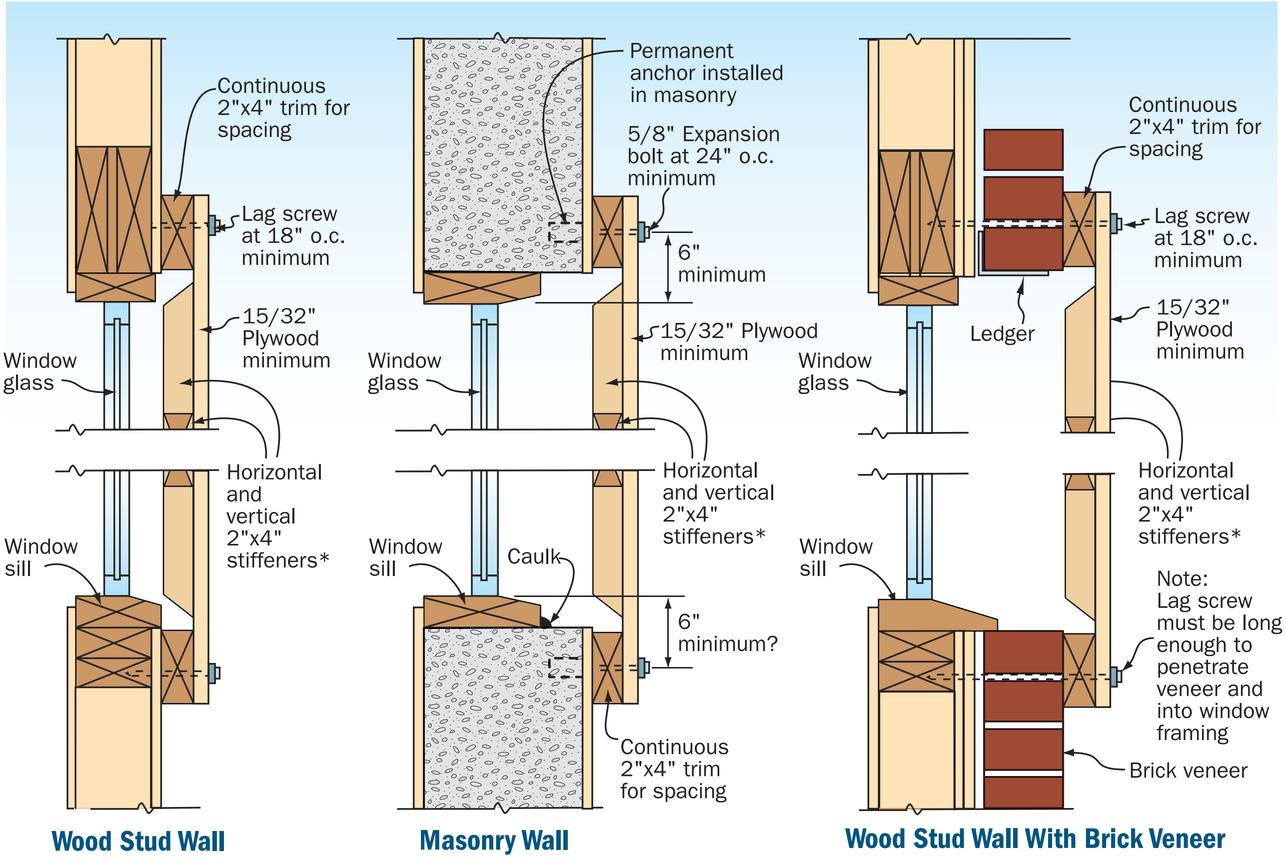
Figure 3-98.
Texas City, TX, house with corrugated clear plastic shutters (Hurricane Ike estimated wind speed in this area: 88 mph, Exposure B)

Figure 3-99. Traditional wood swinging shutters on Tiki Island, TX (Hurricane Ike estimated wind speed in this area: 103 mph, Exposure B)

Figure 3-100. Corrugated metal shutters on house in West Galveston, TX (Hurricane Ike estimated wind speed in this area: 95 mph, Exposure C)

Figure 3-101. Snapped-on vinyl canvas window covers (red arrows) in West Bay, Galveston Island, TX (Hurricane Ike estimated wind speed in this area: 90 mph, Exposure B)

Since Ike's winds were below design wind speeds in both Texas and Louisiana, no failures or debris impacts were observed. The 2006 IRC/IBC and TDI require that all shutters be attached to the building structure and not to the window frame, siding, or veneer (Figure 3-102); they require that all shutters be tested to ASTM Standards E 1886 and E 1996. The MAT observed plywood shutters mounted directly to the wall cladding or window frame as seen in Figure 3-103. Further information regarding shutters can be obtained from Technical Fact Sheet 26, *Shutter Alternatives*, in FEMA 499.



*Stiffener can be on either side, although for inside location, adequate space between windowpane and stiffener must be provided.

Figure 3-102. Common methods for plywood shutter attachment to wood-frame and masonry walls

SOURCE: FEMA 499 TECHNICAL FACT SHEET 26

Figure 3-103. Plywood shutters installed into the wall cladding (red circles) in Clear Lake, TX (Hurricane Ike estimated wind speed in this area: 90 mph, Exposure B)

3.2.5 Soffit and Roof Ventilation

Hurricane winds can drive large amounts of water through attic ventilation openings. The accumulating water soaks insulation, which can lead to mold growth and, in some cases, to the collapse of ceilings. Attic ventilation can be provided by a number of devices, most of which have been observed to allow water intrusion under certain conditions and some of which have been observed to blow away. These devices include:

- Soffit vents
- Ridge vents
- Gable end vents
- Off-ridge vents (not observed by Ike MAT)
- Gable rake vents (not observed by Ike MAT)
- Mechanical vents – wind-powered turbines or electric-powered fans (not observed by Ike MAT)

3.2.5.1 Soffits

The opening created where a roof extends beyond the plane of the wall below (called eaves on the downslope side of a roof and a rake for the end of a gable roof) is normally closed off with a soffit. Soffits typically have small openings, slots, or perforations to provide ventilation to the attic, this ventilation is particularly important in the hot, humid climate of coastal Texas and Louisiana. Soffit venting allows air to enter the attic space, circulate through the attic, and be exhausted through passive vents (ridge vents, gable-end vents) or mechanical vents (either wind-powered turbines or electric-powered fans). The soffits along the roof eave and rake are the primary line of defense against entry of wind-driven rain into attics. Rain driven into attics can cause significant damage as water soaks through ceiling materials and into the interior of the building.

