FEMA 338/*March 1999*

Building Performance Assessment Report

Hurricane Georges...

In The Gulf Coast


NASA

...Building on Success

Observations, Recommendations, and Technical Guidance

Federal Emergency Management Agency
Mitigation Directorate
Washington, DC and
Region IV, Atlanta, Georgia

The Building Performance Assessment Process

In response to hurricanes, floods, earthquakes, and other disasters, the Federal Emergency Management Agency (FEMA) often deploys Building Performance Assessment Teams (BPATs) to conduct field investigations at disaster sites. The members of a BPAT include representatives of public and private sector entities who are experts in specific technical fields such as structural and civil engineering, building design and construction, and building code development and enforcement. BPATs inspect disaster-induced damages incurred by residential and commercial buildings and other manmade structures; evaluate local design practices, construction methods and materials, building codes, and building inspection and code enforcement processes; and make recommendations regarding design, construction, and code issues. With the goal of reducing the damage caused by future disasters, the BPAT process is an important part of FEMA's hazard mitigation activities. For more information about the BPAT program or if you are interested in becoming a member, please visit our website at www.fema.gov/mit/bpat.

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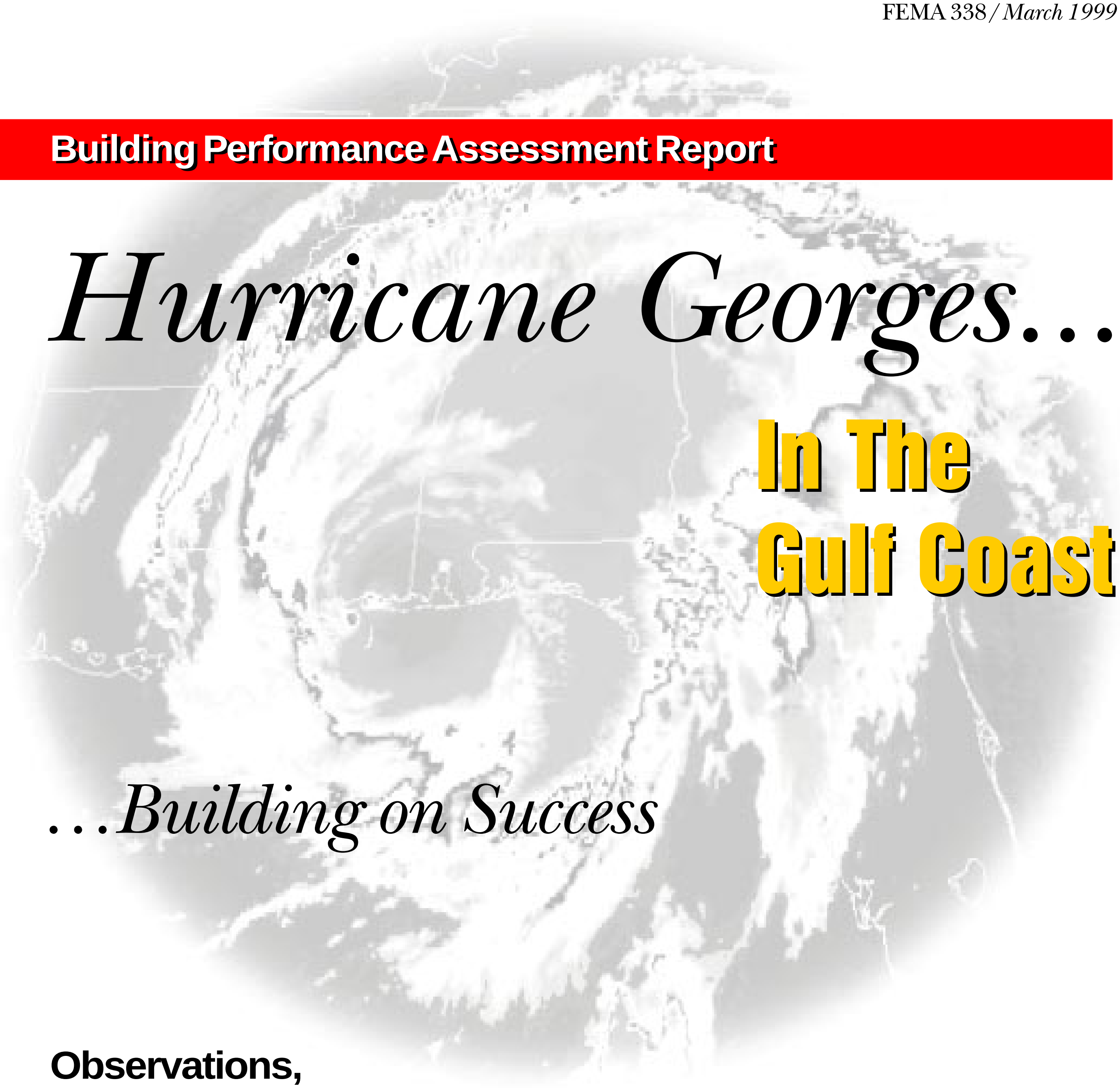

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List of Acronyms

ASCE	American Society of Civil Engineers
A-Zone	Special Flood Hazard Areas, excluding V-Zones
BPAT	Building Performance Assessment Team
BFE	Base Flood Elevation
CCCL	Coastal Construction Control Line
cfs	cubic feet per second
DFCO-M	Deputy Federal Coordinating Officer - Mitigation
FEMA	Federal Emergency Management Agency
FIA	Federal Insurance Administration
FIRM	Flood Insurance Rate Map
FMAP	Flood Mitigation Assistance Program
HMGP	Hazard Mitigation Grant Program
HUD	Department of Housing and Urban Development
msl	mean sea level
mph	miles per hour
NFIP	National Flood Insurance Program
NGVD	National Geodetic Vertical Datum
NOAA	National Atmospheric and Oceanic Administration
NWS	National Weather Service
SBA	Small Business Administration
SBC	Standard Building Code
SFHA	Special Flood Hazard Area
TPI	Truss Plate Institute
USGS	United States Geological Survey
V-Zones	Coastal High Hazard Zones

1 Executive Summary

On September 28, 1998, Hurricane Georges made landfall in the Ocean Springs/Biloxi, Mississippi area. Over the next 30 hours, the storm moved slowly north and east, causing heavy damage along the Gulf Coast in Alabama, Florida, and Mississippi. Preliminary data from National Weather Service (NWS) reports indicate that maximum sustained winds ranged from 46-mph at Pensacola, Florida to as high as 91-mph with peak gusts up to 107-mph at Sombrero Key in the Florida Keys.

Storm surges over the area ranged from more than 5 feet in Pensacola, Florida to 9 feet in Pascagoula, Mississippi. According to the NWS, the Town of Munson, Florida, in Santa Rosa County, received the highest recorded level of rainfall with more than 38 inches. Elsewhere in the Gulf Coast area, total rainfall ranged from 8 to 26 inches.

Hurricane Georges caused extensive erosion to the Gulf Coast. Many coastal barrier islands, including Dauphin Island and the Chandeleur Islands, were completely overwashed in areas, and vertical beach loss and considerable shoreline retreat occurred. High tides and rain washed out major highways and flooded beachfront homes in many areas of Alabama, Florida, and Mississippi.

On October 2, 1998, the Federal Emergency Management Agency (FEMA) Mitigation Directorate deployed a Building Performance Assessment Team (BPAT) to the Gulf Coast to assess damages caused by Hurricane Georges. The team included FEMA Headquarters and Regional Office engineers, planners, and a coastal geologist; consulting engineers; floodplain management specialists; and a forensic engineer.

The BPAT's mission was to assess the performance of buildings in the Gulf Coast area and make recommendations for improving building performance in future hurricanes. The assessment included areas of the Gulf Coast from Pensacola Beach, Florida, to Gulfport, Mississippi (including Mobile Bay, Alabama). In addition, a supplemental assessment of manufactured home performance was conducted in the Florida Keys. The assessment also included inland areas along major streams and rivers that experienced flooding. The BPAT process is intended to provide guidance to state and local governments on post-hurricane reconstruction and new construction with the goal of enhancing future building design and construction.

In conducting this assessment, the BPAT focused on:

- The success and effectiveness of flood and wind hazard mitigation initiatives undertaken prior to Hurricane Georges, including acquisition and removal of structures located in floodprone areas, elevation of floodprone buildings, installation of storm shutters, and high wind roofing systems;
- Siting and other planning issues that contributed to building success, damage, or failure;

- Floodplain management issues, including repetitive loss structures and floodplain mapping; and
- The impact of the hurricane on the shoreline/beach system.

An aerial survey and on-the-ground site investigations were conducted to observe building conditions in selected areas affected by the storm. One- and two-family, one- to three-story wood-frame structures elevated on pilings were the primary building types assessed in coastal areas, although some slab-on-grade structures were included. In riverine areas, one-family wood-frame structures were the primary structures inspected. Foundation types included piles, perimeter wall/crawl space, and slab-on-grade. Several public and commercial buildings in coastal and riverine areas were also evaluated, including a hospital, convention center, fire houses, municipal buildings, schools, and casinos.

The Gulf Coast region experienced the loss of several vertical feet of beach sand and sustained considerable shoreline damage as a result of Hurricane Georges. By far, the most severe flood damage the BPAT observed was a result of coastal surge along the Alabama Gulf Coast, specifically Dauphin Island, the eastern and western shores of Mobile Bay, and the Fort Morgan/Gulf Shores areas. Building damage was concentrated on the front row of houses. Houses set back and properly elevated on deep pilings suffered little damage. Hundreds of inland residential structures in Alabama, Florida, and Mississippi were also inundated with water by riverine flooding.

Hurricane Georges did not cause significant wind-related structural damage along the Gulf Coast. Buildings along the open coast suffered minor wind damage, including loss of sections of composition roof shingles and siding. While limited structural damage was observed, many homes that sustained roof damage were susceptible to further interior damage from rainfall. Wind damage in inland areas included damage to trees and signs. The most severe inland wind damage occurred to signs, roofs, and trees in the Pascagoula, Mississippi area.

The BPAT findings are summarized below:

- Engineered structures constructed in accordance with current building codes, such as the Standard Building Code (SBC), National Flood Insurance Program (NFIP) compliant local floodplain management requirements, and additional state and local standards performed well;
- Communities that recognized and required buildings be designed and constructed for the actual hazards present in their area, sustained reduced damages;
- Manufactured homes with reinforced concrete or reinforced masonry piers and proper anchoring performed well;
- Specialized building materials such as siding and roof shingles designed for higher wind speeds performed well; and
- Publicly financed flood mitigation programs and planning activities clearly had a positive impact on the communities where they were implemented.

The BPAT concluded that several factors contributed to the building damages observed in the Gulf Coast area:

- Riverine flooding in many areas exceeded the 100-year flood level;
- Inadequate pile embedment depths on coastal structures;
- Inadequately elevated and protected on-site utility systems;

- Inadequate designs for frangible concrete slabs below elevated buildings in coastal areas subject to wave action;
- Impact from waterborne debris on coastal structures;
- Siting of houses that did not consider localized impacts of coastal erosion and scour;
- Corrosion of hurricane straps on coastal structures;
- Site-built attachments to manufactured homes; and
- Improperly installed manufactured home anchors.

The BPAT developed recommendations for reducing future hurricane damage. The recommendations address areas of concern, including: continuing development of flood mitigation programs and planning; mitigating residual flood risk; increasing the pile embedment depth for coastal structures; improving the installation of utilities to include greater attention to the potential effects of riverine and coastal flooding; proper design of below-building concrete slabs; mitigating waterborne debris impact; protecting metal structural components from corrosion; improving attachment design and anchoring for awnings, decks, and porches on manufactured homes; and proper use and installation of manufactured home anchors.

2 Introduction

2.1 Purpose

This report presents the Federal Emergency Management Agency's (FEMA) Building Performance Assessment Team's (BPAT) observations on the success and failure of buildings in the Florida Keys and Gulf Coast areas of the United States to withstand the wind and flood forces generated by Hurricane Georges. Recommendations to improve the building performance in future natural disasters in this area are included as well. A separate assessment and report has also been prepared on the effects of Hurricane Georges in Puerto Rico (FEMA 339).

2.2 Background of Storm

Hurricane Georges formed 400 miles south-southwest of the Cape Verde Islands and moved across the Atlantic into the Caribbean on September 16, 1998. On September 17, Hurricane Georges was upgraded to a Category 4 hurricane on the Saffir-Simpson scale as it moved west through the Caribbean packing 150-mph winds. Hurricane Georges was downgraded to a Category 2 hurricane once it moved through the Leeward, U.S. and British Virgin Islands on September 21. The storm passed the Florida Keys on September 25, 1998. It was still a Category 2 hurricane when it made landfall at Biloxi, Mississippi and was downgraded to a tropical storm by late afternoon on September 28, 1998.

At approximately 4:00 a.m. on September 28, 1998, Hurricane Georges made final landfall in the Ocean Springs/Biloxi, Mississippi area (Figure 2-1). Over the next 30 hours, the storm moved slowly north and east, causing heavy damage along the Gulf Coast in Mississippi, Alabama, and Florida.

Preliminary data from National Weather Service (NWS) reports indicate that at landfall, maximum sustained winds in the Gulf Coast region reached 105-mph [U.S. Army Corps of Engineers 1998]. Maximum sustained winds during the storm varied from 46-mph in Pensacola, Florida, 51-mph at the Mobile Regional Airport, Alabama, and 61-mph at Gulfport Harbor, Mississippi. A maximum gust of 117-mph was recorded at Mississippi Power and Light in downtown Gulfport, Mississippi. When the storm passed the Florida Keys, the highest measured sustained wind reported was 91-mph with peak gusts to 107-mph at Sombrero Key. Higher gusts were estimated on Cudjoe and Big Pine Keys [NWS 1998].

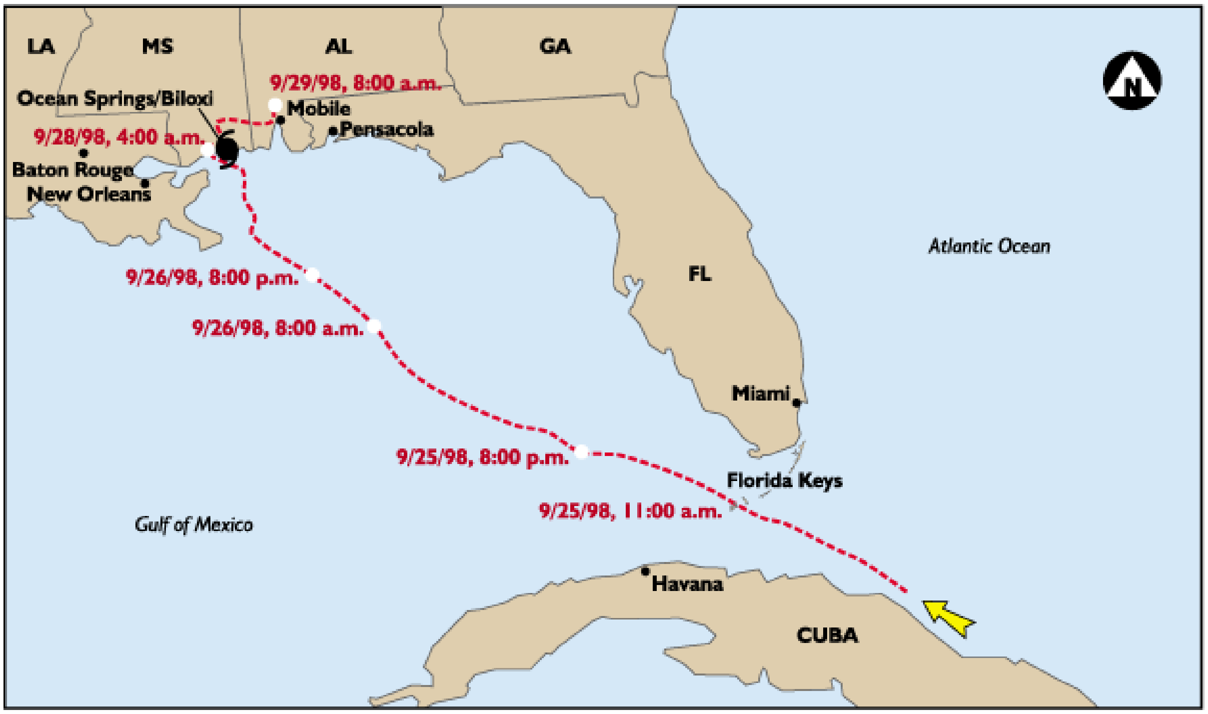


FIGURE 2-1 Track of Hurricane Georges.

Storm surge elevations over the area varied from 5.0 feet in Navarre, Florida, 7.7 feet in Pensacola Beach, Florida, to 8.2 feet in Biloxi and 9.4 feet in Pascagoula, Mississippi (Figure 2-2). According to the U.S. Army Corps of Engineers, storm surges in downtown Mobile, Alabama reached 8.9 feet. Storm surge elevations on the Gulf side of Dauphin Island were 6.7 feet and 9.0 feet in Gulf Shores, Alabama [U.S. Army Corps of Engineers 1998]. In the Florida Keys, the storm surge elevations ranged from 3 feet to 6 feet [NWS 1998].

According to NWS, total rainfall exceeded 16 inches in Pascagoula, Mississippi; 13 inches in downtown Mobile, Alabama; 26 inches in Pensacola, Florida; and 8.4 inches in Key West, Florida [NWS 1998]. The Town of Munson, Florida in Santa Rosa County received the highest recorded level of rainfall with more than 38 inches. Figure 2-3 displays the distribution of rainfall from Hurricane Georges over the Gulf Coast region.

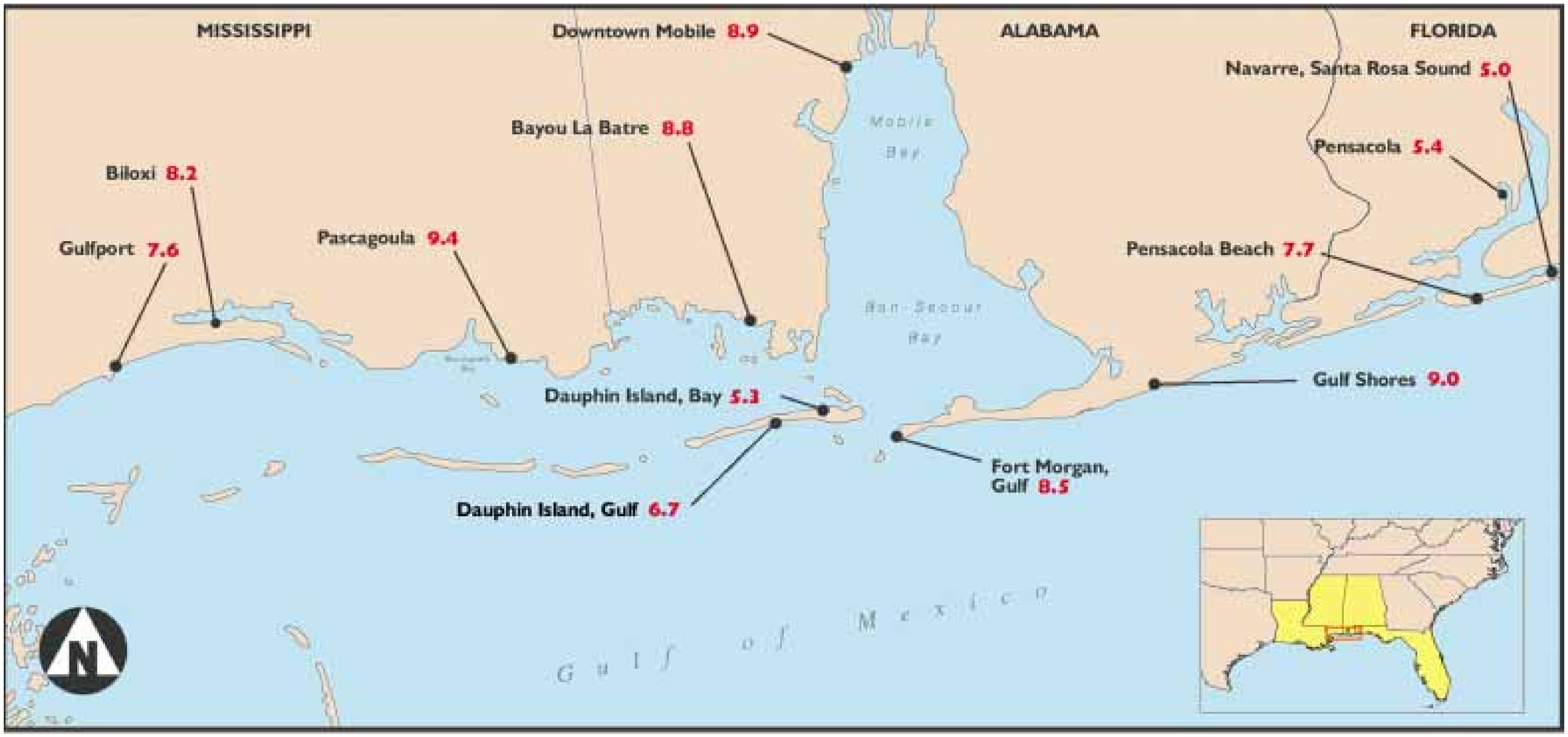


FIGURE 2-2 Representative storm surge elevations, Hurricane Georges.

Sources: Base map from USGS Center for Coastal Geology, October 21, 1998

Storm surge data from U.S. Army Corps of Engineers Report, Mobile District, Hurricane Georges, September 1998

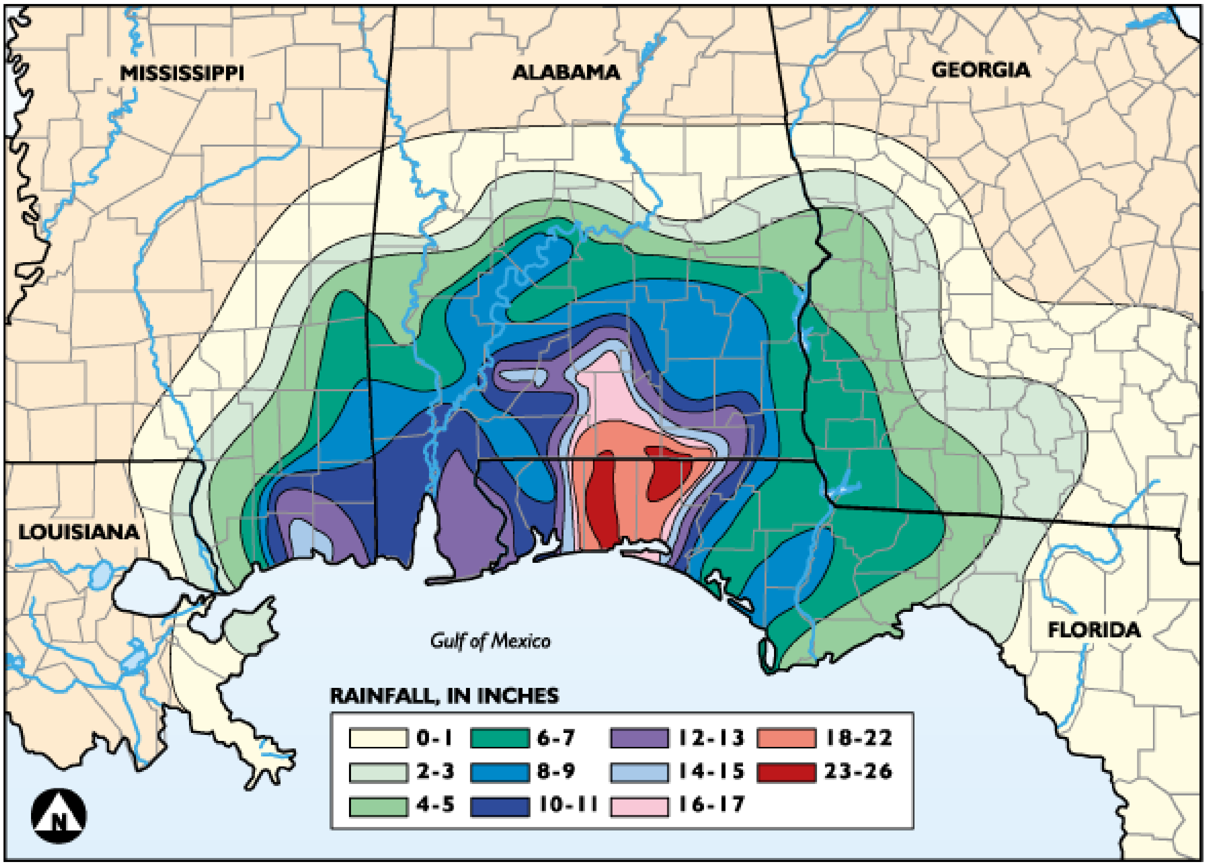


FIGURE 2-3 Hurricane Georges total rainfall distribution.
Source: National Oceanic and Atmospheric Administration (NOAA)/NWS Southwest River Forecast Center

Riverine flooding was extensive and variable throughout the study area (Figure 2-4). In general, flooding increased the farther east the storm moved [U.S. Geological Survey 1998]. Based upon preliminary United States Geological Survey (USGS) river flow data, in Mississippi, most of the recurrence intervals were estimated between 25 and 50 years. Flow estimates in the Mobile, Alabama area indicated similar estimates of recurrence intervals. However, in eastern Alabama and in Escambia, Santa Rosa, and Okaloosa counties in Florida, recurrence intervals were estimated from 25 to 400 years.

Hurricane Georges caused extensive erosion to the Gulf Coast. Many coastal barrier islands, including Dauphin Island and the Chandeleur Islands, were overwashed and several vertical feet of beach sand were displaced. High tides and rain washed out major highways and flooded beachfront homes in many areas of Alabama, Florida, and Mississippi. More than 370 deaths in the Caribbean and four in the United States (two each in Louisiana and Florida) were directly attributed to Hurricane Georges [Associated Press 1998].

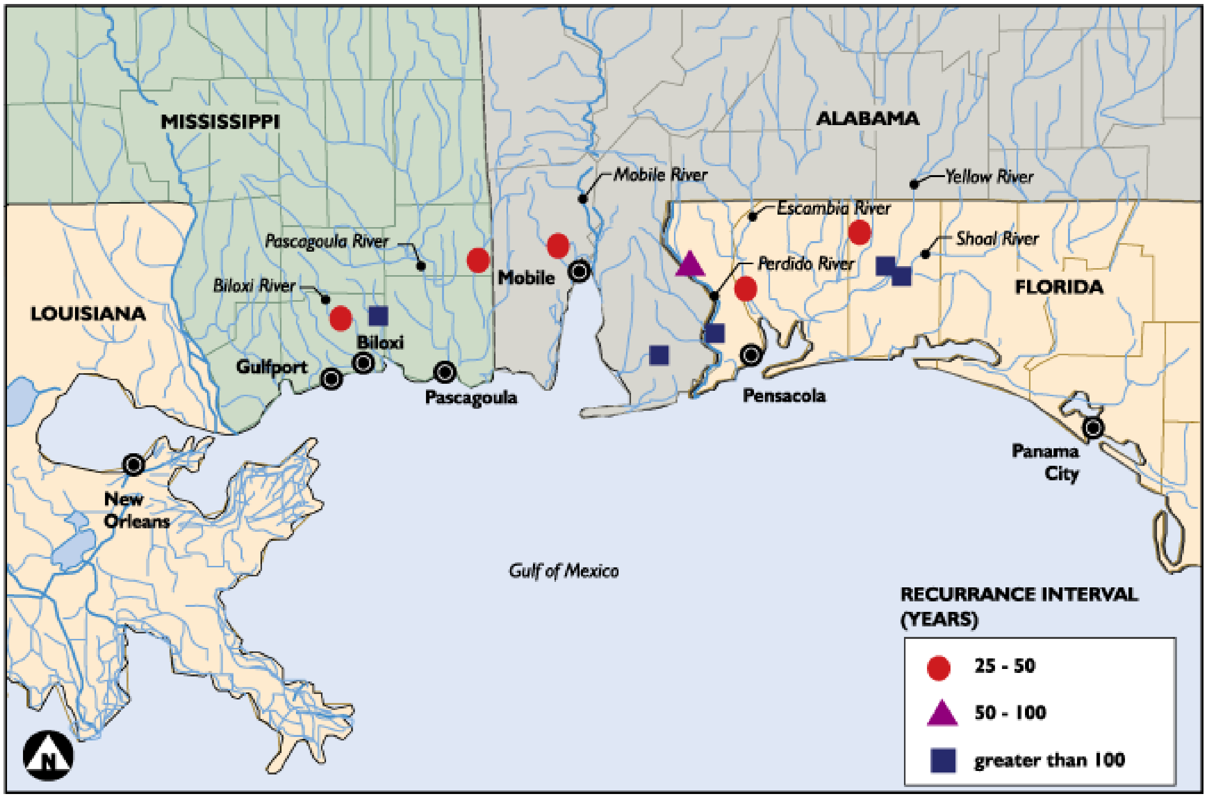


FIGURE 2-4 Hurricane Georges peak flow data.
Source: U.S. Geological Survey, Water Resources Investigations Report 98-4231

2.3 History of Storms

Coastal Alabama, the Florida Panhandle, and Mississippi have experienced many destructive hurricanes in recent years. In 1975, Hurricane Eloise affected the region, causing significant damage to residences with slab-on-grade first floors and other non-elevated structures with shallow footings. In September 1979, Hurricane Frederic made landfall near Gulf Shores-Mobile, Alabama with maximum sustained winds of more than 100 mph (Category 2). The peak storm surge of 12 feet at Gulf Shores, Alabama, destroyed much of the community. Daulphin Island, Alabama recorded an 11-foot storm surge that destroyed the causeway connecting the island to the mainland. During Hurricane Frederic, over 50 homes were destroyed along the 22-mile reach from Fort Morgan to Gulf Shores, Alabama. Approximately 73 percent of the front- row buildings were destroyed.

Hurricane Elena in 1985 made landfall in the Gulfport-Biloxi, Mississippi, area. Wind damage to structures was significant. Many homes lost their roofs, roof overhangs and porches, and many windows were broken by flying debris [FEMA 1986]. The next significant storm to hit the area was Hurricane Opal, which made landfall near Santa Rosa Island, Florida in October 1995. Hurricane Opal was classified as a Category 3 hurricane with recorded sustained wind speeds of approximately 110-115 mph. Opal caused significant storm surge damage to the Gulf of Mexico shoreline in Florida. Data indicated that approximately 990 coastal structures incurred 50 percent or more damage [FEMA 1996].

The most recent hurricane prior to Hurricane Georges was Hurricane Danny, which affected the Mobile Bay area of Alabama in 1997. Hurricane Danny was a slow-moving Category 1 hurricane that made landfall near the mouth of the Mississippi River and in the Mobile Bay area. It produced enormous amounts of rain over extreme southern Alabama.

Storm tides of generally 2 to 5 feet occurred from the Florida/Alabama border to Dauphin Island. A maximum storm tide of 6.5 feet was reported about midway between Gulf Shores and Fort Morgan [National Hurricane Center 1997].

2.4 Team Composition

On October 2, 1998, the FEMA Mitigation Directorate deployed a BPAT to the Gulf Coast to assess damages caused by Hurricane Georges. The team included FEMA Headquarters and Regional Office engineers, planners, and a coastal geologist; consulting engineers; floodplain management specialists; and a forensic engineer. Members of the BPAT are listed in the Appendix of this report.

The BPAT's mission was to assess the performance of buildings in the Gulf Coast area and make recommendations for improving building performance in future hurricanes. The assessment included areas of the Gulf Coast from Pensacola Beach, Florida, to Gulfport, Mississippi (including Mobile Bay, Alabama), and the Florida Keys. It also included inland areas along major streams and rivers that experienced flooding. The BPAT process is intended to provide state and local governments guidance on post-hurricane reconstruction with the goal of enhancing future building design and construction.

In conducting this assessment, the BPAT also focused on:

- The success and effectiveness of flood and wind hazard mitigation initiatives undertaken prior to Hurricane Georges, including acquisition and removal of structures located in floodprone areas, elevation of floodprone buildings, and installation of storm shutters and high-wind roofing systems;
- Siting and other planning issues that contributed to building success, damage, or failure;
- Floodplain management issues, including repetitive loss structures and floodplain mapping; and
- Impacts of the hurricane on the shoreline/beach system.

An aerial survey and on-the-ground site investigations were conducted to observe building conditions in selected areas affected by the storm. The BPAT's mission did not include recording the numbers of buildings damaged by the hurricane, determining the frequency of specific types of damage, or collecting data that could serve as the basis of statistical analysis. Collectively, the team invested more than 1,000 hours conducting site investigations, inspecting damages, preparing documentation, and preparing this report. Documentation of observations made during the ground and aerial surveys included field notes and photographs.

2.5 Methodology

On October 3, 1998, the BPAT conducted an aerial survey along the Gulf Coast from Navarre Beach, Florida, to Gulfport, Mississippi. Ground observations were conducted from October 4 to October 11. Inspections were made along the Gulf Coast from Pensacola Beach, Florida, to Gulfport, Mississippi, and extended into inland areas in Florida, Alabama, and Mississippi that were subject to riverine flooding and wind damage. In addition, a supplemental assessment of manufactured home performance was conducted in the Florida Keys on October 11, 1998.

One- and two-family, one- to three-story wood-frame structures elevated on pilings were the primary building types assessed in coastal areas, although some slab-on-grade structures were included. In riverine areas, one-family wood-frame structures were the primary structures inspected. Foundation types included piles, perimeter wall/crawl space, and slab-on-grade. Several public and commercial buildings in coastal and riverine areas were also evaluated, including a hospital, a convention center, fire houses, municipal buildings, schools, and casinos.

2.6 Local, State, and Federal Regulations Affecting Development and Construction

Construction along the coastal and riverine areas of Alabama, Florida, Mississippi, and the Florida Keys is governed by one or more of the following building codes:

1. The Standard Building Code (SBC), which is enforced by local (city or county) governments;
2. The National Flood Insurance Program (NFIP) construction requirements in identified Special Flood Hazard Areas (SFHAs), which are enforced by local governments through adopted laws and ordinances;
3. In Florida and Alabama, state requirements regarding construction seaward of the Coastal Construction Control Line (CCCL); and
4. State codes that convey to local governments the authority for land-use management through planning, zoning, subdivision, and other special-purpose ordinances.

Additionally, residential construction on Santa Rosa Island, Florida is under the jurisdiction of the Santa Rosa Island Authority, which regulates to more stringent requirements than the NFIP and SBC. They include higher mandated building elevations in V-Zones and A-Zones, and additional pile foundation requirements.

FEMA's Flood Insurance Rate Maps (FIRMs) provide the base flood elevations (BFEs) for coastal and riverine Special Flood Hazard Areas (SFHAs). The base flood, commonly referred to as the 100-year or 1-percent flood, is the flood that has a 1-percent probability of being equaled or exceeded in any given year. It is the basis for the NFIP's regulatory requirements. In coastal areas subject to wave action, BFEs include wave height effects. All of the communities that the BPAT visited participate in the NFIP and therefore have adopted floodplain management ordinances that require, among other things, the lowest floor elevation for new construction or substantial improvements to be at or above the BFE in A-Zones. In addition, in V-Zone areas, the lowest horizontal structural members supporting the lowest floor for new construction and substantial improvements must be at or above the BFE.

Florida established the CCCL along the state's sandy beach shorelines to delineate those areas subject to erosion or other adverse impacts during the 100-year storm. In areas seaward of the CCCL, the state enforces construction requirements that are more stringent than the SBC or the NFIP requirements.

Alabama also established a CCCL. It is a fixed line referenced by State Plane Coordinates and was originally based on the crest of the primary frontal dune that existed prior to the landfall of Hurricane Frederic in 1979. Unlike Florida, Alabama prohibits new construction seaward of the CCCL. There are exceptions, however. In some areas, previously platted lots were "grandfathered" and construction, with restrictions, is allowed.

3 General Assessment/Characterization of Damages

The general types of damages the BPAT observed as a result of Hurricane Georges in the Gulf Coast are discussed below. More detailed descriptions of observed damages and mitigation successes are included in Sections 4, 5, and 6.

3.1 Flood Damage Observations

Hurricane Georges produced significant flooding in riverine and coastal areas. Heavy rainfall resulted in riverine flooding in low-lying areas. Coastal storm surge resulted in inundation along exposed regions of the coastline. In some areas, a combination of riverine and coastal storm surge flooding caused building damage.

3.1.1 Riverine Flood Damage

Hundreds of inland residential structures in Alabama, Florida, and Mississippi were inundated with water by riverine flooding. Structural damage, however, was limited; most damages were caused by water inundation (Figures 3-1 and 3-2). Damages observed included loss of contents, flooring, interior finishes, and portions of wallboard and insulation. Elevated homes generally performed well and required only minor cleanup (Figure 3-3).

FIGURE 3-1 Houses inundated by 2 to 3 feet of floodwaters in the Florida Panhandle.

FIGURE 3-2 Typical flooding to homes in low-lying areas.

FIGURE 3-3 Elevated home along the Fish River in Baldwin County, Alabama, that received minimal damage.

3.1.2 Coastal Surge Damage

The Gulf Coast region lost several vertical feet of sand along beaches as a result of Hurricane Georges. The most significant loss occurred in Gulf Shores and Dauphin Island, Alabama. Moderate overwash was observed in Alabama and along parts of the Mississippi coast. Higher overwash volumes were found in Florida (where sand supply is high) while little to no sand was overwashed elsewhere in Mississippi. Regionally, sand that moved offshore into sandbars during the storm returned to the beach within a few weeks. Bluff and bulkhead erosion was common, but failure or complete undermining of shoreline protection structures was rare.

Building damage was concentrated on the front row of houses. Houses set back and properly elevated on deep pilings suffered little damage. The most severe damage caused to structures by coastal surge was observed on Dauphin Island, Alabama. Pile foundations on several Dauphin Island homes failed due to a combination of erosion and inadequate pile embedment, resulting in the collapse of structures (Figure 3-4). From Gulfport to Biloxi, Mississippi, minimal damage due to coastal surge was observed (Figure 3-5). Few homes are sited on the open coast and little overwash was evident.

FIGURE 3-4 Front-row house separated from its foundation and destroyed by the storm on Dauphin Island, Alabama. Note the properly elevated and set back house on the right fared very well.

FIGURE 3-5 Mississippi Gulf Coast near Biloxi. Minimal coastal surge damage or overwash was observed.

Coastal areas from Gautier to Pascagoula, Mississippi suffered some damage (Figure 3-6). Along Mobile Bay in Alabama, coastal surges severely damaged fishing piers and boatlifts. In addition, scour behind bulkheads caused some damages to front-row buildings (Figures 3-7 and 3-8). In the Florida Panhandle, limited structural damage was observed. Significant sand deposition, however, required extensive cleanup efforts (Figure 3-9).

FIGURE 3-6 Overwashed sand accumulation and minor structural damage near Gautier, Mississippi.

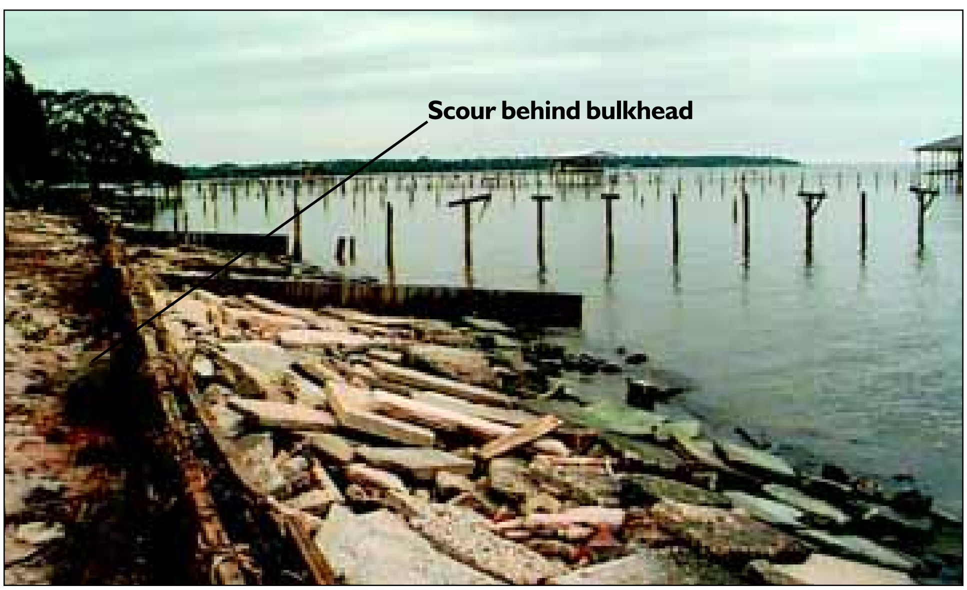


FIGURE 3-7 Remnants of fishing piers in Mobile Bay near Fairhope, Alabama. Note scour behind the bulkhead on the left.

FIGURE 3-8 In some cases, scour behind bulkheads resulted in structural damage along Mobile Bay, Alabama.

FIGURE 3-9 Sand accumulation from overwash in Pensacola Beach, Florida.

Pre-FIRM structures are those built before the effective date of the first FIRM issued by FEMA for the community in which the structure is located. Similarly, a post-FIRM structure is one built after the effective date of the first FIRM. In general, the effective date of a FIRM corresponds approximately to a community's adoption of floodplain management ordinances incorporating NFIP regulations for new construction and substantial improvements of buildings in special flood hazard areas (SFHAs). These regulations include the requirement for elevation of residential structures in SFHAs. In general, the BPAT observed that post-FIRM, elevated structures set back from the shoreline performed well during Hurricane Georges (Figure 3-10).

FIGURE 3-10 Properly elevated and set back houses sustained little damage.

3.2 Wind Damage Observations

Hurricane Georges did not cause significant wind-related structural damage along the Gulf Coast. Buildings along the open coast suffered minor wind damage, including loss of sections of composition roof shingles and siding (Figure 3-11).