In non-high wind regions, a soffit is typically attached with fasteners to the roof structure only on one side—on the house side or to the underside of the fascia—if at all. In such installations, the channel formed by a bend in the fascia cover receives and supports the end of the soffit. In high-wind zones, most soffit manufacturers indicate the soffit should be attached at both ends and at intermediate points so that there is no span greater than 12 inches.

The primary materials observed for roof soffits in the surveyed area were vinyl, aluminum, fiber cement, and plywood. In general, fiber cement and plywood soffits remained connected to the house (Figure 3-104), while vinyl and aluminum soffits were more likely to have blown off.

By far the most frequently observed form of failure was loss of the aluminum fascia cover from the fascia board (the vertical board used to close off the end of eave spaces or form the outer edge of the rake), as shown in Figures 3-105 and 3-106. The fascia cover normally covers the ends of vinyl and aluminum soffits. Aluminum fascia covers are typically nailed every few feet along the length with color matched trim nails. The IRC currently has no guidelines for the installation of fascia covers. Vinyl fascia covers are also available. They are typically installed using utility trim along the upper side of the fascia board. The continuous nature of the attachment may provide better wind resistance than the aluminum covers. The MAT did not observe any vinyl fascia covers.

Figure 3-104.
Fiber cement soffit remained connected; soffit vent slots shown with red arrows. Fiber cement plank siding was damaged (Tiki Island, TX; Hurricane Ike estimated wind speed in this area: 88 mph, Exposure B).

The frequent loss of fascia covers is a significant concern. In most instances where the fascia cover was observed by the MAT to be fully or partially removed, the soffit itself remained in place or lost only a few sections, as further shown in Figures 3-105 and 3-106. The loss of the fascia cover can increase the risk of loss of the soffit. Even where the soffit remains, rain can be driven directly past the exposed soffit ends. The MAT did not have access to the interior of houses to determine whether interior moisture damage was a frequent result of fascia cover loss, but such damage would be expected.

The frequency of fascia cover failure suggests that design and installation of this component needs to be better addressed in construction standards for buildings in high wind locations. The fact that most soffits stayed in place despite loss of the fascia cover suggests that most soffit installations were performed properly or the design was sufficiently robust to resist winds that occurred during Ike. However, loss of soffits exposed by fascia cover removal would likely have been much greater had winds approached design speeds.

Figure 3-105. Loss of aluminum fascia cover (red arrows) exposed ends of vinyl soffit (blue arrows) to direct entry of wind-driven rain (Tiki Island, TX; Hurricane Ike estimated wind speed in this area: 88 mph)

Figure 3-106. Loss of fascia cover (red arrow) led to loss of soffit (blue arrow), exposing the attic to wind-driven rain (San Luis, TX; Hurricane Ike estimated wind speed in this area: 93 mph, Exposure C)

3.2.5.2 Ridge Vents

The exhaust portion of the attic ventilation system includes ridge vents, gable end vents, off ridge vents, and mechanical vents. The MAT only observed damage produced by ridge vents and gable end vents. To accommodate the ridge venting system, roof decking is cut or left short of the gable ridge beam. Buildings can be retrofitted for ridge vents by cutting the gable slot in the existing deck. The ridge vent is normally the last part of the roof cover to be installed. The ridge vent should be a tested assembly with a baffle in front of the vent tube that provides passageway for hot attic gases to escape. The baffle is intended to trip any flow of wind and water blowing up the surface of the roof and deflect it over the top of the roof ridge. The ridge vent should be installed with stainless steel screws, not roofing nails, into the roof structure. The MAT team was unable to climb onto residential roofs, but it was reported by the homeowner that the damage to a second floor ceiling shown in inset of Figure 3-107 was the result of a leaking ridge vent.

Figure 3-107.
The roof ridge vent (red arrows) on this Bolivar Peninsula, TX, home leaked, and it is presumed that the water was shed down the underside of the roof decking and/or structure, thereby producing ceiling damage along the wall of this second story room (Hurricane Ike estimated wind speed in this area: 110 mph, Exposure C)

3.2.5.3 Gable End Vents

Virtually all gable end vents (Figure 3-108) will leak when the wall they are mounted on faces into the wind-driven rain. The pressure developed between the outside surface of the wall and the inside of the attic are sufficient to drive water uphill for a number of inches and, if there is much wind flow through the vent, water carried by the wind will be blown considerable distances into the attic. Remedial measures include installing shutters, preferably on the outside of the house (Figure 3-109). The gable end vent shown in Figure 3-110 was not attached to the building structure and was blown off the apartment building.

Refer to FEMA Hurricane Ike Recovery Advisory, *Minimizing Water Intrusion Through Roof Vents in High-Wind Regions* (Appendix D), for further discussion of off-ridge vents, gable-end rake vents, and mechanical vents.