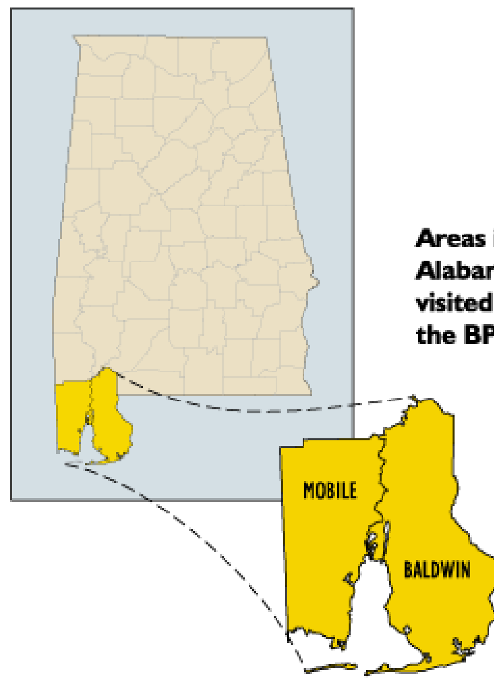
Many homes that lost their roofs were susceptible to further interior damage from subsequent rainfall. Wind damage in inland areas included damage to trees and signs. The most severe inland wind damage occurred to signs, roofs, and trees in the Pascagoula, Mississippi area (Figure 3-12).

FIGURE 3-11 These condominiums near Pascagoula, Mississippi suffered wind damage to roofing shingles and siding.

FIGURE 3-12 Wind damage to roofs and trees in Pascagoula, Mississippi.

4 Alabama Observations

The BPAT conducted aerial and on-the-ground investigations of the damage that occurred along the coastal and riverine areas of Mobile and Baldwin Counties in southern Alabama. This area included Dauphin Island, eastern and western shores of Mobile Bay, and the Fort Morgan/Gulf Shores areas in Baldwin County. Buildings that successfully withstood Hurricane Georges were also assessed.



Areas in Alabama visited by the BPAT

4.1 Flood Observations: Damages and Successes

Flooding included riverine flooding due to excessive rainfall and inflow of coastal surge waters that prevented outflow from the rivers, creating a backup of waters along the coastal rivers. Coastal flooding was characterized by storm surge overwash and erosion along the barrier islands and wave action on Mobile Bay.

4.1.1 Riverine Flooding

Riverine flooding and subsequent damage was most evident in the lower reaches of the Dog River in Mobile County; the Fish River in Baldwin County; and in downtown areas adjacent to the Mobile port facilities in the upper Mobile Bay. The Fish River experienced flooding levels less than the 100-year event. A USGS gaging station on Fish River near Silver Hill recorded flood heights during Hurricane Georges that indicate discharges of approximately 6,400 cfs (cubic feet per second), corresponding to a recurrence interval of approximately 10 years [Pearman 1998]. In comparison, during Hurricane Danny in 1997 the Fish River flowed at a rate of approximately 16,900 cfs, which was estimated to have been approximately a 50-year flood event. No recorded discharge information for the Dog River watershed was available. However, based on rainfall and nearby river flow data, the recurrence interval on the Dog River is estimated at 25 to 50 years.

Estimates on the streams of the lower Mobile River which discharge into Mobile Bay indicate a 25- to 50-year recurrence interval. The gaging station at Chickasaw Creek north of Mobile recorded its second highest peak of record, exceeded only by a flood that occurred in 1955. A gage on the Styx River in southern Baldwin County recorded a peak stage that was

7 feet higher than the bridge deck. The peak discharge on this gage was 48,000 cfs, which corresponds to a recurrence interval of 100 to 200 years.

Damage consisted mostly of loss of contents; damage to exterior and interior finishes, including doors, cabinets, carpeting/flooring, and painted surfaces; inundation of air conditioning compressors; and damage to wallboard and insulation. In the Dog River area, houses experienced up to 5 feet of flooding (Figure 4-1). The Fish River area experienced 4 to 5 feet of flooding. In one instance, a pre-FIRM house built on a slab-on-grade foundation sustained damage while a post-FIRM elevated addition apparently was not affected (Figure 4-2).

FIGURE 4-1 Homeowner removing damaged contents from house flooded along the Dog River.

FIGURE 4-2 Approximately 5 feet of flooding at this house along the Fish River caused no damage to the elevated addition.

Acquisition and elevation projects in the riverine areas of Baldwin County preceded by a planning effort that identified properties repeatedly affected by flooding. As a result, the Baldwin County Government has been pursuing the enactment of ordinances to address riverine and coastal erosion and flood hazard reduction. Damages from Hurricane Georges have caused the county to strengthen its efforts on these proposed mitigation planning activities, which include:

- An erosion control ordinance (either as a supplement to the building code or a separate ordinance);
- A Flood Hazard Overlay (zoning) District, which will provide for setbacks from waterways and lot size and coverage requirements; and
- Subdivision regulations that will feature setback requirements and cluster development provisions.

A comprehensive house elevation and property acquisition effort is ongoing in the Dog and Fish River basins using funds from the Hazard Mitigation Grant Program (HMGP), Flood Mitigation Assistance Program (FMAP), as well as private funds. Property acquisitions and subsequent removal of the structures eliminated the potential for flooding and subsequent losses (Figure 4-3). Elevation of structures along the Dog River in Mobile County (Figure 4-4) and the Fish River in Baldwin County (Figure 4-5) to above the BFE resulted in reduced damages.

FIGURE 4-3 The previous location of several repetitive-loss properties in Mobile County that had been acquired and demolished.

FIGURE 4-4 Elevated house along the Dog River that suffered minimal flood damage.

FIGURE 4-5 House along the Fish River, elevated through FEMA's HMGP that suffered minimal flood damage.

Elevated structures still have some degree of residual flood risk. The house pictured in Figure 4-6 was previously elevated by the homeowner and subsequently was flooded approximately 1 inch to 2 inches above the first floor by Hurricane Danny. Fortunately, flood levels in this area during Hurricane Georges were less than those experienced during Hurricane Danny. The only damage to this home during Hurricane Georges was to the contents stored below the first floor.

FIGURE 4-6 Previously elevated house along the Fish River suffered damage to contents below the first floor. Note that the homeowner also elevated utilities on the right side of house, preventing loss or damage.

Located in Upper Mobile Bay, the Mobile Convention Center, which was constructed in 1993, is the centerpiece of downtown Mobile's revitalization efforts (Figure 4-7). Elevated above the BFE, the Convention Center received only minor damage from Hurricane Georges. Total damage — including flood fighting and cleanup costs — has been $156,000 to date with approximately $350,000 estimated for additional repairs. Most of the damage incurred was due to wind-driven rain that entered around windows and doors. Since the Convention Center was properly elevated, it was able to resume operations within three days after Hurricane Georges. In addition, the center received additional bookings from other

FIGURE 4-7 Despite approximately 7 feet of flooding in this area, the Mobile Convention Center suffered only minor damage and was operational when the floodwaters receded.

nearby facilities that were damaged by the storm. The design and elevation of this building was an economic success in terms of both the damage avoided and the business that was not interrupted (Figure 4-8).

FIGURE 4-8 The area below the BFE is used for parking and required only minor clean-up following the flood.

4.1.2 Coastal Flooding

By far, the most severe damage the BPAT observed was the result of coastal surge and flooding along the Alabama Gulf Coast, specifically Dauphin Island, the eastern and western shores of Mobile Bay, and the Fort Morgan/Gulf Shores areas. Damages included beach erosion and scour; washouts caused by channelized flow; complete and partial destruction of structures that included grade-level concrete slabs, pile foundations, walkways and on-site utility equipment; loss of roadways; and problems associated with the creation/accumulation of sand and debris.

Significant erosion of the Gulf Coast beach occurred on Dauphin Island. Overwash was evident across virtually the entire width of the western end of the island. The eastern end of the island, which has greater topographic relief, vegetation, and dunes, fared well. No significant shore-parallel dunes or other protective berm existed on the western beaches prior to the storm. Most overwashed sand ended up being deposited in the roads. Vertical beach loss due to erosion on the Gulf side was estimated to be 3 to 6 feet. Scour was localized around obstructions (posts/piles, abandoned concrete septic tanks). In addition, 3 to 6 feet of erosion occurred beneath several A-Zone houses located on the back-barrier shoreline across from shore-perpendicular streets (Figure 4-9). Side streets located perpendicular to the shoreline provided a preferred path for storm surge and retreat flow across the island.

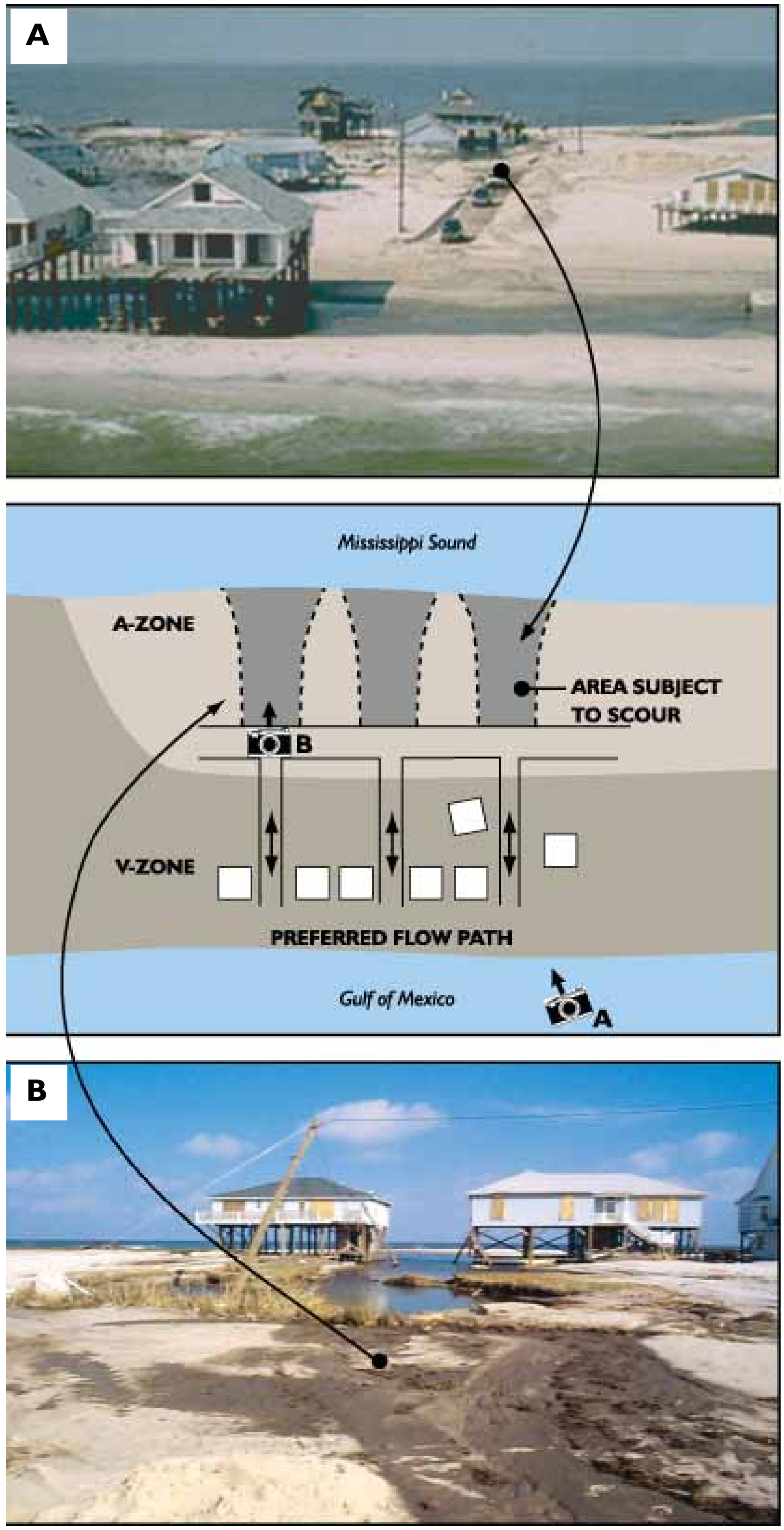


FIGURE 4-9 Side streets perpendicular to the shoreline, combined with a break in the existing scattered dunes and vegetation where the side streets meet the main east-west road, provided a preferred path for storm surge and retreat flow across the island.

A combination of inadequate pile embedment with erosion and scour resulted in the failure of several homes on pile foundations on the windward/southern side of Dauphin Island (Figure 4-10). While some structures did not suffer complete losses, they did suffer severe damage due to the surge. Damage included loss of piles, movement and/or settlement of piles, leaning or partial collapse of the structure, washout and scour around piles and around and under grade level concrete slabs, loss of exterior access stairways, and loss of lower level enclosures.

FIGURE 4-10 The structure on the right lost its pile foundation system and was washed into the structure on the left.

In some cases, pile failures were exacerbated by inadequate embedment depths and increased scour around piles as a result of concrete collars or slabs (Figures 4-11 to 4-14). The use of crossbracing was not widespread. Crossbracing observed was for serviceability and not intended to provide structural support or to prevent permanent deformation.

FIGURE 4-11 This house lost its deck and sustained structural damage to the Gulf side of the house.

FIGURE 4-12 The BPAT observing a partially collapsed front-row structure.

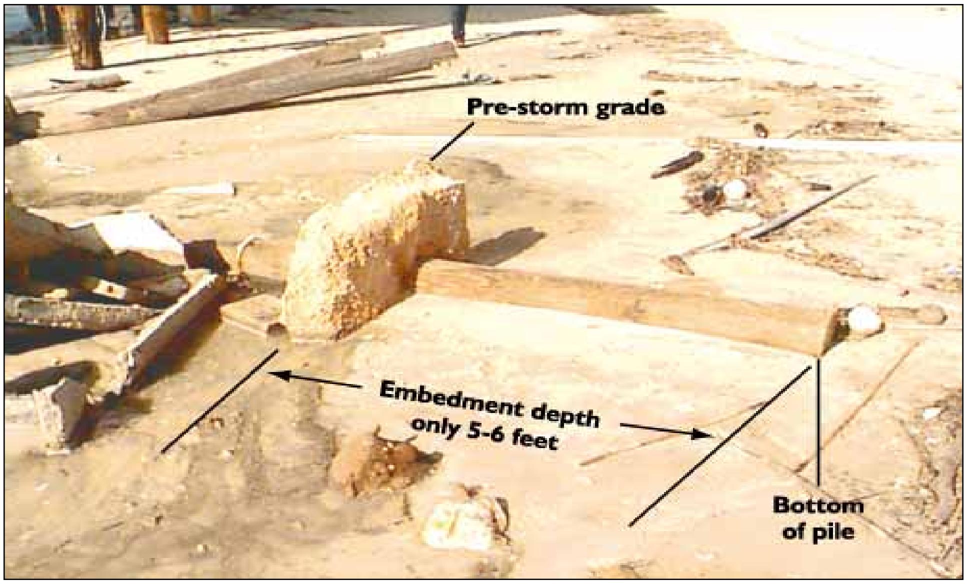


FIGURE 4-13 Pile failure due to scour around concrete collar and inadequate embedment depth.

FIGURE 4-14 This house suffered pile settlement due to scour around piles with concrete collars. In addition, note the loss of stairs and damage to lower-level enclosed area.

Waterborne debris impact caused a significant amount of damage. Several front row homes on Dauphin Island failed due to inadequate pile embedment and erosion/scour. The debris from these failed structures affected adjacent and landward structures (Figure 4-15 and 4-16). In most cases, the structure affected would not have been damaged otherwise or would have received only minor damage if it had not been impacted by waterborne debris. Debris impact from dislodged decks and stairs was more common than the debris impact from entire dislodged houses. This type of debris was carried by the storm surge and damaged buildings (Figure 4-17).

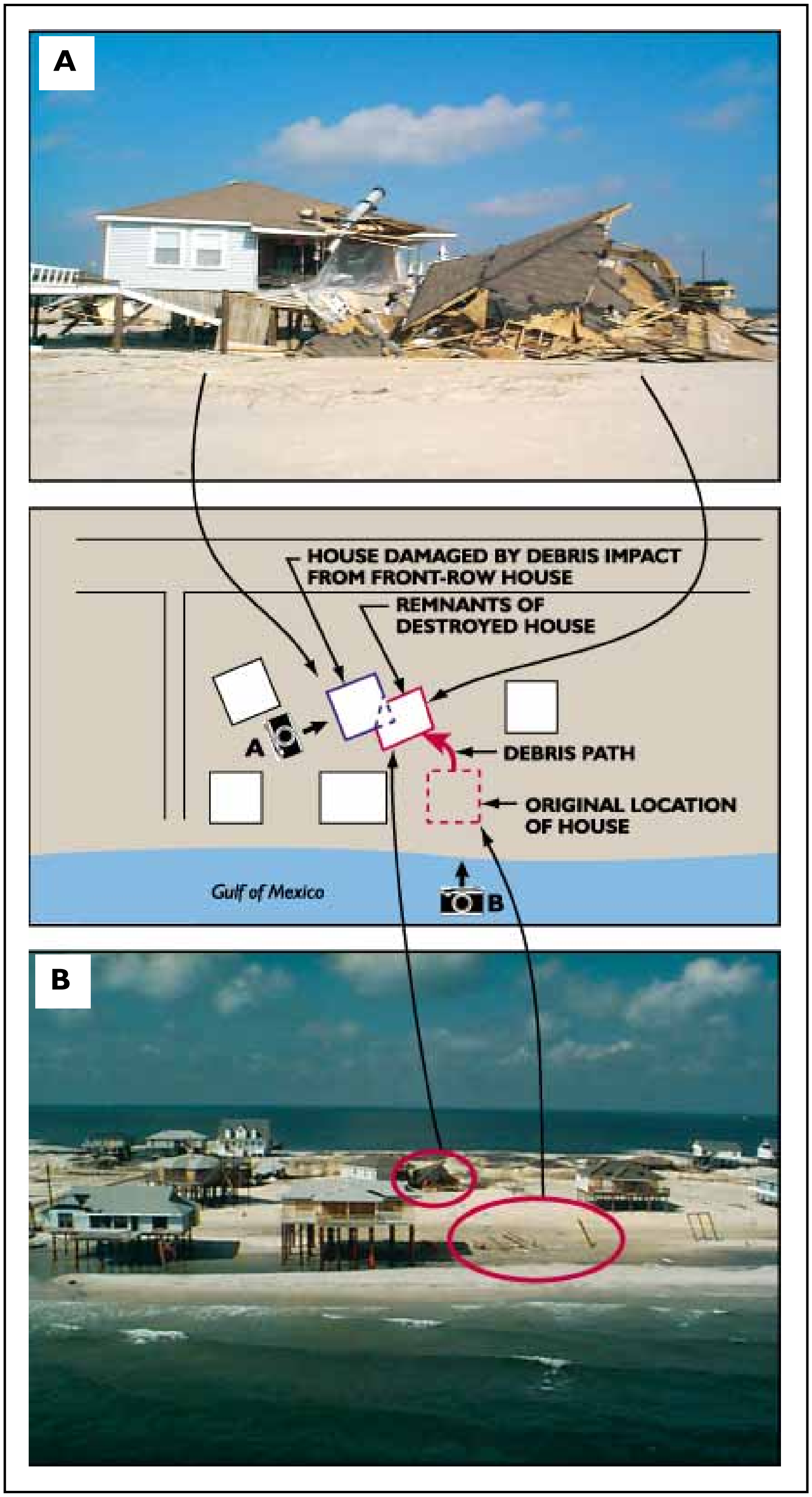


FIGURE 4-15 Significant debris impact created by destruction of a front-row house.

FIGURE 4-16 House on back side of Dauphin Island suffered partial collapse when impacted by a dislodged house from the Gulf side of Dauphin Island.

FIGURE 4-17 Damage to piles of a newly constructed house caused by impact of waterborne debris from a nearby collapsed deck.

Most homes and portions of the infrastructure on Dauphin Island performed well (Figure 4-18). This success can be attributed to sound local building code requirements, enforcement of 10-foot minimum pile depths, and compliance with NFIP V-Zone construction standards. The majority of the observed failures were to older houses built to lesser standards and lower elevations prior to FEMA's inclusion of wave height effects on the community's FIRM.

FIGURE 4-18 This house sustained no damage with the exception of loss of stairs and items stored below the first-floor elevation.

Dauphin Island's attention to utility systems was another example of successful mitigation. In response to repetitive damage to individual septic systems by past storms, the community installed a new municipal sewer system. The system performed well and suffered only minor damage as a result of the storm. Extensive beach erosion from Hurricane Georges would have required complete replacement of the individual septic systems for homes that were converted to the municipal system (Figure 4-19). In addition to the sanitary sewer system, the community is also elevating utility platforms for cable television and telephone switching stations to minimize damage due to coastal surge. As shown in Figure 4-20, the elevated platform performed well and adequately protected the utility boxes.

FIGURE 4-19 Old concrete septic tanks (circled) and drain fields have been superceded by the new municipal sanitary sewer system. The old systems still create a hazard as waterborne debris.

FIGURE 4-20 Other than losing part of the lattice screening, this elevated utility platform performed well.

In Fort Morgan, Gulf Shores, and Orange Beach, vertical beach loss was approximately 5 to 6 feet. Post-storm beach profiles taken at Orange Beach by the University of South Alabama showed a concave-up shape consistent with modeled profiles used by the Alabama Department of Environmental Management – Coastal Programs Division. Portions of the boardwalk and parking areas in Gulf Shores were undermined by wave action and storm surge, and additional scour occurred around buildings constructed at the minimum setback from the local CCCL. Overwash of sand was common, with some vertical accretion (1 to 3 feet) beneath structures. Some dunes persisted on the wide beach in unincorporated Baldwin County near Fort Morgan.

Although damage along the Fort Morgan/Gulf Shores shorelines was less severe than that observed on Dauphin Island, evidence of scour was more prevalent. This was due to more frequent use of at-grade concrete slabs and bulkheads in this area (Figure 4-21). While the depth of piles was not identified as a problem, concrete slab connections to piles or damage to piles as the slabs broke up was a concern due to the creation of unanticipated loads on the building foundations.

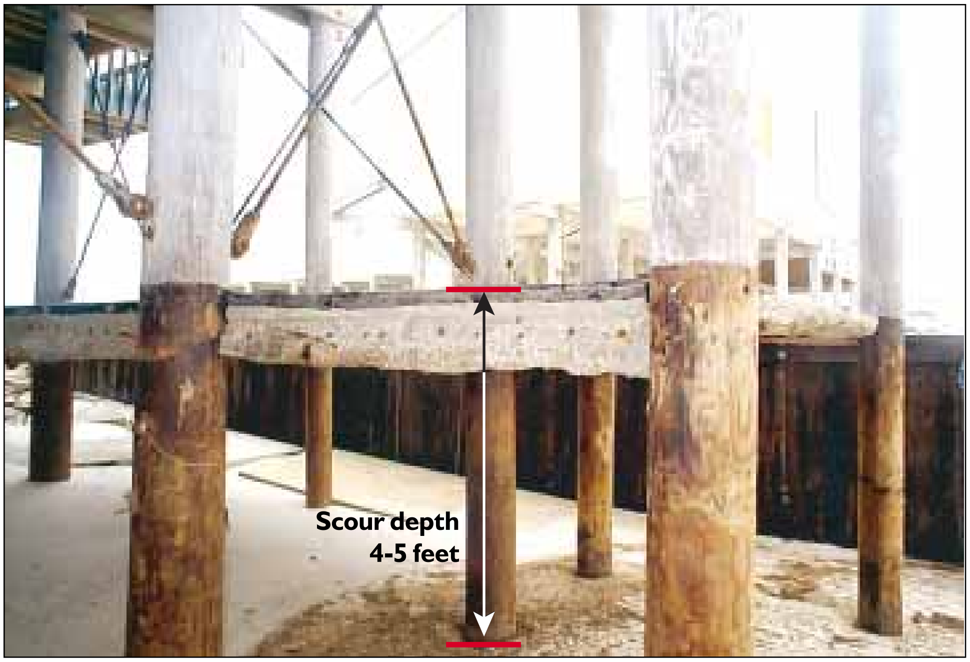


FIGURE 4-21 Erosion/scour behind bulkhead and below the concrete slab caused by storm surge. Note the concrete slab did not completely detach from the piles.

The placement of on-site exterior utility equipment (air conditioner/heat pump compressors) was a concern at both Dauphin Island and Fort Morgan/Gulf Shores areas. In several instances, damage occurred because these utilities were not elevated and not properly anchored.

For the most part, when structures were elevated an effort was also made to elevate air conditioning/heat pump compressors and other similar on-site utility equipment. When elevated to the BFE and placed on adequately supported platforms the facilities performed well (Figure 4-22). Where installation was inadequate, they generally failed (Figure 4-23).

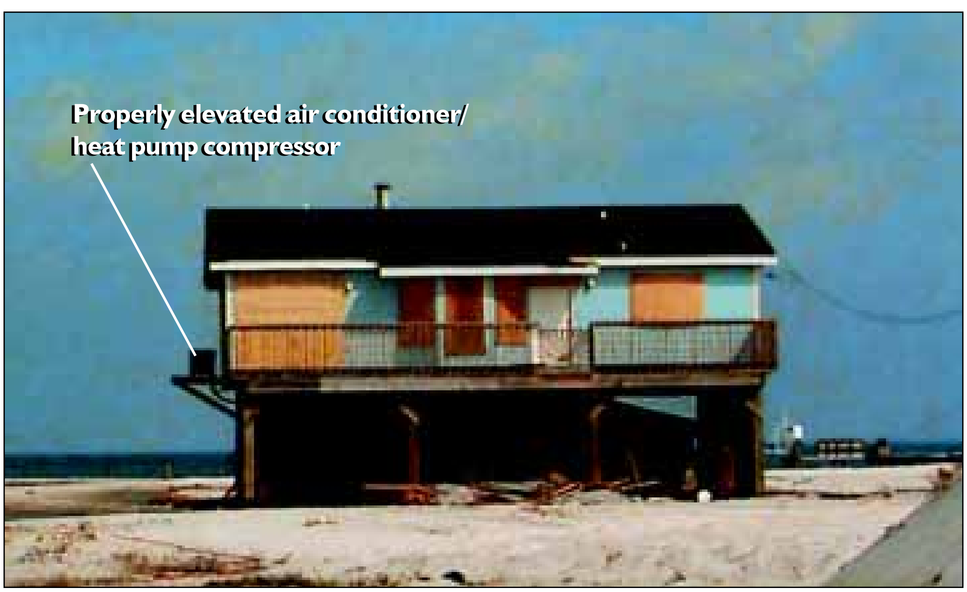


FIGURE 4-22 This cantilever platform performed well.

FIGURE 4-23 These air conditioner/heat pump compressors in Gulf Shores were not elevated and therefore were severely damaged.

Another issue of concern to the BPAT was the condition of metal hurricane straps, clips, and joist hangers. The salty coastal environment appeared to have caused deterioration of hurricane straps and clips. In some instances, the straps were completely corroded (Figure 4-24). In these cases, only the dead load of the building resisted the overturning or sliding of the building off its foundation.

FIGURE 4-24 Only remnants of corroded hurricane straps remain.

A number of buildings that withstood Hurricane Georges were observed in the Fort Morgan/ Gulf Shores areas (Figures 4-25 to 4-27). These successes are attributed to:

- Conformance with building requirements such as elevation of the first floor to the BFE, foundation systems with pile embedment depths capable of withstanding the loss of several feet of sand, and proper building setback from the shoreline; and
- Proper construction techniques such as selection of hip roof designs that minimize the use of vulnerable gable ends, and the proper selection and installation of hurricane-resistant construction materials, including siding and roofing materials.

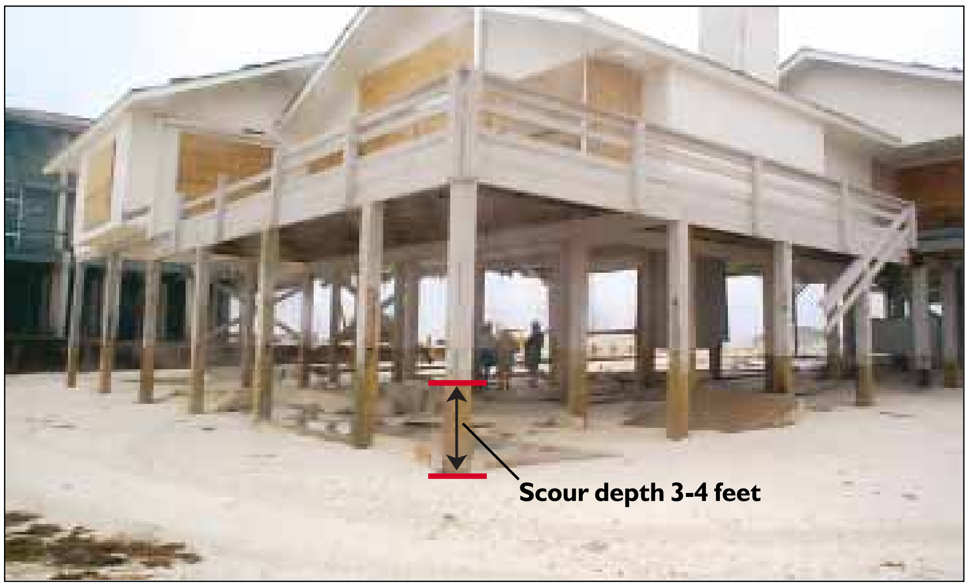


FIGURE 4-25 Despite the loss of 3 to 4 feet of sand, this structure performed well. Note at-grade slabs broke away as intended.

FIGURE 4-26 These multi-family buildings in Fort Morgan suffered no damage from coastal storm surge. Proper elevation, siting, and building materials contributed to their success. Note roof design that minimizes the use of gable ends.

FIGURE 4-27 This properly elevated structure in Gulf Shores suffered no damage other than the loss of breakaway walls and slight damage to its stairs.

Damages on the shores of Mobile Bay included loss of beach and shoreline, overwash and damage to bulkheads and seawalls, and loss of piles and wharves. A majority of the developed lots on the shoreline in the lower Mobile Bay are stabilized by bulkheads. Shoreline retreat distances (inland limit of erosion) were approximately the same for protected and natural beaches, with natural beaches retreating a little farther but maintaining a gentle slope (Figure 4-28). Other areas had moderate bluffs with a visible scarp (Figure 4-29).

FIGURE 4-28 Typical shoreline erosion along low-lying areas adjacent to Mobile Bay.

FIGURE 4-29 Typical erosion along bluffed shoreline areas of Mobile Bay (western side).

Wave action removed sand in front of bulkheads and overtopping removed much of the material from behind. Erosion was retarded by a relatively resistant, hard red clay layer located at a depth of 8 to 14 inches below grade. Following the hurricane, most bulkheads were still structurally sound as shown in Figure 4-30. Additional horizontal scour adjacent to bulkheads, caused by wrap-around/focusing of wave energy, was common along Mobile Bay.

FIGURE 4-30 Bulkheads on Mobile Bay still in place after storm.

Along the lower eastern shore of Mobile Bay, approaching Weeks Bay, the damages cited were evident (Figure 4-31). Other damages included significant loss of contents and personal possessions debris from bayfront homes washed across the roadway (Figure 4-32). Properly elevated and setback structures along Mobile Bay performed well and suffered only minor damage to areas below the first floor (Figure 4-33).

FIGURE 4-31 Non-elevated pre-FIRM structure severely damaged by coastal storm surge.

FIGURE 4-32 Debris accumulation along coastal roadway.

FIGURE 4-33 A properly elevated post-FIRM front-row coastal house that suffered only minor damage to stairs. Note the storm shutter on the front window.

4.2 Wind Observations: Damages and Successes

Wind effects along the Alabama Gulf Coast area generally were confined to damage to roofing shingles and metal roofing panels, exterior siding/sheathing, electrical power poles and power lines, signs, and trees. In addition, wind-driven rain resulted in damages to the interiors of structures, such as the Mobile Convention Center. The BPAT observed this damage to be less severe and extensive than flood damage. However, wind damage did occur throughout all of the coastal counties affected by the storm.

Wind damage to structures, although minimal, was observed along the western end of Dauphin Island. Several structures experienced damage to composition shingles and siding (Figure 4-34). Power poles and power lines on Dauphin Island were damaged, probably as a result of the combination of wind, coastal surge, and erosion effects (Figure 4-35). In the Fort Morgan area and the western end of Gulf Shores, wind damage to roof shingles and siding was evident (Figure 4-36).

FIGURE 4-34 Wind damage to composition roof shingles and siding on newly built coastal home.

FIGURE 4-35 Utility poles damaged by wind, coastal surge, and erosion.

FIGURE 4-36 Houses in Gulf Shores with roof damage. Note loss of roof covering on front-row buildings.

No significant wind damage was observed in Alabama's inland or coastal areas. In inland areas, roof damages were minor and buildings that did require repairs and cleanup were those infiltrated by wind-driven rain. The lack of significant wind damage along the Alabama Gulf Coast can be attributed to two factors: the wind velocities were not a design event, and improved building standards, methods and materials that were implemented as a result of past hurricanes performed successfully. For example, on Dauphin Island, the town developed specific requirements for the installation of asphalt/composition roof shingles, requiring six nails per shingle and the first two courses to be cemented to the roof underlayment. According to the local building official, implementation of these measures resulted in only minimal damage to asphalt/composition shingle roofs from Hurricane Georges (Figure 4-37). The BPAT was able to confirm that damage to roof shingles on Dauphin Island was, in fact, minimal.

FIGURE 4-37 Fully exposed front-row houses that exhibited minimal wind damage.

Metal roofs are becoming more common along the Alabama coastal and inland areas, specifically on Dauphin Island, Gulf Shores, and the Mobile Bay area. During this disaster, metal roofs appeared to have sustained little damage (Figure 4-38). However, since they are relatively new, their success must be further evaluated and based on longer exposure to salty, corrosive conditions and other environmental factors. The long-term performance of fasteners/connectors has been a particular concern in the past. In addition, most metal roofs the BPAT observed probably were not exposed to design level or greater winds.

FIGURE 4-38 Metal roofing system on multi-family building in Fort Morgan performed well.

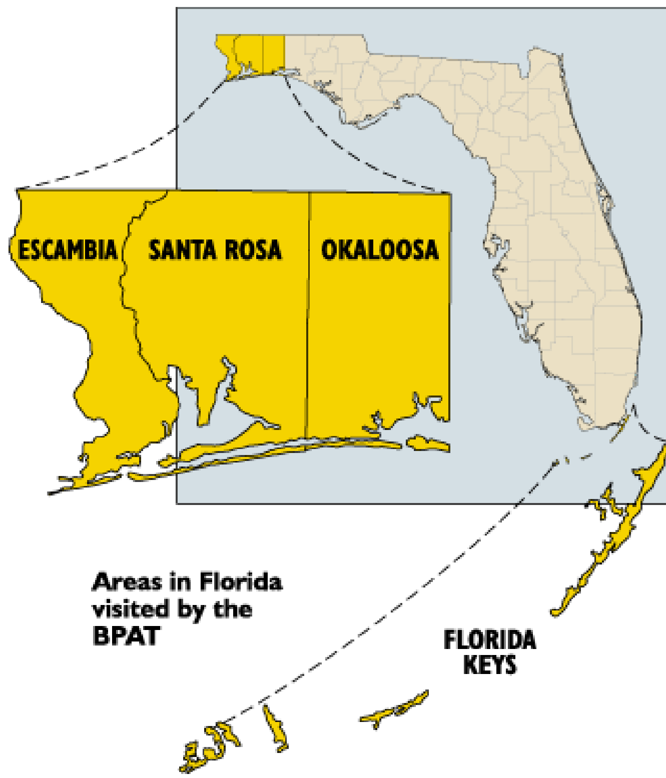
The BPAT discovered two structures in the Fort Morgan area with fiber-reinforced concrete siding. Upon inspection, this siding appeared to suffer no wind damage. The strength and rigidity of the material, the use of stainless steel nails, and the adherence to a specified nailing pattern apparently contributed to the successful performance of the siding (Figure 4-39).

FIGURE 4-39 Fiber-reinforced concrete siding suffered no damage.

5 Florida Observations

5.1 Flood Observations: Damages and Successes

Based on the aerial survey and ground reconnaissance, the BPAT did not expect to observe any significant structural damage to buildings in Florida. Areas inundated by riverine or coastal flooding suffered losses to interior contents, finishes, wallboard, insulation, and electrical wiring.



5.1.1 Riverine Flooding

Flooding was extensive in the Yellow River, Perdido River, Escambia River, and Blackwater River watersheds in Florida. The recurrence intervals for the floods caused by Hurricane Georges exceeded the 100-year threshold for the Shoal and Yellow Rivers in the Yellow River watershed (see Figure 2-4, Section 2). Floods were estimated between the 50- and 100-year recurrence interval for the Perdido River in the Perdido River watershed, the 25-year recurrence interval for the Escambia River in the Escambia River watershed, and between the 25- and 50-year recurrence interval for the Blackwater River watershed.

The BPAT visited sites of riverine flooding along the Yellow and Shoal Rivers in Okaloosa and Santa Rosa Counties. The home shown in Figure 5-1 was flooded by several feet of water and is typical of the pre-FIRM, at-grade houses located in these areas.

FIGURE 5-1 Repetitively flooded home slated for acquisition under FEMA's HMGP.

In accordance with the County's NFIP compliant floodplain management requirements, the replacement home shown in Figure 5-2 was recently built to the BFE with a Small Business Administration (SBA) disaster loan after flooding damaged it earlier this year. Floodwaters exceeded the BFE, reaching approximately 3 feet above the first-floor elevation. While the construction of the home to the BFE reduced the damages from Hurricane Georges — and will protect against damage from less intense, future storms — a residual risk still remains from floods exceeding the BFE. A freeboard requirement would have further reduced the risk of flooding. Fortunately, a condition of the SBA loan required the property owner to maintain flood insurance coverage on the home. Proceeds from the insurance claim will help the homeowner recover from this flood.

FIGURE 5-2 A high water mark is visible approximately 3 feet above the first floor elevation. The house, located along the Shoal River in Okaloosa County, suffered little damage because insulation and wallboard had not yet been installed.

The BPAT assessed damage from riverine flooding on the Shoal River that exceeded the base flood level by several feet. Homes elevated to the BFE flooded when water levels exceeded the BFE, as was the case with the home in Figure 5-2. Homes built outside, but adjacent to, the SFHA were flooded when water levels exceeded the limits of the SFHA. Homes in Figure 5-3 were built in the last five to seven years and they experienced significant flooding and damage when water levels exceeded the BFE and the limits of the SFHA.

The 100-year (24-hour) rainfall in the vicinity of Crestview is 13 inches [NWS 1961]. Hurricane Georges exceeded the 100-year rainfall by producing approximately 20 inches of rainfall in the Crestview area [NWS 1998]. A USGS river gaging station on the Shoal River near Crestview, Florida, is located just upstream of the neighborhood where the homes in Figure 5-3 are located. During the storm, a record height of 21.40 feet above the gage datum was recorded; the previous peak height was 15.58 feet. This new record corresponds to 68.61 feet, referenced to the National Geodetic Vertical Datum (NGVD). The neighborhood is located approximately 1,000 feet downstream of the gaging station, and the first floor elevations of the homes range from 62.0 to 64.5 feet (NGVD). The BFE at this site is 61.4 feet. The BPAT observed flooding depths of 3 to 4 feet in these homes, indicating that the flood was greater than a 100-year event.

The flood discharge along Shoal River is estimated to have reached 59,000 cfs, more than twice the previous peak discharge record. This discharge is estimated to have a 300- to 400- year recurrence interval, far exceeding the discharge of the 100-year flood event, which is estimated at approximately 32,000 cfs.

Several other rivers in the Florida Panhandle region experienced floods of equal magnitude. The Perdido River at Barrineau Park, near the Florida/Alabama border, reached flows of 44,000 cfs, which is estimated to have a recurrence interval of 50-100 years. The previous peak discharge of record was 39,000 cfs, occurring in 1995. Additionally, Elevenmile Creek near Pensacola, Florida peaked at about 13,000 cfs, which is also estimated as a 100- to 200-year event.

While locating homes directly adjacent to but outside the SFHA may eliminate both the mandatory flood insurance purchase requirement and floodplain management construction requirements, the risk of flooding is not completely eliminated. This residual risk, without the financial protection of flood insurance coverage, left many homeowners whose flooded homes were located outside the SFHA, ill-prepared to recover from flood damage caused by Hurricane Georges.