Figure 3-108. Gable end vent (red arrow)

Figure 3-109. Shuttered gable end vent (red arrow)

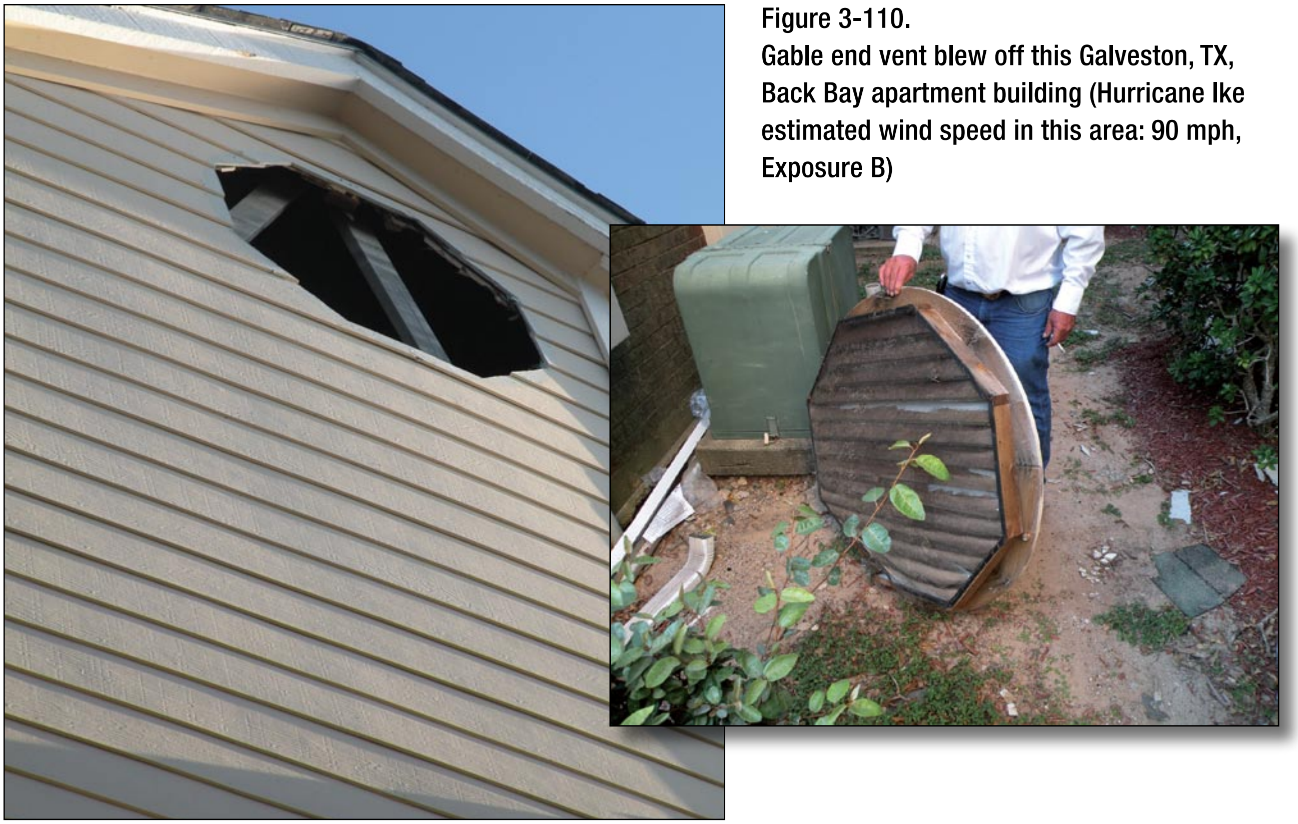


Figure 3-110.
Gable end vent blew off this Galveston, TX, Back Bay apartment building (Hurricane Ike estimated wind speed in this area: 90 mph, Exposure B)

3.2.6 Exterior-Mounted Equipment

Residential condensing units should be elevated in floodprone areas. Condensers at many residences observed by the MAT were supported on cantilevered platforms as shown in Figure 3-111. Cantilevered platforms are preferred because they are less susceptible to damage from floodborne debris impacts than are pile or knee-brace supported platforms. Outside floodprone areas, condensers are normally mounted at grade or on rooftops. In all cases, the units should be permanently anchored to prevent them from being moved (Figure 3-112).

Figure 3-111. Typical cantilevered condenser (Jamaica Beach, TX; Hurricane Ike estimated wind speed in this area: 80 mph, Exposure B)

Figure 3-112. Improperly secured condensing unit was knocked from its platform (Kahala Beach, TX; Hurricane Ike estimated wind speed in this area: 80 mph, Exposure B)

Maintenance should be considered in the design and installation of elevated supports. Figure 3-113 shows a unit that is closely caged, making maintenance difficult. If units are caged, the railings should either be removable or the platform made sufficiently large to allow service to the unit. Further information regarding equipment protection can be obtained from Technical Fact Sheet 29, *Protecting Utilities*, in FEMA 499.

Figure 3-113.
Elevated condenser is tightly enclosed, making service access difficult (Bermuda Beach, TX; Hurricane Ike estimated wind speed in this area: 95 mph, Exposure C)

3.3 Other Damage

3.3.1 Breakaway Walls

The Ike MAT found that solid breakaway walls performed as expected in the vast majority of cases. The walls broke free without causing significant or structural damage to elevated buildings. In some cases, failure of the breakaway walls led to propagation of damage to the building exterior above the lowest floor (Figure 3-114). In other cases, attachment of utilities to breakaway walls either prevented their successful breakaway, or contributed to utility damage (Figure 3-115).