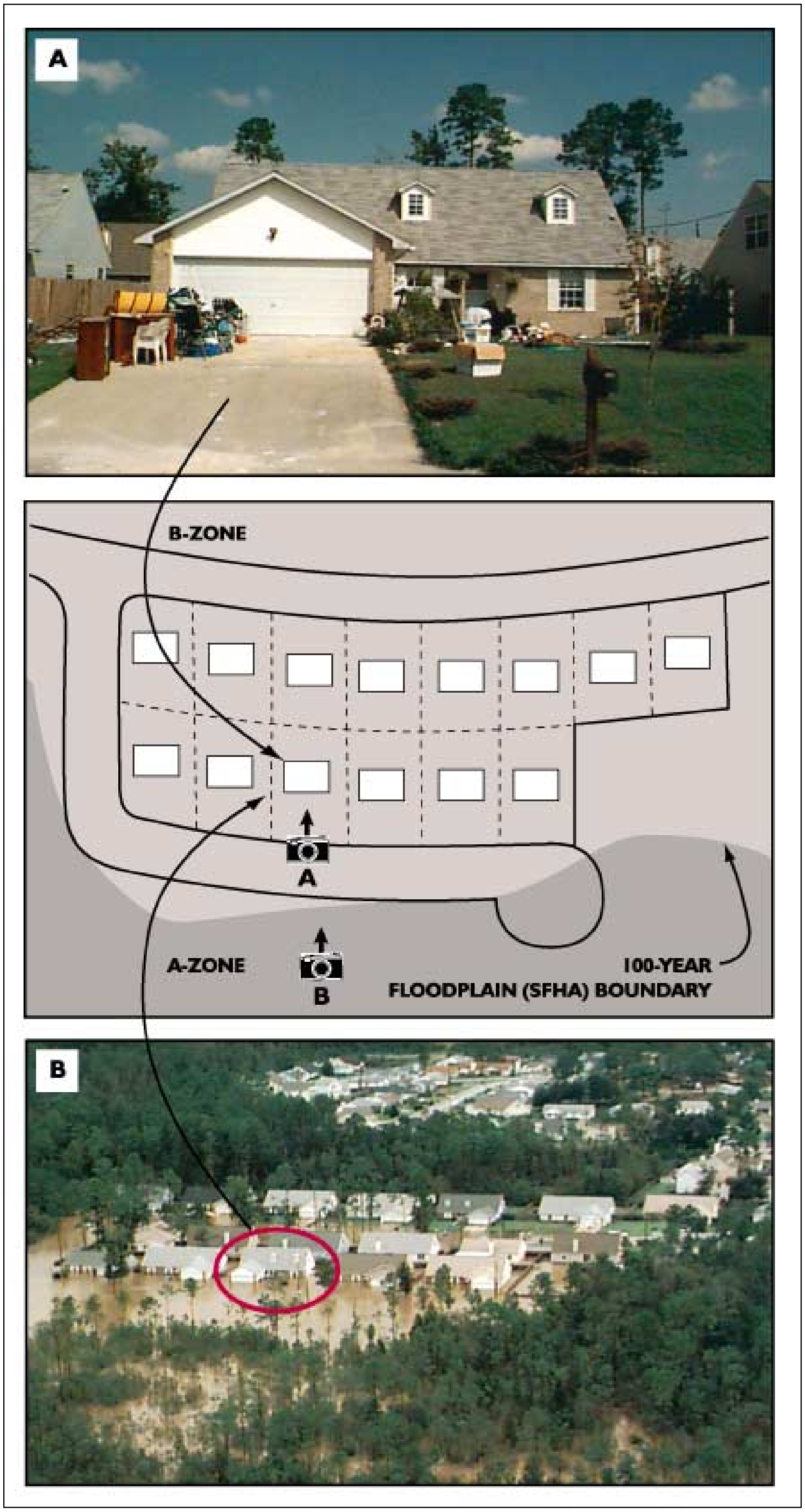


FIGURE 5-3 The home pictured above is one of approximately 10 homes in this subdivision which experienced flood depths of 2 to 3 feet when the water levels exceeded the BFE and extended beyond the limits of the SFHA.

5.1.2 Coastal Flooding

The BPAT conducted an aerial inspection of the coastal areas of Florida from Pensacola Beach to Navarre Beach. On-the-ground inspections of coastal damages were confined to Pensacola Beach.

In Pensacola Beach, prolonged wave attack and storm-surge flooding associated with the hurricane eroded most of the primary dune system and narrowed the beach (Figures 5-4 and 5-5). Overwash was significant, but not as severe as experienced during Hurricane Opal. Vertical sand accretion beneath some structures was 3 to 5 feet. Even after Hurricane Georges, Pensacola Beach remains relatively wide with scattered residual dunes. Offshore sandbars were observed migrating back onto the beach in some locations.

FIGURE 5-4 Pensacola Beach before Hurricane Georges.

FIGURE 5-5 Pensacola Beach after Hurricane Georges. Note the loss of dune and vegetation in the foreground of the photo.

Much of the sand that was washed inland buried roads, utilities and lower areas of buildings. As shown in Figure 5-6, homeowners removed excess sand.

FIGURE 5-6 Excess sand (circled) from beneath houses and on roadways that was returned to the beach.

The volume of overwashed sand made the road from Pensacola Beach to Navarre Beach impassable. Reportedly, significant portions of the post-Hurricane Opal reconstructed dune in Navarre Beach were lost (Figures 5-7 and 5-8).

FIGURE 5-7 Navarre Beach before Hurricane Georges.

FIGURE 5-8 Navarre Beach after Hurricane Georges. Note the loss of revegetated dune.

In Pensacola Beach, post-FIRM elevated structures performed well, suffering only residual damage to storage, access, and parking areas below the first floor (Figure 5-9). In V-Zone areas, the BPAT observed minimal enclosures below the first floor of elevated structures. Breakaway walls, where observed, performed as intended.

FIGURE 5-9 The structures to the left were elevated and set back and performed well.

The house in Figure 5-10 clearly illustrates the reduction in flood damages that occur when homes are properly elevated. The elevated addition suffered no damage while the pre-existing, at-grade portion of the home suffered extensive flood damage from overwash.

FIGURE 5-10 An existing slab-on-grade home was expanded with a properly elevated addition.

The BPAT also investigated the performance of several Pensacola Beach hotels. Older, pre-FIRM buildings, such as the hotel in Figure 5-11, suffered flood damage. Flood and rain damage forced the hotel in Figure 5-11 to close for repairs. The property management company reported that it would be closed for three to four months, forcing the layoff of approximately 50 housekeeping and support staff. In contrast, newer hotels with elevated first floors in compliance with the current floodplain management ordinance suffered minimal damage (Figure 5-12). The hotel in Figure 5-12 suffered minimal damage and was able to continue operations without disruption.

FIGURE 5-11 An older hotel that suffered significant damage to the interior due to storm surge and roof leakage.

FIGURE 5-12 A newer hotel with an elevated first floor that suffered minimal damage.

5.2 Wind Observations: Damages and Successes

In general, Hurricane Georges caused minimal wind damage in Florida. Buildings highly exposed along the open coast suffered some wind damage, including loss of sections of composition roof shingles and small sections of siding, which allowed rain infiltration to damage building interiors and contents (Figure 5-13).

FIGURE 5-13 The house on the left suffered wind damage to roofing shingles.

The BPAT assessed the performance of several window and door shutter projects funded under FEMA's HMGP. The shutter projects were applied to public buildings, including municipal office buildings, fire stations, and police stations. While there was little evidence that wind forces and airborne debris caused damage to windows and doors in the area, buildings with shutters showed no damage and provided a safe and secure shelter facility during the hurricane (Figures 5-14 to 5-16).

FIGURE 5-14 Window shutters on the Pensacola Fire Station No. 4.

FIGURE 5-15 Window shutters on the Pensacola Police Headquarters.

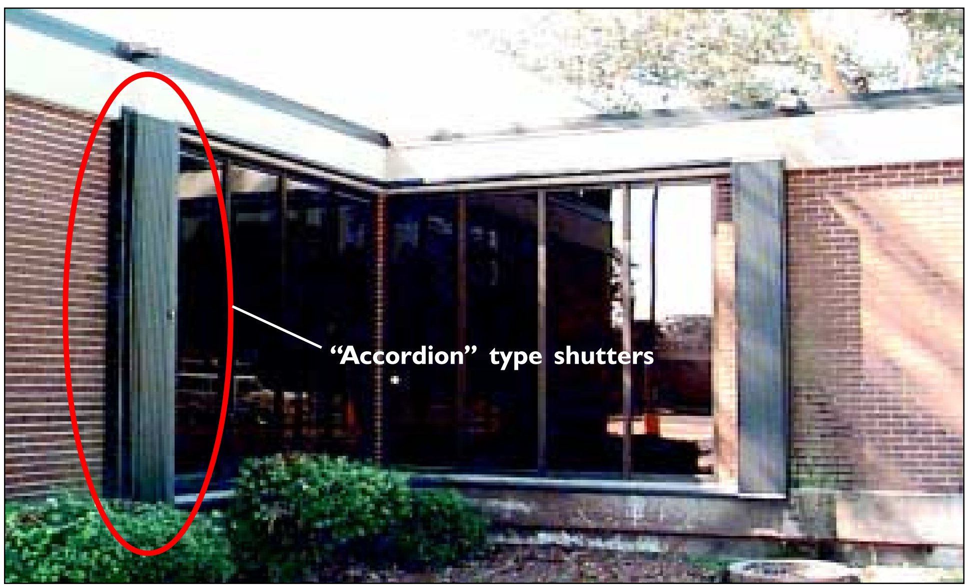


FIGURE 5-16 Window shutters on the Escambia County Administration Building.

5.3 Manufactured Homes in the Florida Keys

On October 11, 1998, damages to manufactured homes on Cudjoe Key, in Monroe County, Florida, were assessed. Wind gusts were estimated at 105-110 mph in this area [NWS 1998]. Hurricane Georges, although not a design event, was a good test of the ability of manufactured homes constructed to current standards to withstand wind damage. Only manufactured homes on Cudjoe Key were assessed; other types of housing (including modular housing) or public buildings were not included in the assessment. Therefore, the discussion that follows only pertains to manufactured housing.

The U.S. Department of Housing and Urban Development (HUD) regulates construction of manufactured homes (HUD-labeled homes), except modular units and units with the chassis removed and installed on permanent foundations. HUD regulations stipulate construction standards for manufactured homes that vary depending on the wind exposure where the home will be installed. Manufactured homes built after July 13, 1994 for Wind Zones II and III, and that are to be installed in the NFIP V-Zone within 1,500 feet of the coast, are required to have an increase in structural resistance to wind meeting American Society of Civil Engineers (ASCE) 7 Exposure D. Further provisions regarding wind-resistant doors and windows are required for manufactured homes built after January 17, 1995.

The State of Florida, Department of Highway Safety and Motor Vehicles regulates the installation of manufactured homes, except modular units which are built and installed to meet the requirements of the Standard Building Code. The state regulations are enforced at the state, county, and/or municipal level.

In addition to HUD and State regulations, the NFIP requires participating communities to adopt and enforce regulations that require that new manufactured homes and manufactured homes in SFHAs that have been substantially damaged to be elevated to the BFE and anchored to resist flotation, collapse, or lateral movement. In existing manufactured home parks or subdivisions, such as those in the area the BPAT assessed, replacement homes are only required to be elevated on a permanent foundation, and to a height of 36 inches or to the BFE, whichever is lower. If a manufactured home in an existing manufactured home park is substantially damaged by a flood, then any future manufactured homes on that lot must be elevated to the BFE.

The NFIP regulations are adopted and enforced by Monroe County as part of its floodplain management ordinance. HUD and state installation requirements for new manufactured homes are also enforced by Monroe County. In addition to the enforcement of these requirements, Monroe County has adopted provisions into its building code for foundation systems and installation of used manufactured homes.

Wind and coastal storm surge damages were evaluated on Cudjoe Key. Elevated homes were exposed to only limited storm surge; most damage was attributed to wind. In general, manufactured homes built after implementation of the new HUD and state regulations (July 1994) performed much better than older (pre-1994) manufactured homes. Damage to the newer homes was superficial and often could be attributed to an attached awning or the impact of airborne debris from an adjacent structure. The manufactured home in Figure 5-17 was located directly in the path of the storm just to the east of the eye and received maximum wind exposure. The home itself sustained only ancillary damage as a result of the awning being torn away.

FIGURE 5-17 This home suffered damage when its awning blew off. The lot next door contained an older manufactured home that was completely destroyed by high winds and coastal surge.

The successful performance of new manufactured homes installed in the Florida Keys can be attributed to four major factors:

- Manufactured homes constructed after July 13, 1994, are built to resist higher wind speeds and Exposure D and are therefore more solidly built and installed;
- The State of Florida has strong installation standards, which include a manufactured home installer education, testing, and certification program for the HUD homes;
- Monroe County's enforcement of NFIP, HUD, and state requirements; and
- The public and local governments are well educated about the new building standards.

Foundation systems for the manufactured homes installed during the past four years were typically reinforced concrete or reinforced masonry piers (Figure 5-18). These homes were at or above the coastal storm surge elevation experienced during Hurricane Georges. Most of these homes experienced only non-structural damage to lower area skirting. In some cases, water damage occurred to insulation below the floor.

FIGURE 5-18 Reinforced masonry pier foundation system under a newer manufactured home that performed well. The air conditioner compressor (circled) washed under the home provides evidence of the coastal surge at this location.

Homes generally appeared to be well anchored to the foundation piers. Many had steel plates attached to the piers and secured to the frame with large bolts (Figure 5-19). There were usually at least three connections per beam under the home. The minimum number observed was two, located at the ends of each beam.

FIGURE 5-19 Reinforced masonry pier with metal anchoring plate.

As stated earlier, most of observed damages were to older manufactured homes that were not constructed to the current HUD code or installed to the current standards that are being enforced by Monroe County. Aside from the home construction standards, deficiencies in older manufactured homes include a lack of adequate elevation, the use of un-reinforced piers (dry stacked blocks), inadequate anchors, and attached site-built additions. Although these issues are addressed in the current regulations enforced by the county, it is important to mention them in this report.

Older manufactured homes were typically elevated 1 to 2 feet on dry stacked blocks. These homes were damaged and sometimes destroyed by a combination of wind and coastal storm surge (Figure 5-20).

FIGURE 5-20 Older, non-elevated manufactured home with an addition that sustained substantial damage.

Some of the anchoring and installation problems observed on older homes included poorly attached anchors, lack of corrosion resistant materials, and homes not anchored tightly against support piers (Figures 5-21 to 5-23). Another anchoring problem observed was improperly attached tie-down straps (Figure 5-24). Figure 5-25 shows a correct strap installation that was observed.

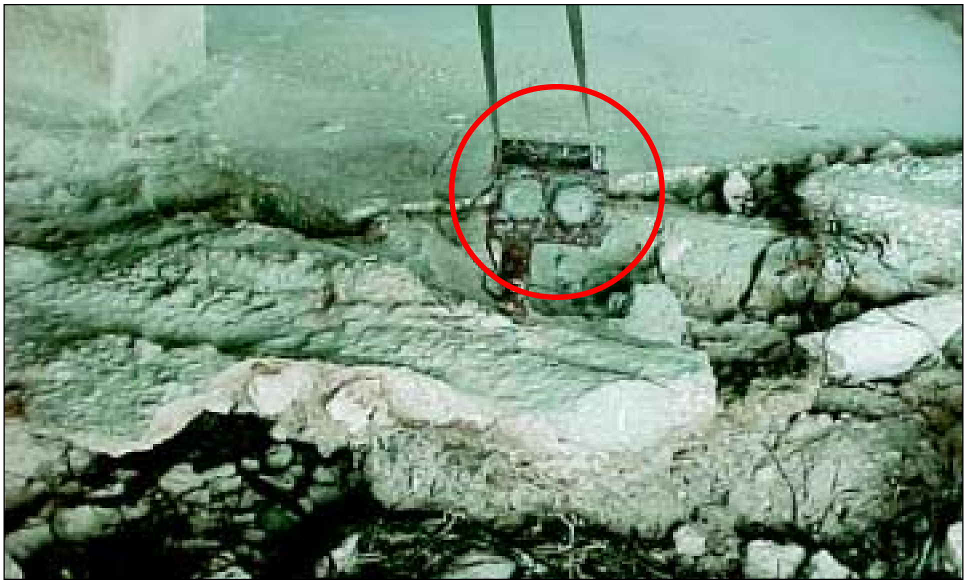


FIGURE 5-21 This anchor is only encased on the edge of the concrete fill pad and could easily be dislodged when the home is subjected to more severe wind or flood loads.

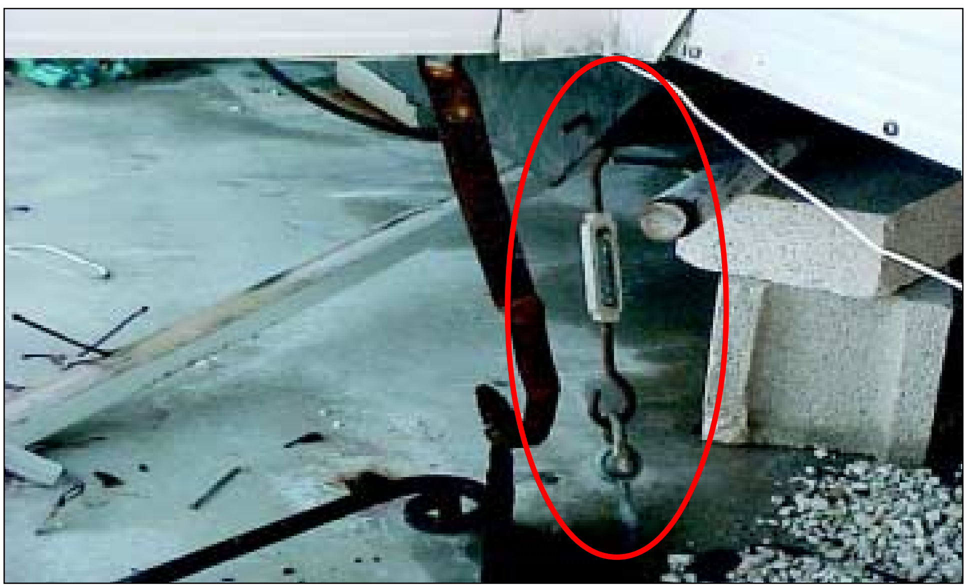


FIGURE 5-22 Inadequate turnbuckle anchor installed by homeowner on this older manufactured home. The home was severly damaged due to the lack of elevation, an unreinforced foundation system, and poor anchoring.

FIGURE 5-23 Rusted anchor under an older manufactured home. The State of Florida mandated galvanized anchors after January 1, 1999.

FIGURE 5-24 Improper strap installation. The buckle should be positioned where the strap wraps around the beam as shown in Figure 5-25.

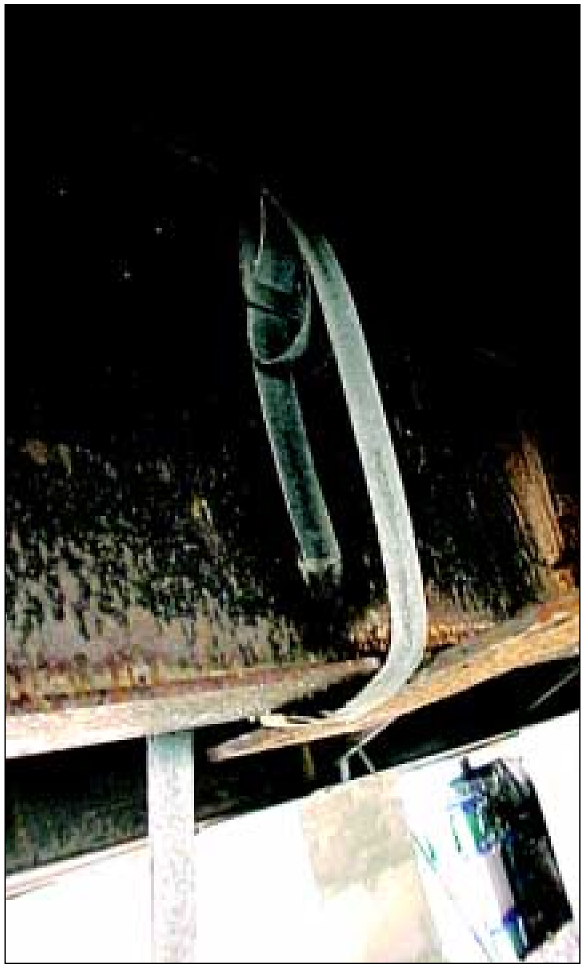


FIGURE 5-25 Proper strap installation.

Manufactured homes that sustained the most damage appeared to be older homes with attached decks, porches, and awnings (Figure 5-26). Although undamaged during this storm, the manufactured home in Figure 5-27 could sustain significant damage if hurricane-force winds or storm surges were to get under the deck and pull it away from the building. It should be noted that site-built, attached additions to manufactured homes are no longer permitted after March 1997.

FIGURE 5-26 The addition to this manufactured home was destroyed, causing considerable damage to the rest of the home.

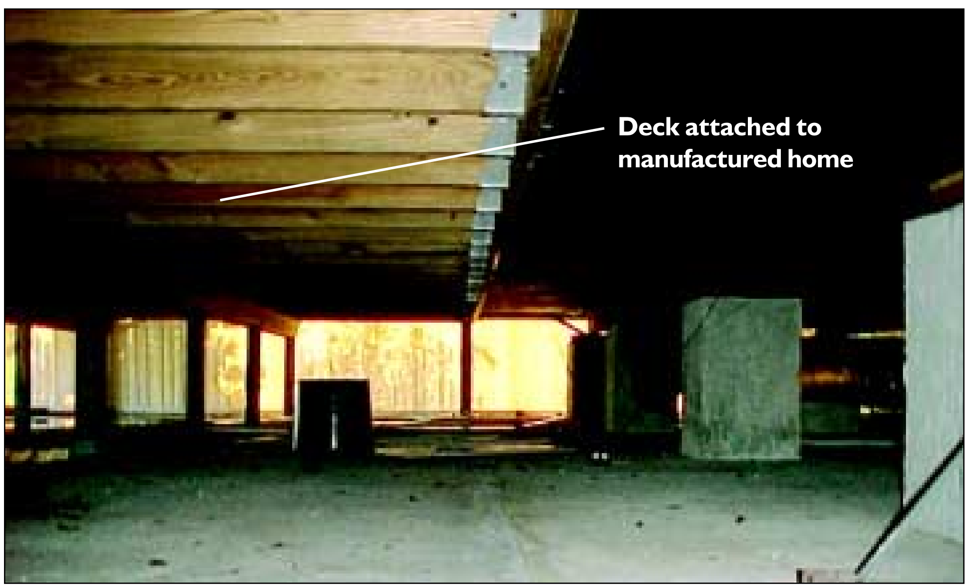


FIGURE 5-27 The underside of a deck that has been attached to the sidewall of a new manufactured home. The deck is not anchored as well as the home.