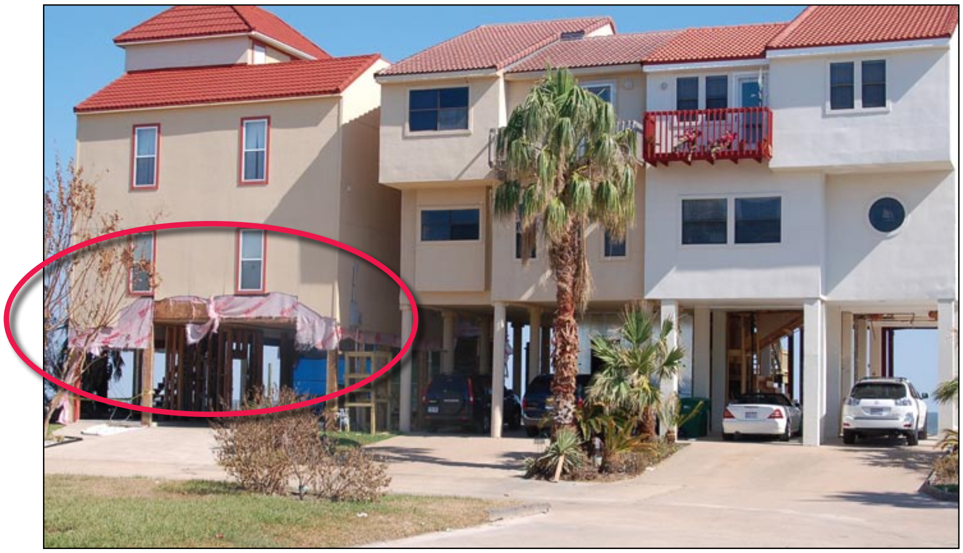


Figure 3-114.
Propagation of damage above lowest floor when breakaway walls broke free (Seabrook, TX)

Figure 3-115. Attachment of utilities to breakaway wall may have prevented the wall from breaking away, thereby resulting in additional damage to the structure (Galveston Island, TX)

The MAT did not document specific cases where breakaway wall panels from one building led to identifiable damage to adjacent buildings. However, the ubiquitous presence of breakaway walls beneath elevated buildings would undoubtedly increase the quantity of floodborne debris during a severe flood event, and could potentially contribute to damage at adjacent structures.

The MAT observed some breakaway walls in excess of 11 feet high (Figure 3-116). While FEMA promotes elevating houses above the BFE (i.e., adding freeboard), one of the unintended consequences appears to be an increased size of floodborne debris elements due to the presence of these taller breakaway walls.

The MAT observed that louvered panels remained intact longer than solid breakaway walls under the same flood conditions. As a result, houses with louvered panels had less flood-related damage (and repair cost) and contributed less floodborne debris. Figure 3-117 shows louvered panels that allowed Ike floodwaters to pass into and out of the below-BFE enclosure without damage to the louvered panels. These louvers were installed on the same building shown in Figure 3-116, where the solid breakaway wall panel was displaced by floodwaters trapped inside the enclosure.

Figure 3-116.
This 11-foot high breakaway wall panel was pushed out by floodwaters trapped inside the enclosure (Galveston Island, TX)

Figure 3-117.
Louvered panels allowed Ike floodwaters to pass into and out of the below-BFE enclosure without damage to the panels. The building shown here is the same as in Figure 3-116, where a solid breakaway wall panel broke away.

Numerous building owners in one community (Tiki Island, TX) were observed to be replacing solid breakaway walls lost during Ike with louvered panels (Figure 3-118). This action will reduce future flood damages and can result in lower flood insurance premiums. Zone V flood insurance premiums are much less for a building with a below-BFE enclosure formed by louvers than for a building with an enclosure formed by breakaway walls. A building with an enclosure formed by louvers is classified the same as if it had insect screening or open lattice, i.e., as “free of obstructions,” while a solid breakaway wall enclosure results in a “with obstruction” rating for the building.

Based on these observations, the Ike MAT recommends the use of louvered panels rather than solid breakaway walls below the BFE. See the Hurricane Ike Recovery Advisory, *Enclosures and Breakaway Walls*, in Appendix D for more details on this topic.

Figure 3-118. Solid breakaway walls lost during Ike are being replaced with louvered panels (Tiki Island, TX)

3.3.2 Sheathing on the Underside of Elevated Buildings

Sheathing is typically installed on the underside of the lowest-floor joists on elevated buildings. Besides protecting batt insulation that is placed between joists, sheathing can also protect electrical and plumbing lines from floodborne debris. A variety of sheathing materials are used, most often sheets of plywood, hardboard, or fiber cement panels. The sheathing is sometimes covered with vinyl soffit material, or left uncovered and painted.

In locations where the water level or waves reached the elevation of the building, sheathing and any covering was frequently found to be partially or completely removed (Figures 3-119 and 3-120). This was particularly true of the thinner panel types, such as ⅛-inch fiberboard. Other forms of damage, such as gouges from floodborne debris, were observed on the underside of panels.

Figure 3-119.
Plywood sheathing removed by storm surge (Jamaica Beach, TX, house on West Bay)

Figure 3-120.
Fiber cement board sheathing (red arrow) was removed from the underside of this house, which was elevated approximately 12 feet above ground level (Bolivar Peninsula, TX)

Several examples of vinyl soffit attached directly to floor joists, without sheathing, were observed by the MAT (Figure 3-121).

Where floodwaters did not reach the underside of the building, damage due to wind accelerating underneath the building was often observed. In these cases, vinyl soffit was often blown off. In some cases, but not all, the sheathing above the soffit was also removed. The vinyl soffit covering on the Tiki Island house shown in Figure 3-122 was probably blown off by wind action rather than storm surge.

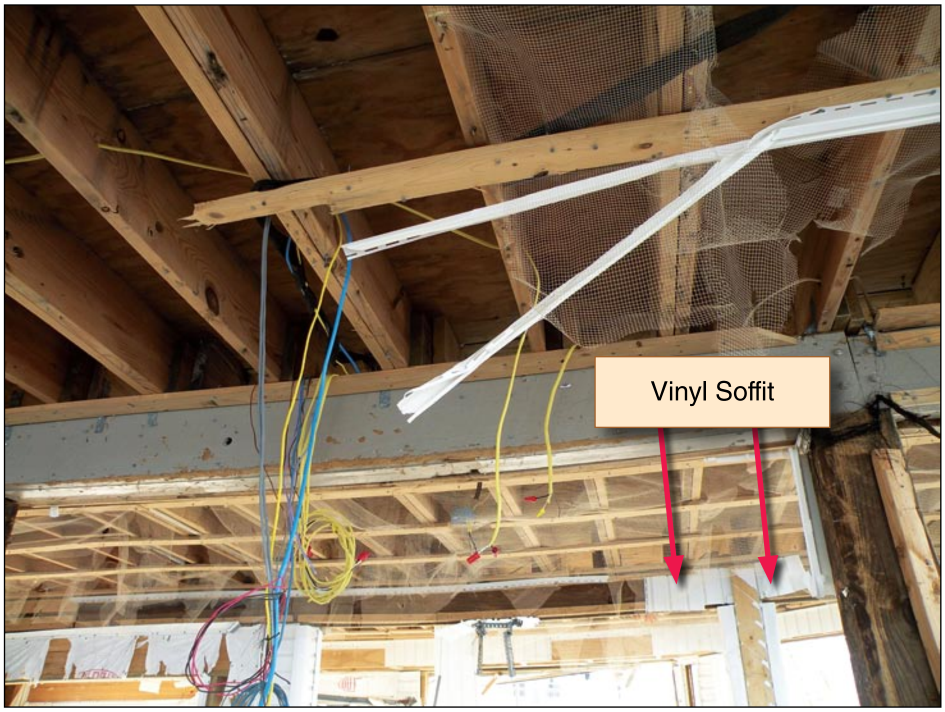


Figure 3-121.
Tiki Island house with vinyl soffit applied without sheathing removed by storm surge (netting was used to contain insulation in joist space)

Figure 3-122.
Vinyl soffit covering over plywood sheathing partially removed (Tiki Island, West Galveston Bay; Estimated Hurricane Ike wind speed: 103 mph, Exposure C)

For further information on the performance of sheathing on the underside of elevated buildings, see FEMA 489.

3.3.3 Parking Slabs and Grade Beams

Many of the houses supported on pile foundations that the MAT visited had concrete slabs constructed at grade. These slabs were typically used as parking slabs beneath the elevated houses (Figure 3-123). Some of the slabs were thin (less than 4 inches thick); others were much thicker. Some had thickened edges and interior sections that acted as grade beams, presumably to stiffen the foundation. Virtually all slabs were reinforced with welded wire mesh and/or steel reinforcing bars.

Figure 3-123. Typical concrete parking slab beneath a pile-supported house (Bolivar Peninsula, TX)

Many of the slabs failed once they were undermined. Where the piles were embedded deep into the ground, the slab was either undermined (and sometimes settled) as shown in Figure 3-124, or the slab collapsed without visible damage to the foundation (Figure 3-125).

Figure 3-124. Undermining of concrete slab that settled but remained intact (Galveston Island, TX)

Figure 3-125. Pile-founded house with a slab thickened to create grade beams. The unthickened portion of the slab collapsed when undermined (Galveston Island, TX).

Where the piles were thought to be less well embedded, failure of the slab could have caused the pile foundation to rotate or rack (Figure 3-126). The MAT believes this was more common with older houses, and was likely a result of portions of the slab causing eccentric loads on the piles and the transfer of flood forces from the slab to the foundation.

The MAT observed instances where the weight of the slab likely contributed to foundation failure and building settlement, illustrated in Figures 3-127 and 3-128. Figure 3-127 shows a Holly Beach, LA, house under construction at the time of Ike. The piles and elevated floor beams had been placed, and a thick slab had been cast; when Ike undermined part of the slab, it cracked and settled, pulling some of the piles and beams downward. Figure 3-128 shows a house at Surfside Beach, TX, that was subject to considerable scour and erosion—when the slab settled and collapsed, it could have pulled part of the house lower as it went. Pile embedment appears to have been the larger issue at the houses shown in Figures 3-127 and 3-128, and insufficient embedment likely allowed the slabs to induce or worsen building settlement.

Figure 3-126.
Slab failure probably contributed to foundation damage (West Galveston Island, TX)