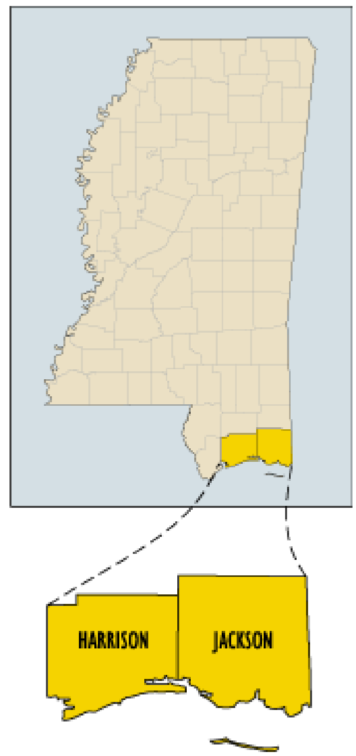
6 Mississippi Observations

6.1 Flood Observations: Damages and Successes

The aerial survey and ground reconnaissance indicated that with the exception of damage in eastern coastal areas, minimal structural damage was observed in Mississippi. Damages to buildings inundated by riverine or coastal flooding was mostly limited to interior contents, finishes, wallboard, insulation, and electrical wiring.

6.1.1 Riverine Flooding

Flooding was significant in Mississippi in the Biloxi, Tchoutacabouffa, and Pascagoula River watersheds. With the exception of gage data recorded on the Tchoutacabouffa River at D'Alberville, Mississippi, and the Tuxachanie Creek near Biloxi (where floods were estimated over the 100-year recurrence) the recurrence intervals were estimated between 10 and 50 years in Mississippi.



Areas in Mississippi visited by the BPAT

The BPAT visited several low-lying areas flooded by Hurricane Georges, including the Pascagoula River, its tributaries, and Franklin Creek in Jackson County. Although there is no river gage on Franklin Creek, observations in the area suggest a recurrence interval of approximately 25 years for this creek. The Franklin Creek watershed is located between the Fowl River and the Big Creek watersheds, and all three have similar watershed characteristics. The Fowl River and Big Creek discharges recorded during Hurricane Georges are estimated to be at a 25-year recurrence interval. Franklin Creek is a tributary to the Escatawpa River, for which a 30,000-cfs discharge was measured, which was also estimated to be a 25-year recurrence interval. Based on these observations, it is reasonable to estimate that Franklin Creek experienced a 25-year flood. Since flood levels in most cases were at or below the 100-year flood level, most damage was confined to non-elevated pre-FIRM buildings.

Typical of the flood damage observed in the Pascagoula area is the home shown in Figure 6-1. In addition to flood damage, some homes in this area also suffered roof damage due to high winds. Many homes in low-lying areas of Pascagoula, such as those shown in Figures 6-2 and 6-3, have been flooded previously. The frequent flooding in this area is likely a result of the inability of the storm drains to convey the rainfall runoff and the inability of the storm drainage system to discharge into the Gulf during periods of coastal surge, or a combination of both of these factors. During Hurricane Georges these homes were flooded to a depth of 3 to 4 feet. No structural damage to homes was observed; however, there were significant losses to contents, interior finishes, wallboard, insulation, and electrical systems.

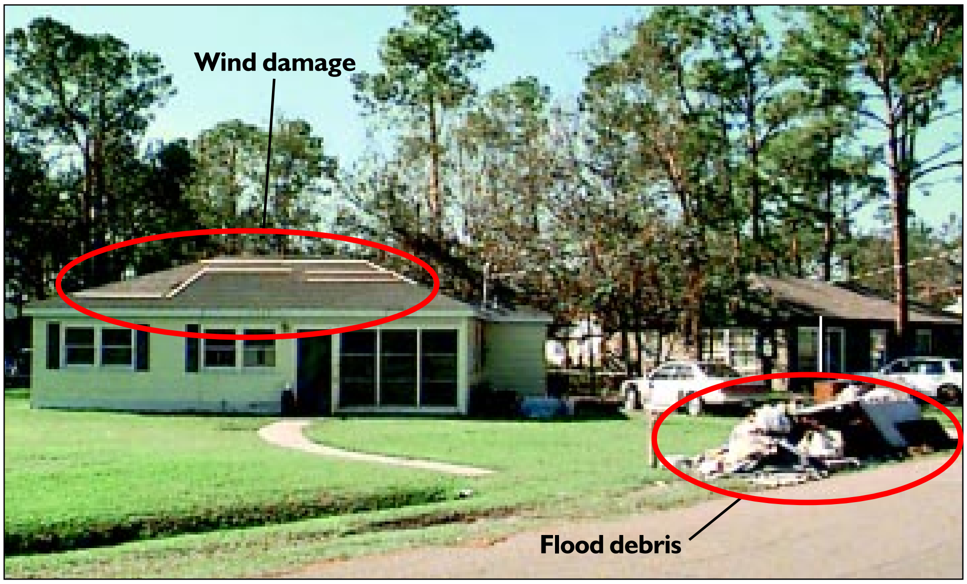


FIGURE 6-1 Home in Pascagoula that sustained wind and flood damage.

FIGURE 6-2 Typical pre-FIRM at-grade house flooded several feet in Pascagoula.

FIGURE 6-3 This home has suffered flood damage on numerous occasions. During Hurricane Georges it flooded several feet.

The house shown in Figure 6-4, located in the Franklin Creek watershed, was elevated in 1996 under FEMA's HMGP. It was elevated 40 inches, bringing the lowest floor to an elevation of 16 feet NGVD which is one foot above the 100-year flood elevation (approximately 15 feet NGVD). Prior to Hurricane Georges, floods have threatened the home four times since it was elevated but it has not sustained any damage. Unfortunately, flooding from Hurricane Georges inundated this house approximately 3 inches above the lowest floor (Figure 6-5). Given the estimated recurrence interval of approximately 25 years, flood elevations exceeding the 100-year flood could be attributed to backwater effects from where Franklin Creek meets the Escatawpa River.

While the 3 inches of flooding did cause damage, if the house had not been elevated it would have received 43 inches of flooding. Elevating homes has been proven to reduce flood damages; however, there is still a residual risk that a flood greater than the 100-year flood will cause damage. The only way to completely eliminate the risk is to relocate well outside the 100-year floodplain.

FIGURE 6-4 Home in eastern Jackson County elevated approximately 40 inches.

FIGURE 6-5 The high water mark on the air conditioner compressor indicates that the flood level was approximately 3 inches above the lowest floor.

6.1.2 Coastal Flooding

Coastal surge from Gulfport to Biloxi caused only minimal structural damage. In these areas, buildings are well set back from the shoreline as shown in Figures 6-6 and 6-7. The impacts of storm surge, wave action, erosion, and scour were reduced to set back structures. In addition, Hurricane Georges' impact on these beaches appeared to be minimal. As shown in these figures, no appreciable road damage or overwash of sand onto Highway 90 was observed where the road followed the shoreline in Gulfport and Biloxi.

FIGURE 6-6 Coastal area near Gulfport. Note how buildings are set back from the shore.

FIGURE 6-7 Another coastal area near Gulfport.

Casino barges in Gulfport and Biloxi suffered minimal damage and disruption of business from coastal surge. Some roof damage due to high winds, as discussed in Section 6.2, resulted in rain infiltration damage to some casinos (Figure 6-8). The shipyards in Pascagoula were inundated by coastal storm surge and suffered some damage (Figure 6-9). Ingalls Shipbuilders, the area's largest employer, has already retrofitted its shipyard, thereby protecting its means of production from the effects of Hurricane Georges and making the region's economic base more secure.

FIGURE 6-8 Casinos suffered minimal damage from coastal storm surge.

FIGURE 6-9 Ingalls shipyard only suffered minor damage due to coastal storm surge.

Further eastward along the Mississippi Gulf Coast in the Belle Fontaine/Fountaine Bleau area (located between Ocean Springs and Gautier), more significant damage due to coastal surge was observed. The shoreline in this area consists of alternating sections of natural beach and bulkheads, dominated by narrow beaches without dunes (Figures 6-10 and 6-11).

FIGURE 6-10 Scour behind bulkhead near Belle Fontaine.

FIGURE 6-11 Severe beach erosion caused by wave action and storm surge.

Rip-rap at a public beach, old abandoned bulkheads, and old foundation piles, suggest a history of episodic and long-term erosion issues. Overwash was common, covering the roadway in the western areas. Vertical beach loss of several feet occurred, as did localized scour around bulkheads. Lack of adequate building setbacks from the shoreline in combination with inadequate foundation systems left many houses extremely vulnerable to storm surge and wave-induced damage in the Belle Fontaine/Fountaine Bleau area (Figures 6-12 to 6-16). Adequately sited and elevated homes performed well (Figure 6-17).

FIGURE 6-12 Highly exposed structure that suffered damage from storm surge and high winds.

FIGURE 6-13 Only the deck remains standing on this home. House debris can be seen in the background. Storm-induced beach erosion and inadequate pile embedments contributed to the failure of this home.

FIGURE 6-14 The houses in this area were destroyed. Piles were embedded in concrete to a depth of only 2 feet. Storm-induced erosion of 2 to 3 feet resulted in complete failure of the foundation systems.

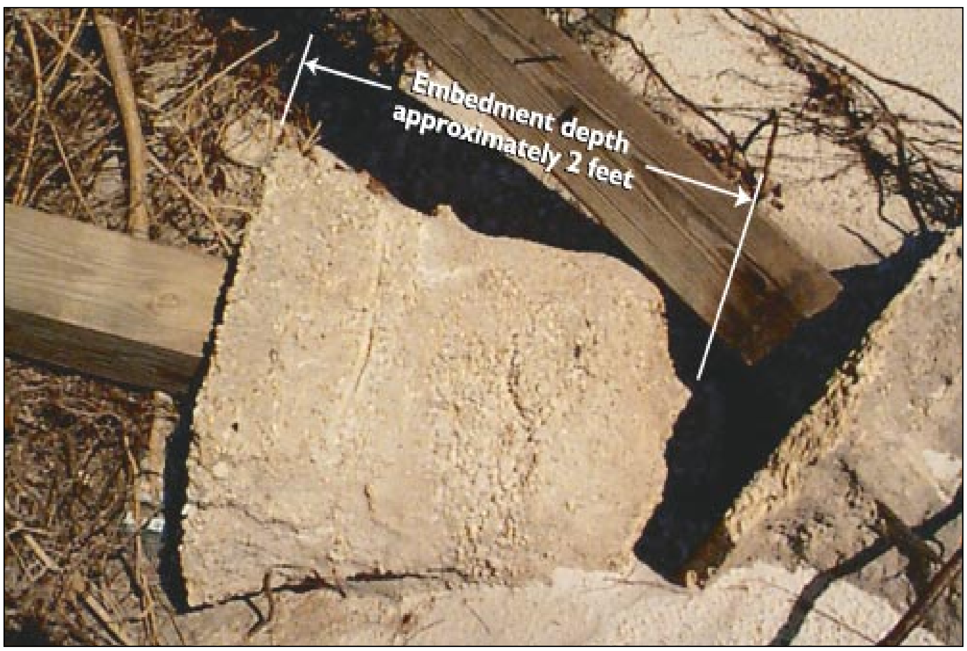


FIGURE 6-15 Inadequate embedment of piles from a destroyed home.

FIGURE 6-16 All that remains of this oceanfront manufactured home that was located on this lot is the bent metal frame. The foundation system was dry-stacked blocks. Tiedown anchors on the Gulf side of the home failed due to erosion and flood forces.

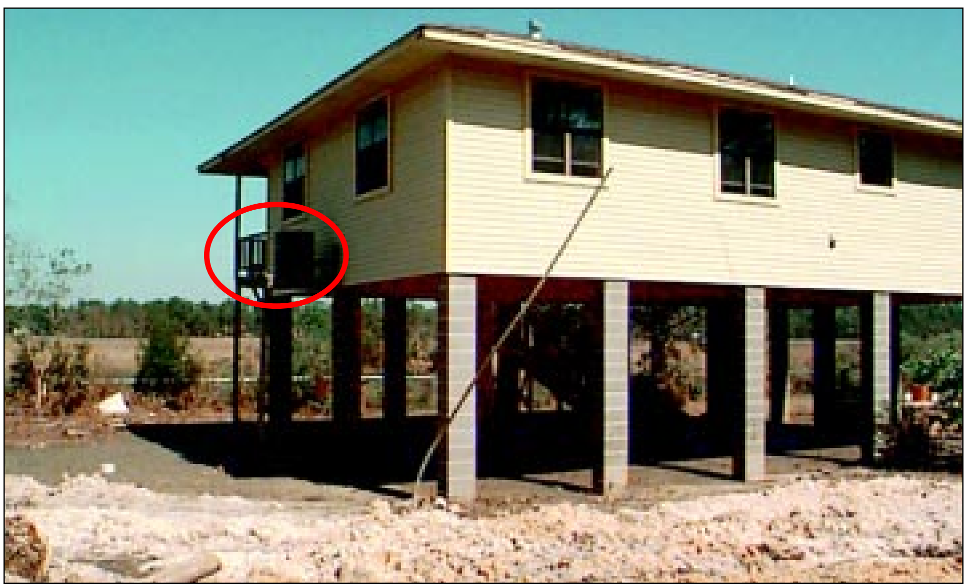


FIGURE 6-17 This house was set back 100 feet or more from the open coast out of reach of velocity flow and wave action. Note elevated utility platform.

6.2 Wind Observations: Damages and Successes

The effects of hurricane-force winds were more obvious in the Gulfport-Biloxi area than the BPAT observed in either Alabama or Florida. Numerous built-up flat roofs on large institutional buildings failed, leaving the buildings open to rain damage. For example, the roof of the Singing River Hospital, a regional medical center in Pascagoula, was partially torn off. The loss of portions of the roof resulted in the evacuation of patient rooms and other areas of the hospital, including delivery rooms. Figure 6-18 shows the roof of the hospital being repaired.

FIGURE 6-18 Singing River Hospital, where emergency roof repairs are underway.

Damage occurred to the roofs of several buildings at the Mississippi Gulf Coast Community College in Gautier. Infiltration of rainwater due to the roof damage resulted in damage to interior areas (Figure 6-19). Loss of roof shingles and damage to signs was evident throughout the area (Figures 6-20 to 6-22).

FIGURE 6-19 Mississippi Gulf Coast Community College in Gautier, where restoration services are underway to dry out interior areas.

FIGURE 6-20 Roof damage to a hotel in Pascagoula.

FIGURE 6-21 Shingle roof damage to homes along the open Mississippi coast.

FIGURE 6-22 Sign damage in Pascagoula.

The team assessed the performance of several window and door shutter projects funded under FEMA's HMGP. The shutters were installed on public buildings. While there was little evidence of damage to the windows and doors of buildings from wind loads and airborne debris in the areas where these shutters were installed, it is worth noting that the buildings with shutters showed no damage as well and provided safe and secure shelter during the hurricane (Figure 6-23).

FIGURE 6-23 Window and door shutters on the Harrison County Municipal Building.

7 Conclusions and Recommendations

The BPAT's conclusions and recommendations are presented in this section. The conclusions presented in Sections 7.1 and 7.2 are drawn from the building successes and damages observed by the BPAT during the field assessment and based on a collaborative evaluation of the observations. Sections 7.3 and 7.4 provide technical guidance for mitigating damage from future storms.

7.1 Successful Building Performance

This section summarizes the factors that contributed to the successful performance of buildings subjected to the flood and wind forces of Hurricane Georges.

Engineered structures constructed in accordance with current building codes, such as the SBC, the NFIP compliant local floodplain management requirements, and additional state and local standards performed well.

Buildings built to these requirements sustained less damage than pre-FIRM structures. The post-FIRM structures were able to withstand Hurricane Georges' increased wind and flood loads.

Elevating buildings to the NFIP requirements substantially reduced the damages in both riverine and coastal areas. Elevated residential structures and public structures such as the Mobile Convention Center received considerably less damage than they would have if they had not been elevated. NFIP requirements mandate that structures built in V-Zones, as shown on the FIRMs, must be elevated so that the lowest horizontal structural member is at or above the BFE and the area below the building is free of obstructions. In Coastal A-Zones and in riverine A-Zones, a building's lowest floor must be elevated to or above the BFE.

Communities that recognized and required buildings be designed for the actual hazards present in their area, sustained reduced damages.

Some communities recognize the actual hazards and mandate more stringent siting and building standards. For example, under the jurisdiction of the Santa Rosa Island Authority, the City of Pensacola Beach enforces V-Zone construction standards for single family residential structures in all of the barrier island areas shown as A-Zones on the current FIRM. These requirements and others reflect the actual risk on Pensacola Beach and helped to significantly reduce the extent of damage to buildings on the city's barrier island A-Zones. The application of the V-Zone standards is credited with significantly reducing damages to A-Zone buildings caused by Hurricane Opal and Hurricane Georges.

On Dauphin Island, Alabama, the implementation of more stringent local requirements for installation of asphalt/composition roofing shingles resulted in only minimal damage to roofs. The local building code requires that shingles be attached using six nails and mastic on the first two rows of shingles (Figure 7-1). In addition, the local building code requires pile embedments to extend to a minimum of 10 feet below mean sea level (msl) or to a depth equivalent to the height of the lowest floor above msl.

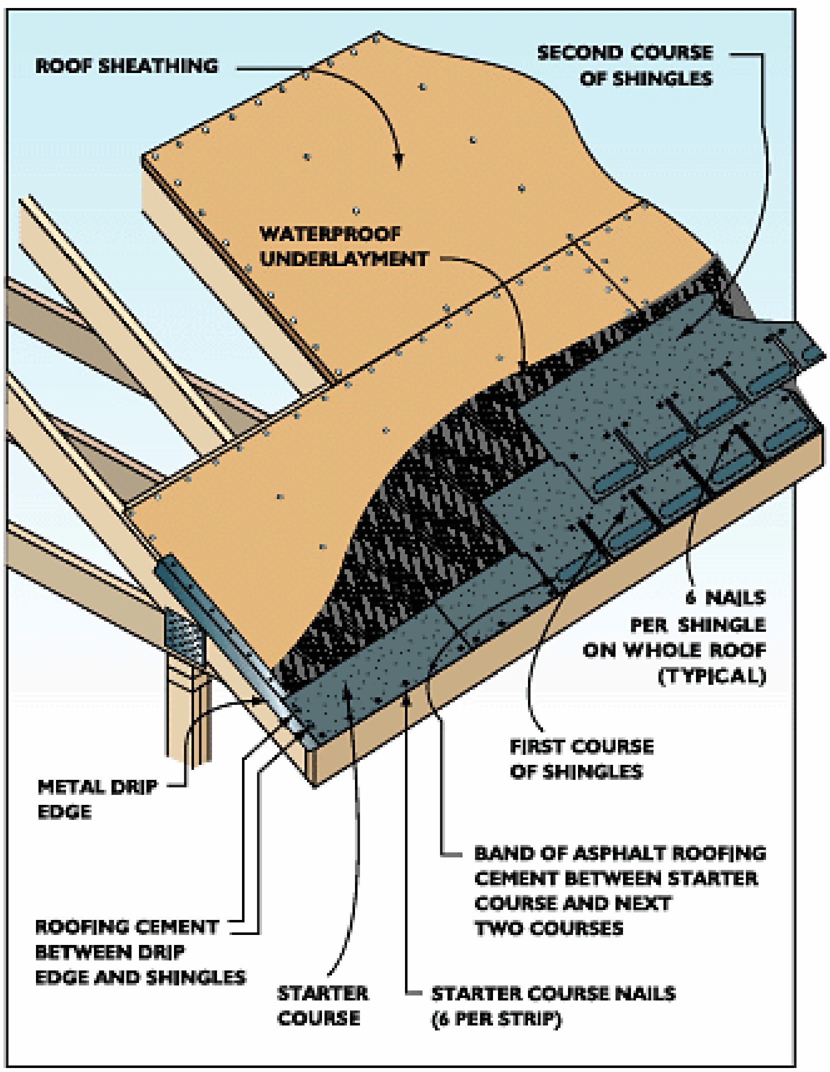


Figure 7-1 Shingle installation technique implemented on Dauphin Island, Alabama.

Home builders have learned from past hurricanes and implemented appropriate construction techniques to reduce future damages. One example was the widespread observation that minimal enclosures were constructed below structures in V-Zones. On Dauphin Island, Alabama, builders used V-Zone construction standards on many homes located in coastal A-Zones on the landward side of the island. Even though the area is shown as an A-Zone, the area is subject to some velocity wave action and overwash as evidenced by the observed scour and debris damage. Construction to

V-Zone standards allowed floodwaters and debris to flow freely under the houses, resulting in reduced damage.

Manufactured homes with reinforced concrete or reinforced masonry piers and proper anchoring performed well.

Manufactured homes in the Florida Keys with reinforced concrete or masonry piers and properly installed anchoring systems yielded lower damages. A manufactured home installer training program is successfully promoting proper installation techniques in Florida.

Specialized building materials designed for higher wind speeds performed well.

New building materials, including fiber-reinforced concrete building siding and metal roofs, withstood Hurricane Georges' wind forces. New materials warrant further study to determine long-term reliability and functionality.

Publicly financed flood mitigation programs and planning activities clearly had a positive impact on the communities where they were implemented.

Elevation of floodprone buildings proved to be a cost-effective technique to break the cycle of damage to repetitive loss properties along the Fish and Dog Rivers in Alabama.

Furthermore, most public facilities retrofitted for wind hazard mitigation, such as police stations, fire stations, and public buildings, performed very well and operated without disruption during Hurricane Georges.

In addition to the mitigation projects already completed or underway, communities in the region are demonstrating further commitment to hazard mitigation through the planning process. For example: the South Alabama Regional Planning Commission is preparing a regional hazard mitigation plan for Baldwin, Mobile, and Escambia Counties; both Dauphin Island and Gulf Shores, Alabama are preparing comprehensive plans that include provisions for hazard mitigation; and Pascagoula, Mississippi will develop a post-hurricane recovery plan to identify long-term solutions to its flood problems. This activity follows upon the hazard mitigation plan prepared prior to Hurricane Georges under FEMA's Project Impact Initiative.

7.2 Factors Contributing to Building Damage

This section summarizes the factors that contributed to the observed building damages described in Sections 3 through 6 of this report.

Riverine flooding in many areas exceeded the 100-year flood level. Structures built to post-FIRM building standards in SFHAs are still exposed to a residual risk of flood damage. In many of the areas affected by Hurricane Georges, flooding exceeded the BFE (see Figure 2-4, Section 2). When this occurred, structures built within the SFHA sustained damage. Likewise, structures built outside the SFHA, where no NFIP floodplain management requirements apply, were also flooded and sustained damage.

Inadequate pile embedment depths on coastal structures. Piling foundations of residential structures, including decks that were not built to withstand the forces of the storm surge, failed. Erosion and scour combined to affect coastal piling foundations, causing them to be undermined and ultimately fail in several cases. Beachfront homes are most at risk from pile embedment failure.

Inadequately elevated and protected on-site utility systems. Many electrical meters, air conditioners, and heat pumps were damaged or destroyed although the buildings themselves received little or no damage. Individual costs of these items often exceeds several thousand dollars, but the potential loss of habitability is of greater concern when these utilities are damaged. The BPAT observed many cases in coastal V-Zones where air conditioners and heat pumps were elevated, but their platforms were destroyed because they were supported by inadequate piles or posts. In some cases the air conditioners and heat pumps were properly elevated but still sustained damage because the units were not properly anchored to the platform.

Inadequate designs for frangible concrete slabs below elevated buildings in coastal areas subject to wave action. Many concrete slabs-on-grade were either too thick, connected to the piles, or steel-reinforced and did not allow for the proper break-up of the slab when affected by the storm surge, erosion, and scour. The BPAT observed significant pile damage caused by debris impact from improperly designed slabs.

Impact from waterborne debris on coastal structures. Debris from ancillary structures such as docks, porches, decks, and stairways damaged adjacent structures. In many cases, the failure of ancillary structures from front-row houses contributed to damage to houses properly set back.

Siting of houses that did not consider localized impacts of coastal erosion and scour. As observed on Dauphin Island, Alabama, roads perpendicular to the shoreline provided a preferred flow path for coastal surge and overwash resulting in a concentration of significant erosion and scour on the back bay side of the island. Houses built in these areas were severely damaged or destroyed due to eroded foundation systems and waterborne debris impact.

Corrosion of hurricane straps on coastal structures. Although the BPAT could not directly attribute coastal building failure to hurricane strap failures, many houses observed had severely corroded or completely failed hurricane straps. These corroded straps leave buildings highly vulnerable to damage from future storms.

Site-built attachments to manufactured homes. A significant amount of damage to older manufactured homes was attributed to attachments such as awnings, decks, and porches that became detached by wind or flood forces. These attachments either damaged the home in the process of being separated from the home or by becoming waterborne or windborne debris.

Improperly installed manufactured home anchors. Many cases of anchor problems were observed on older manufactured homes. Either improper anchors were used or the anchor was not properly installed.

7.3 Recommendations

The following recommendations address the factors described in Section 7.2, and when implemented, will reduce future storm damage.

7.3.1 Flood Mitigation Programs and Planning

Development of hazard mitigation plans are critical to the implementation of a comprehensive and effective hazard mitigation program. State and local governments, as well as regional planning commissions and authorities should continue development and maintenance of hazard mitigation plans.

Publicly financed mitigation projects, such as elevation or acquisition of repetitive-loss properties in SFHAs and placement of door and window shutters on public buildings to reduce wind damage need to continue. Selection of any mitigation project must include a thorough benefit-cost analysis to ensure that maximum benefit from available funds is achieved.

7.3.2 Mitigating Residual Flood Risk

Exceeding the minimum lowest floor elevation requirements of the NFIP can reduce residual flood risk. Structures should be built higher than the BFE by mandating at least 1 foot of freeboard to further reduce the risk of future damages. For example, a house that was elevated 1 foot above the BFE in Jackson County, Mississippi, was successfully protected from four recent flooding events. However, flooding from Hurricane Georges exceeded the 100-year flood level and resulted in 3 inches of water in the building's first floor. A requirement of an additional foot of freeboard (raising the house two feet above the BFE), would have prevented significant damage. The cost of elevating the house the extra foot would have been minimal compared to the total cost of elevating the house. In addition, a benefit to homeowners elevating above the BFE is reduced flood insurance premiums.

Elevation of manufactured homes is more critical than site-built homes. Typically, when inundated by flood waters, even at minimal levels, manufactured homes suffer substantial damage. Therefore, elevation above the BFE is strongly recommended.

Replacement manufactured homes placed in existing manufactured home parks, such as those assessed in the Florida Keys, are highly susceptible to severe flood damage. As described in Section 5.3, minimum NFIP requirements for placement of replacement homes in existing manufactured home parks (unless substantially damaged by a flood) only require elevation to the BFE or 36 inches, whichever is lower. This means that when the BFE results in a flood depth greater than 36 inches, the first floor of the home is below the 100-year flood level. It is therefore recommended that all replacement homes be elevated above the BFE.

7.3.3 Pile Foundation Systems

It is important that coastal foundations be designed to survive the anticipated amount of erosion and scour (Figure 7-2). Erosion and scour combine to impact coastal piling foundations in three distinct ways. First, in the absence of crossbracing, the loss of soil adjacent to a thin vertical foundation member, such as a pile, results in a longer unsupported length. The increase in unsupported length allows for greater deflection of the vertical member. Second, the loss of soil adjacent to pilings leaves less soil to counteract lateral loads applied to the pilings by the structure above, the velocity flow of the storm surge, wave action, and debris impact. Third, pilings, which rely on friction between the piling and the adjacent soil to transfer loads into the ground, lose some of the resisting friction when the adjacent soil is eroded and scoured (Figure 7-3). The loss of friction reduces the ability of the piling to resist uplift loads from wind.

The BPAT recommends that, in the absence of State or local requirements based on detailed engineering studies or the historical performance of coastal buildings subjected to base flood conditions, piling for structures in areas subject to erosion and scour be embedded to –10 feet below mean sea level. Piles also should not be encased in concrete collars since this causes further scour around the pile.

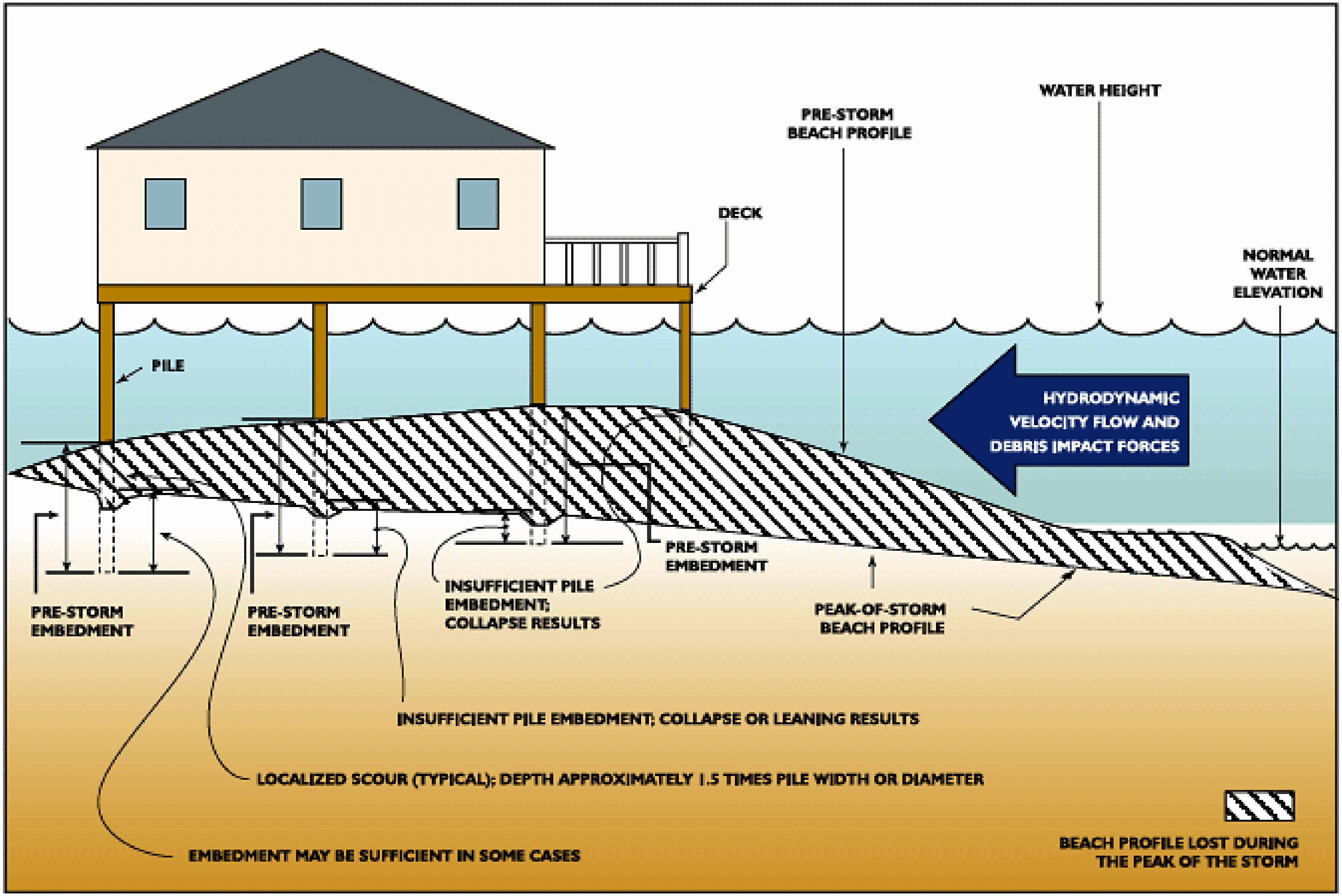


FIGURE 7-2 Typical collapse mechanism of post-FIRM buildings due to storm-induced erosion and scour.

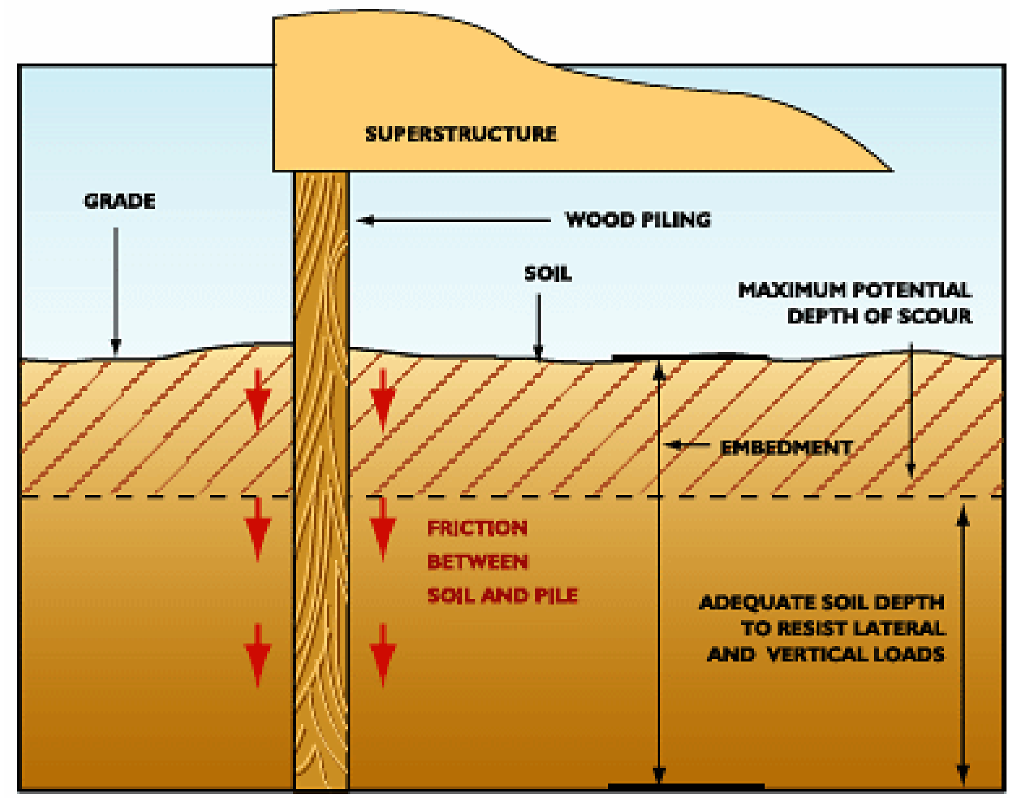


FIGURE 7-3 The depth of pile embedment provides stability by enabling the pile to resist lateral and vertical loads through passive earth pressure. Soil depth below maximum potential depth of scour must be adequate to withstand lateral and vertical loads during the base flood.

7.3.4 On-Site Utility Systems

On-site utilities should be installed with much greater attention to the potential effects of riverine and coastal flooding. NFIP regulations require that if a proposed building site is in a floodprone area, all new construction and substantial improvements shall be constructed with electrical, heating, ventilation, plumbing, air conditioning equipment, and other service facilities that are designed and/or located so as to prevent water from entering and accumulating within the components during conditions of flooding. Elevation provides the preferred method of preventing water from damaging utilities in both coastal and riverine floodprone areas. In some cases, such as placement of electrical meters, installation should be coordinated with local public utility companies. Installation of other items, such as septic systems, may fall under the jurisdiction of local or State Health Departments.

7.3.4.1 Air Conditioner/Heat Pump Compressor Platforms

Platforms that support air conditioner/heat pump compressors must be designed to withstand the forces associated with the base flood. In coastal V-Zones, the best way to avoid damage to these platforms is to employ the method used for the protection of buildings — elevation. Therefore, the bottom of the lowest horizontal structural member of the platform should be elevated to or above the BFE. Ideally, air conditioner/heat pump compressor platforms should be cantilevered from an elevated floor diaphragm (Figure 7-4). This design would be most appropriate for structures subjected to coastal storm surge. An alternative is to support the platform partially or completely on piling (Figure 7-5). Note that specific pile embedment depths must be implemented depending upon whether the site is subject to erosion. Vertical foundation members for platforms should meet the same requirements as the main building support system. Air conditioner/heat pump compressors in riverine areas that are not subjected to significant erosion or scour can be reasonably elevated 3 to 4 feet on a solid platform (Figure 7-6).

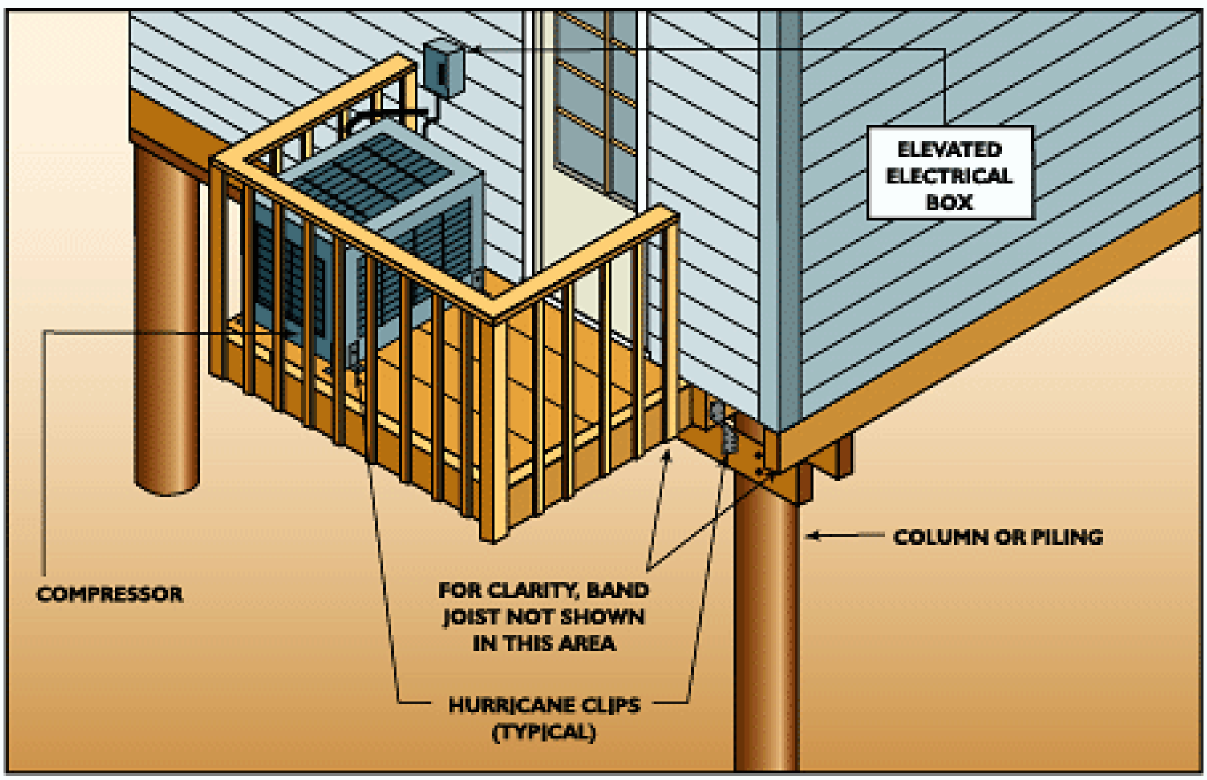


FIGURE 7-4 Cantilevered air conditioner/heat pump compressor platform.

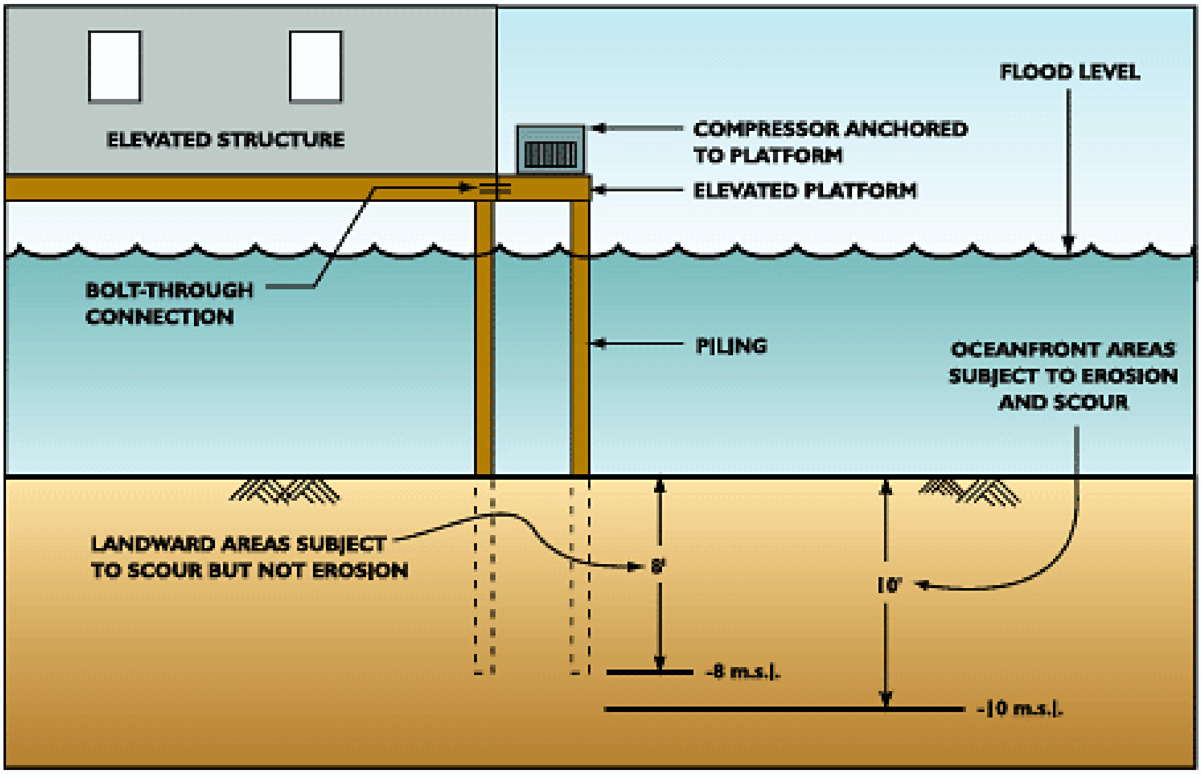


FIGURE 7-5 Air conditioner/heat pump compressor platform supported by pilings.