PHOTO COURTESY OF STUART ADAMS, LSU HURRICANE CENTER

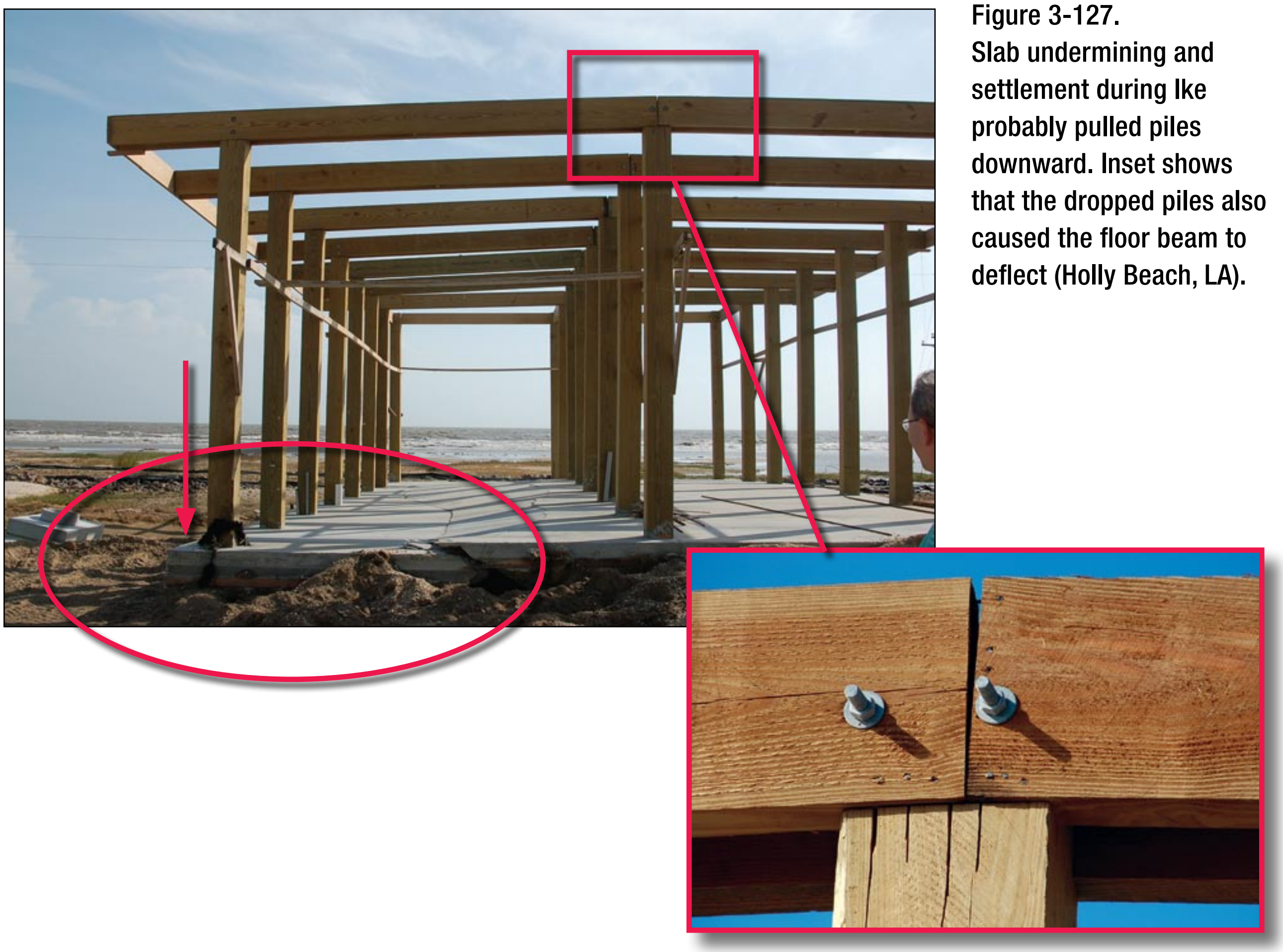


Figure 3-127.
Slab undermining and settlement during Ike probably pulled piles downward. Inset shows that the dropped piles also caused the floor beam to deflect (Holly Beach, LA).

Figure 3-128.
The weight of this slab, undermined due to scour and erosion, could have contributed to settlement and racking of this elevated house (Surfside Beach, TX)

The MAT observed several houses on Galveston Island where parking slabs were constructed in 4-foot square sections and unreinforced. This method of construction is consistent with that recommended in FEMA 55, Third Edition. Where these slabs were observed, their failure did not appear to adversely affect foundations or elevated buildings (Figure 3-129). Section III of the *Galveston County Dune Protection and Beach Access Plan* (2006) requires use of unreinforced fibercrete or concrete slab sections (maximum 4-inch thickness) within 200 feet of the vegetation line in eroding areas.

Figure 3-129.
Thin, unreinforced parking slab sections separated when undermined and collapsed in place, with no apparent adverse impact to the foundation (Galveston Island, TX)

3.3.4 Mold and Contamination

Hurricanes introduce various forms of contaminants and pollution into floodwaters and flooded buildings. Hurricanes also lead to the post-event growth of mold in wind- and flood-damaged buildings. Figure 3-130 illustrates one of many examples of mold and mildew growth observed by the Ike MAT. Guidance on cleanup and restoration of flooded buildings can be found in the Hurricane Katrina Recovery Advisory 2, *Initial Restoration for Flooded Buildings* (July 2006d), and Katrina Recovery Advisory 4, *The ABCs of Returning to Flooded Buildings* (July 2006e).

Figure 3-130. Mildew and mold forming on wall sheathing following flooding (Golden Meadow, LA)

3.3.5 Other Issues and Problems

The MAT observed other construction deficiencies and community enforcement problems. While the details of these particular deficiencies are not known, their existence indicates potential compliance issues that should be monitored and addressed in communities visited by the MAT. Figure 3-131 shows a case where floor beams and joists were improperly notched to allow for plumbing installation. This practice can weaken structural members and should only be done at the direction of a structural engineer. Figure 3-132 shows a case where flood vents did not penetrate through the entire enclosure wall—if this installation was complete when observed by the MAT, this practice is a clear violation of NFIP flood opening requirements.

Figure 3-131. Floor joists and beams were notched to allow for plumbing (Sulphur, Calcasieu Parish, LA)

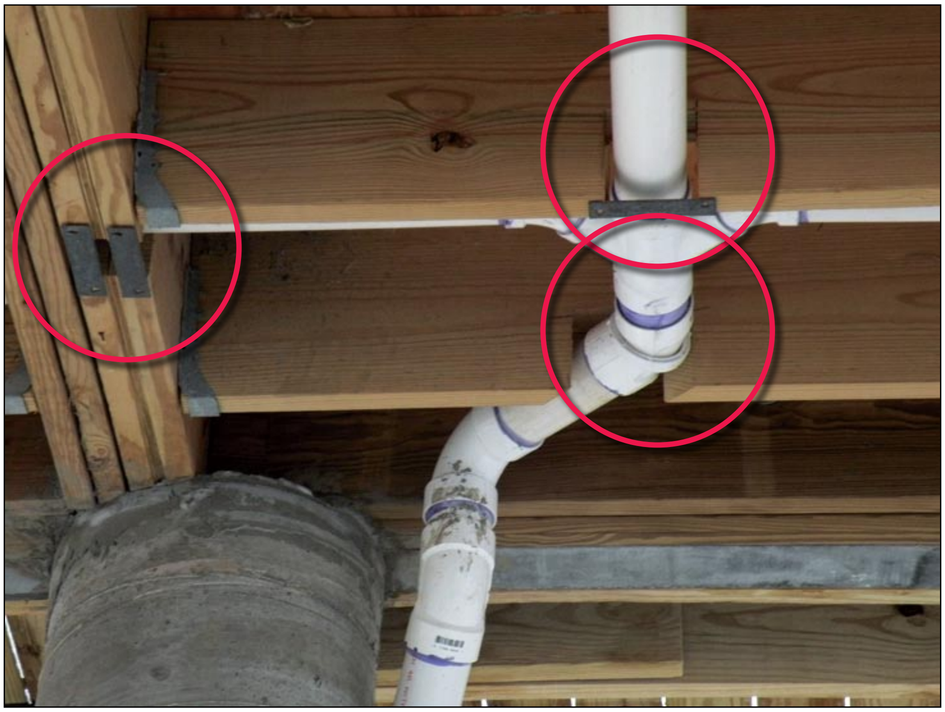


Figure 3-132. Flood vent openings (red circles) that do not extend through the walls (Hackberry, Cameron Parish, LA)

3.4 Manufactured Housing

The MAT visited several communities in south Louisiana and east Texas where large numbers of manufactured homes were damaged by some combination of storm surge, waves, floodborne debris, and wind. In some locations in southwest Louisiana, manufactured housing installed after Hurricane Rita was not elevated to or above the BFE. This may have occurred in existing manufactured housing parks where an NFIP exception allows some homes to be elevated 3 feet above grade, even where this is lower than the BFE, or it may have occurred through incorrect application of the 3-foot exception. Whether this practice was allowed by the NFIP exception or not, the result was the same—large numbers of manufactured homes installed below the BFE after Hurricane Rita were heavily damaged or destroyed by Hurricane Ike.

3.4.1 Texas

In San Leon, TX, the MAT observed a manufactured home that was knocked off its foundation and destroyed. The home was located in a Zone AE (BFE = 11 feet) approximately 150 feet landward of a rip-rapped shoreline. High water marks in the area indicated water levels were over 12 feet NGVD, and 5 feet or more above grade. Coastal A Zone conditions (wave heights between 1½ and 3 feet) likely existed there during Ike.

The home, shown in Figure 3-133, was placed on short, unreinforced and un-mortared "dry stack" masonry piers placed on pre-cast concrete pads (at 8-foot centers [+/-]), and was secured with ground anchors spaced at 4-foot centers (+/-) with metal stabilizer plates.

Figure 3-133. Destroyed manufactured home (San Leon, TX)
SOURCE: GOOGLE MAPS FOR INSET SHOWING LOCATION

Evidence suggests that the home was displaced from its piers by moving floodwaters or waves. Scour, undermining the concrete pads beneath the piers, may have contributed. Ground anchor failures were not noted, but the straps connecting the home to the anchors had torn away from the house's anchorage points (Figure 3-134). HUD's 2007 *Manufactured Home Construction and Safety Standard* (MHCSS), 24 CFR Parts 3280 and 3285, place this site in a Wind Zone II. The MHCSS requires Wind Zone II homes to be secured and anchored to their steel frames and to wall ties. No wall ties were observed. This suggests that the home was either non-compliant or was installed before the HUD standards went into effect.

Figure 3-134.
Scour depressions existed around the masonry piers, pads, and ground anchor stabilizer plates (San Leon, TX)

In Oak Island, TX, some manufactured homes were elevated on timber piles. The elevation prevented foundation failure, but some of the homes were still damaged by inundation (Figure 3-135).

Figure 3-135.
Manufactured home in Oak Island, TX. The house foundation did not fail, but the elevation was insufficient to prevent damage from inundation.

3.4.2 Louisiana

The MAT observed that Zone A manufactured homes elevated at or above the BFE/ABFE on reinforced concrete or reinforced masonry piers with proper anchoring performed well. The best performance of foundations in Zone V was found to be timber piles embedded sufficiently to withstand erosion and scour effects. Zone V homes on piers resting on concrete pads often failed due to flood and erosion/scour effects.

3.4.2.1 Cameron and Vermilion Parishes

Many of the manufactured homes that were present in Cameron and Vermilion Parishes in 2005 are no longer in place. Those structures were destroyed by Hurricane Rita and in many instances, had not been replaced. Many of those that had been replaced after Rita and not elevated to or above the BFE/ABFE were damaged by Ike.

The manufactured homes shown in Figure 3-136 are located immediately east of the Cameron Parish offices along LA Hwy 82 in South Cameron. They are currently located within Zone A, but will be classified as Zone V when the pending new flood maps are adopted. The homes were not properly anchored and were forced off their foundation piers by the storm surge.

Figure 3-136.
Two manufactured homes in Cameron, LA. Homes were displaced off foundations and siding peeled due to inundation and storm surge of approximately 4 feet above ground.

3.4.2.2 Jefferson Parish

The manufactured home shown in Figures 3-137 and 3-138 is located in Zone A (BFE = 10 feet, ABFE = 12 feet) on Grand Isle, Jefferson Parish. Ike floodwaters were approximately 6 feet deep and did not reach the home, which was elevated in compliance with NFIP requirements. Support framing was in place, and strapping secured the walls and the steel chassis frame to the foundation. While effective during Ike, the strapping was installed using non-conventional methods. Its ability to resist a design wind event could not be determined.

The home experienced some wind damage (vinyl siding and portions of the roof covering were dislodged) despite the fact that the Ike wind speeds and wind pressures were far below the HUD and ASCE 7-05 design wind speeds and pressures. Section 305 of the MHCSS, 24 CFR Part 3280, requires that siding be designed to resist wind loads for Exposure C specified in ANSI/ASCE 7-88, or wind pressures specified the HUD Standard table titled Table of Design Wind Pressures. The MHCSS places Jefferson Parish in HUD Wind Zone III, and the Table of Design Wind Pressures requires exterior coverings within 3 feet of corners to resist +/- 58 psf, and exterior coverings in other areas to resist +/- 46 psf. The ASCE 7-05 wind pressures (for a 150 mph basic wind speed) are +49/-65.7 psf at the corners of a building and +49/-53.1 psf in other areas.

Figure 3-137.
This elevated manufactured home in Grand Isle of Jefferson Parish, LA, had siding and roof damage, but did not move from its foundation

Figure 3-138.
The framing and anchoring system of the house shown in Figure 3-137. Strapping secured the home's walls and frames to its foundation. While the strapping held the home to its foundation during Ike, it could not be determined if the strapping would resist a design wind event (Estimated wind speed during Ike: less than 60 mph, 3-second gust).

3.4.2.3 Lafourche Parish

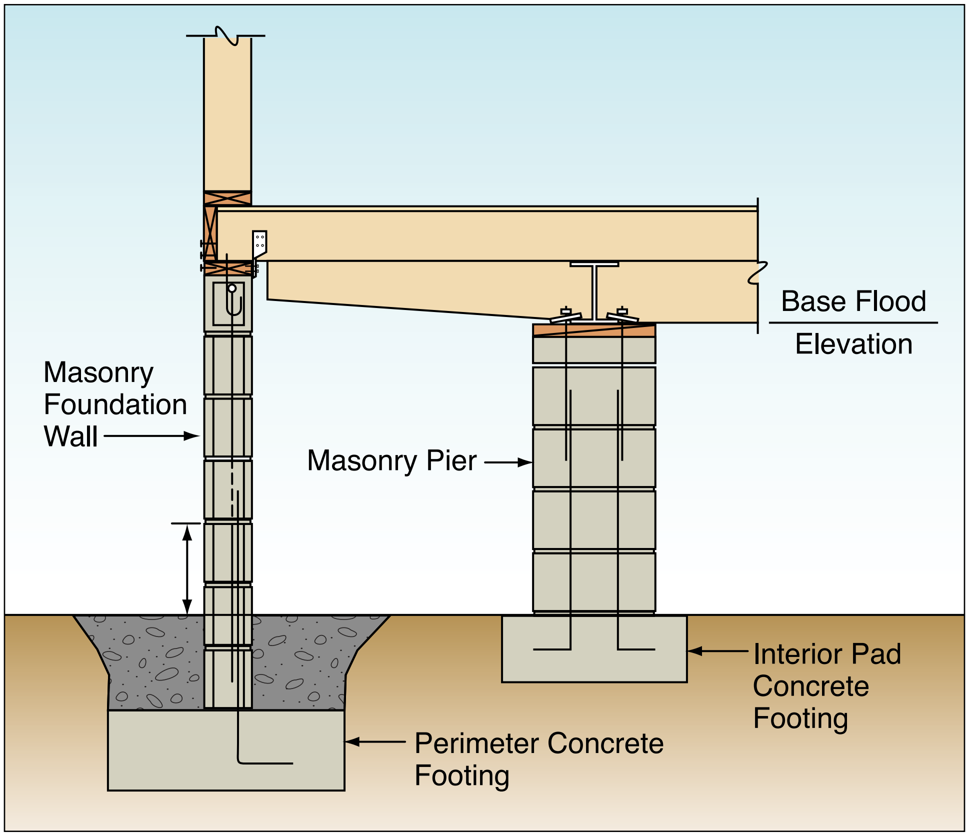
The Zone A home shown in Figure 3-139 in Lafourche Parish was elevated, but not above the BFE. It suffered flood damage from about 3 to 4 feet of water above the floor. Interviews with nearby residents indicated the floodwaters reached the eaves on the house with the green roof to the right. Flood velocities were not sufficient to shift the manufactured home off of its foundation and the floodwaters rose slowly enough to allow leakage into the home, thereby preventing the home from becoming buoyant and floating off its foundation.

Figure 3-139.
Zone A manufactured home in the Golden Meadows section of Lafourche Parish, LA, sustained 3 to 4 feet of flooding above the floor, but did not shift or float off of its foundation. The red arrow indicates the flood level reported by neighbors.

3.4.2.4 Manufactured Home Anchoring and Support Systems

Manufactured homes in SFHAs must be placed on foundation systems that will resist flotation, collapse, and lateral movement (Figure 3-140). The 2005 edition of the NFPA 225, *Model Manufactured Home Installation Standard,* contains performance requirements for flood-resistant manufactured home installations. The 2008 edition, issued in January 2009, also contains prescriptive flood-resistant installations. Other flood-resistant foundation solutions will be contained in the revised FEMA 85, scheduled to be completed in 2009.

Figure 3-140. Prescriptive Flood-Resistant Foundation Design



3.5 Mitigation Projects

The MAT typically looks at funded mitigation projects to determine if the projects were successful. The MAT visited 27 residential mitigation projects in Louisiana and 10 in Texas. Thirty-four of the projects visited were elevation projects, and three were acquisition projects. All of the projects received funds through the Hazard Mitigation Grant Program (HMGP) or through Increased Cost of Compliance payments via NFIP flood insurance policies. There were no structures visible at the three acquisition project sites, and the land had been cleared and restored.

Three of the 34 elevation projects had not been undertaken at the time of the MAT visit. The remaining 31 elevation projects had been completed and were successful as far as preventing Ike flood damage—none of the elevated buildings appeared to have been flooded during Ike, even though many of the building sites were inundated. Most of the buildings had been elevated on masonry piers, tall masonry columns, or timber piles.

While most of the elevation projects appeared to have been constructed in accordance with applicable codes and standards, some load path deficiencies (Figure 3-141) were noted that indicate possible project design and/or compliance problems that should be investigated. Some of the elevated buildings sustained wind damage to the building envelope during Ike (Figure 3-142); this is likely a result of older homes being elevated, as opposed to a problem with the elevation project itself.

Figure 3-141.
Zone A house elevated with Increased Cost of Compliance funds on masonry piers (Iberia Parish, LA). There was no evidence of pier reinforcement, mortar between masonry blocks, or ties between the piers and the elevated home.

Figure 3-142.
House elevated with Increased Cost of Compliance funds (Kemah, TX). Inset shows evidence of wind damage to roof (Hurricane Ike estimated wind speed in this area: 90 mph, Exposure B).