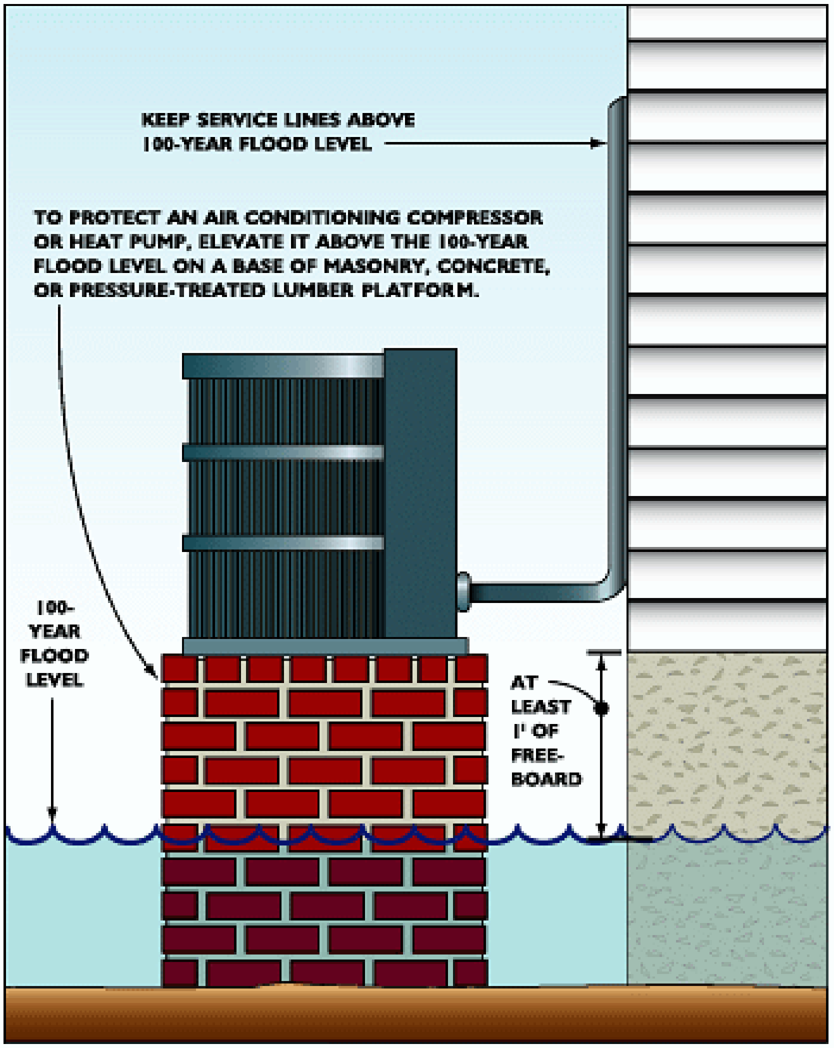


FIGURE 7-6 Elevated air conditioner/heat pump compressor in an A-Zone area not subject to significant velocity flow and debris impact.

Platforms designed and constructed with vertical foundation members must be protected from localized scour and, in oceanfront areas, protected from erosion so that the foundation members can resist the velocity flow, wave action, and debris impact found in coastal areas. When a vertical foundation member loses its ability to support the platform, the platform collapses, becoming waterborne debris that is then carried into the structure or nearby structures. Because of the cost of the compressor, often $2,000 or more, the potential loss of habitability when the compressor is rendered inoperable, and the debris the platforms generate once they collapse, these platforms cannot be considered sacrificial.

7.3.4.2 Placement of Utilities Adjacent to Vertical Support Members

Utilities installed on the landward side of vertical foundation members are shielded by the foundation members against damage from velocity flow and debris impact. Service connections such as electrical meters, telephone junction boxes, and cable junction boxes that must be exposed to flooding should be placed on the landward side of the most landward vertical foundation member (Figure 7-7). Vertical utilities such as sewer and water risers should also be placed on the landward side of vertical foundation members.

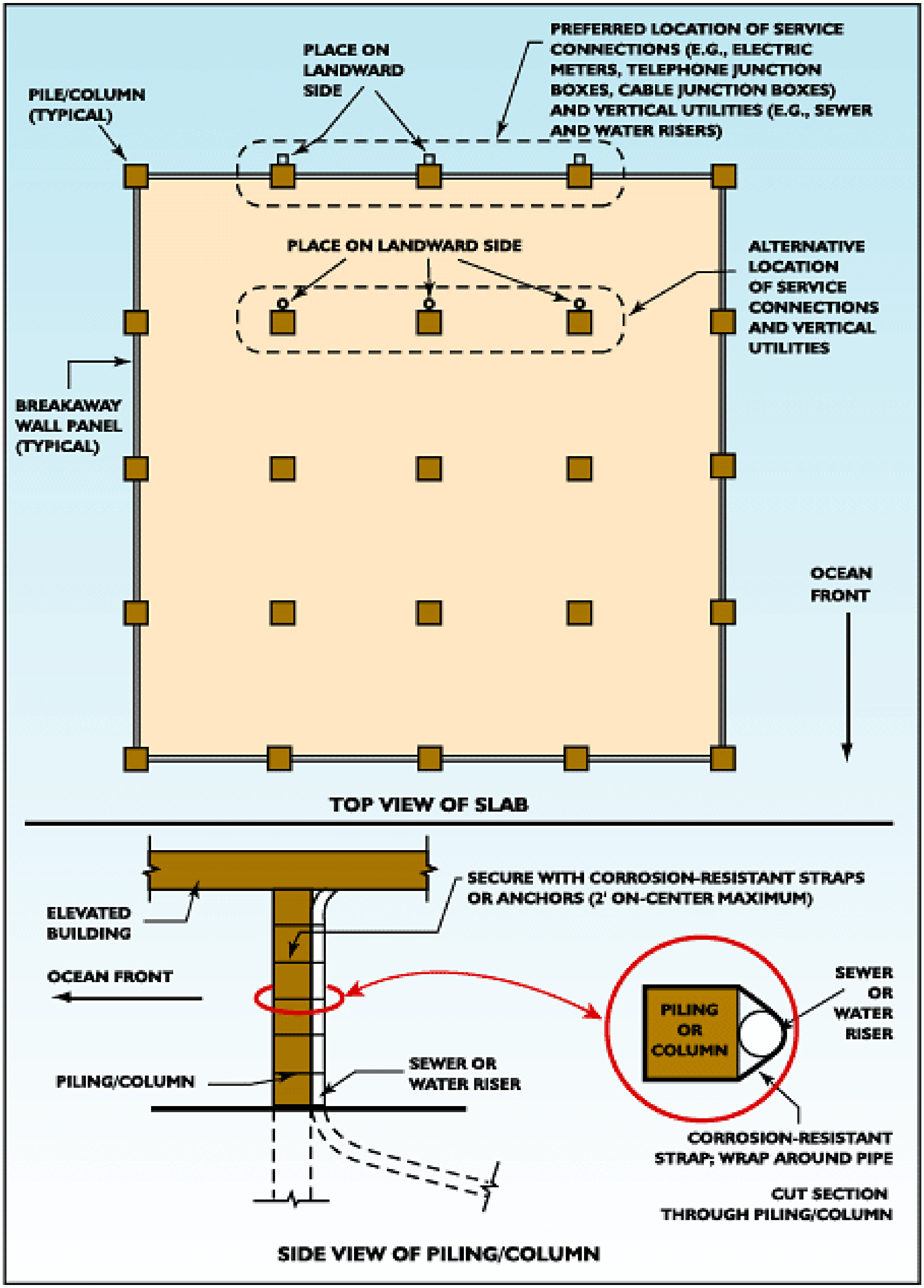


FIGURE 7-7 Proper location of utilities.

7.3.4.3 Septic Tanks

Septic tanks should be installed as far landward as practical and permitted by the authority having jurisdiction. Before septic tanks are installed, local and State Health Departments should be consulted concerning whether such tanks are permissible and how and where they should be installed. Further guidance may be found in the International Private Sewage Disposal Code, Section 303 [International Code Council 1995].

7.3.5 Below-Building Concrete Slabs

When a slab-on-grade is constructed below an elevated building in a coastal area subject to wave action, it should be designed and constructed in such a way that it will not damage the building foundation when acted on by flood forces (Figure 7-8). Issues requiring special consideration include the thickness of the slab, slab joints, and construction practices that are not appropriate for coastal flood hazard areas subject to erosion and scour:

- **Slab thickness** - Slabs below elevated buildings in areas subject to erosion and scour should be no thicker than 4 inches. Thicker slabs present two problems: they are harder to break into small pieces and each piece weighs more per unit of surface area than a same-sized piece of a thinner slab.
- **Slab joints** - Contraction joints are the most important for ensuring the frangibility of below-building slabs. As shown in Figure 7-8, contraction joints should be cut into the surface of the slab from piling to piling in both directions across the entire slab. Expansion and isolation joints should be installed as appropriate in accordance with standard practice or as required by State and local codes.
- **Wire mesh** - Wire mesh retards the ability of the slab to break apart and therefore should not be used.
- **Connecting the slab to the vertical foundation members** - Slabs should never be connected to vertical foundation members when the slab is underlain by granular soil in areas subject to erosion and scour. This practice unnecessarily threatens the stability of the foundation system of elevated buildings.
- **Casting concrete grade beams and slabs-on-grade monolithically** - Grade beams and slabs-on-grade should never be cast monolithically in areas subject to erosion and scour. In these areas, grade beams must be designed to be self-supporting (to account for the loss of supporting soil from erosion and scour) and to withstand velocity flow and debris impact as well as stiffen the foundation system. All slabs-on-grade must be designed to act separately from grade beams.
- **Concrete collars** - In areas subject to erosion and scour, concrete collars should not be placed around foundation pilings.

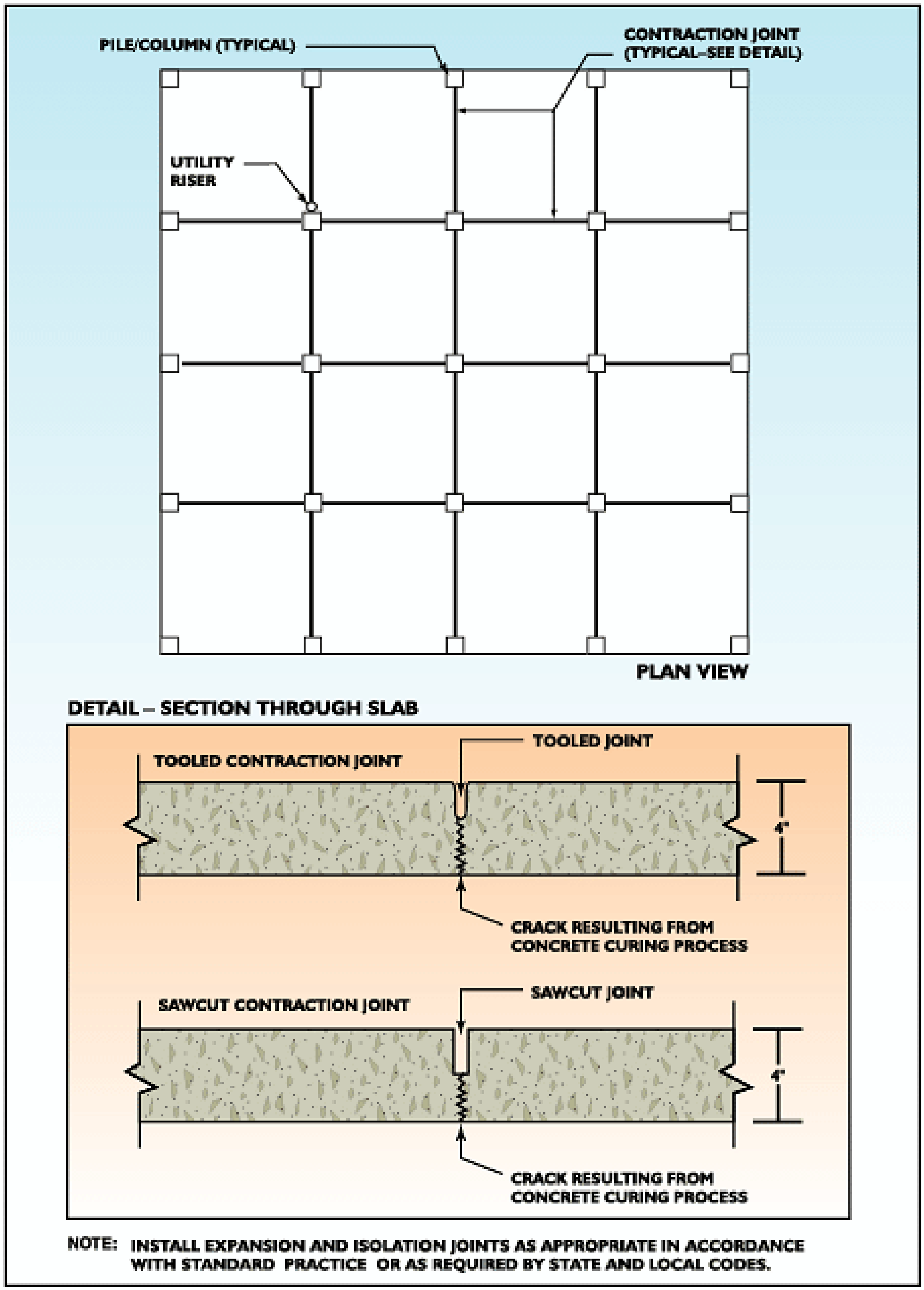


FIGURE 7-8 Recommended contraction joint layout for frangible slab-on-grade below elevated building.

7.3.6 Waterborne Debris Impact

Debris or impact loads are imposed on a building by objects carried by moving water. In coastal areas the source of debris is often wooded stairs, walkways, and decks that are below the elevation of the base flood. These components are often considered sacrificial in coastal V-Zone areas. In extreme cases an entire house may be separated from its foundation system during a severe storm and become a debris problem as was observed in Dauphin Island, Alabama. Inadequately elevated and anchored air conditioner/heat pump compressors can also be a source of waterborne debris. In addition, private boat docks and fishing piers, which are not typically highly engineered structures, can become a source of waterborne debris, as was observed in Mobile Bay, Alabama.

Designing a foundation system to withstand the loads caused by debris is difficult due to the unpredictable nature of debris. However, in areas such as Mobile Bay where hundreds of fishing piers and boat docks exist, there is a known degree of certainty that significant debris will be present during a hurricane or other major storm. In such cases the design engineer must include debris loading in the foundation system design calculations. In addition to sizing a foundation system to withstand these forces, the effects of debris on pile support systems could be minimized by armoring the piles or by placing sacrificial piles seaward of the structure.

Communities can also mitigate debris impact problems by curbing debris. This can be accomplished by:

- Ensuring that buildings are constructed with adequate foundation systems so these systems do not fail, resulting in floating houses;
- Ensuring that stairs, walkways, and decks have adequate foundation systems;
- Ensuring that air conditioner/heat pump compressor platforms have adequate foundation systems and that the compressor is properly anchored to the platform;
- Limiting the size and placement of building components below the lowest floor of the home such as stairs, walkways, and decks; and
- Regulating the size, placement, and construction of docks, fishing piers, and accessory buildings and sheds.

7.3.7 Protection of Metal Structural Components from Corrosion

Maintaining the design strength of all structural components is critical. Any loss of strength can lead to structural failure during subsequent hurricanes. Special attention to the proper type of metal connectors should be considered because of the harsh, corrosive environment of coastal areas. For exposed exteriors near the shoreline, stainless steel connectors or connectors with thick galvanizing should be used. Standard galvanized sheet metal connectors should be replaced with either stainless steel or thick galvanized connectors as soon as partial rusting appears.

For many connector applications in corrosion-prone buildings, the use of corrosion-resistant materials is the best choice for new construction. The choice of alternative connector material or coating specifications should be guided by the location of the building relative to the observed corrosion hazards in each community and by the class of exposure in the building (Figure 7-9). Recommended materials for a typical community are listed in Table 7-1.

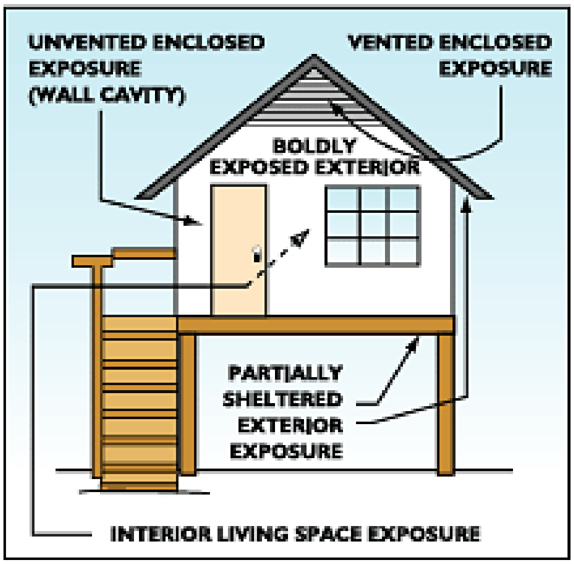


FIGURE 7-9 The locations of the five classes of exposure.

Table 7-1 Recommendations for Corrosion-Resistant Materials and Methods*

Location Class of Exposure **	Oceanfront Buildings (300 feet or less from the shoreline)***	Intermediate Rows of Buildings in Corrosion-Prone Areas (300 to 3,000 feet from the shoreline)***	Buildings Farther Inland (Greater than 3,000 feet from the shoreline)***
Partially sheltered exteriors	1. Avoid sheetmetal connectors where possible. 2. Use stainless steel connectors. 3. Use connectors with thicker galvanizing and replace them when necessary.	Use connectors with thicker galvanizing. (Optional: stainless steel)	Use connectors with standard galvanizing. (Optional: thicker galvanizing)
Boldly exposed exteriors	1. Avoid sheetmetal connectors where possible. 2. Use stainless steel connectors. 3. Use connectors with thicker galvanizing and replace them when necessary.	Use connectors with thicker galvanizing. (Optional: stainless steel)	Use connectors with standard galvanizing. (Optional: thicker galvanizing)
Vented enclosures	1. Use connectors with thicker galvanizing. (Optional: stainless steel) 2. Use TPI**** paints on truss plates. (Option for truss plates: thicker galvanizing, TPI paints over thicker galvanizing, or stainless steel)	1. Use connectors with thicker galvanizing near vents. 2. Use TPI paints on truss plates near vents. (Optional: thicker galvanizing for all connectors)	Use connectors with standard galvanizing. (Optional: thicker galvanizing)
Unvented enclosures	1. Use connectors with thicker galvanizing. 2. Use TPI paints on truss plates. (Optional for truss plates: thicker galvanizing)	Use connectors with standard galvanizing. (Optional: thicker galvanizing)	Use connectors with standard galvanizing. (Optional: thicker galvanizing)
Interior living space	Use connectors with standard galvanizing. (Optional: thicker galvanizing)	Use connectors with standard galvanizing. (Optional: thicker galvanizing)	Use connectors with standard galvanizing. (Optional: thicker galvanizing)

* Recommendations are based on the available research and are subject to change in future Technical Bulletins.

** See Figure 7-9 for exposure classes.

*** Distances may vary considerably depending on local climate. The width of the corrosion hazard area relative to the ocean should be determined in each community from field observations and any existing corrosion studies.

**** Truss Plate Institute

In Table 7-1, building locations are categorized as oceanfront buildings, intermediate rows of buildings in corrosion-prone areas, or buildings near the coast but far enough away from the ocean that excessive corrosion is not anticipated. In most communities, connectors on oceanfront buildings can be expected to corrode at high rates. Corrosion rates should approach inland levels 300 to 3,000 feet (roughly 100 to 1000 meters) landward of the ocean in most communities. Types of connector exposures in a building are listed in Table 7-1 in order of decreasing severity of location. Truss plate treatments are noted separately, based on TPI recommendations for corrosive environments. Recommendations in the table are in some cases based on limited research. When the severity of the exposure is unknown, selecting more corrosion-resistant materials is prudent. Optional materials for superior corrosion resistance are noted also.

Additional guidance regarding the selection, installation, and maintenance of metal connectors, such as truss plates and hurricane straps, can be found in FEMA's NFIP Technical Bulletin No. 8, *Corrosion Protection for Metal Connectors in Coastal Areas.*

7.3.8 Attachments to Manufactured Homes

Typical attachments such as decks, porches, or awnings should be minimized for manufactured homes in SFHAs. These homes are typically not designed to withstand loads to walls or floor systems that may be exerted by attached decks, porches, or awnings. These features should be designed and anchored to the same standards as the manufactured house. Site-built decks, porches, or overhead awnings must not be permitted except as standalone units. Additionally, if a standalone porch or deck is going to be added, design criteria for vertical foundation members on the addition should be equivalent to those for the foundation system of the main structure to prevent damage to the main structure or adjacent structures.

7.3.9 Manufactured Home Anchoring Systems

Manufactured homes in SFHAs must be placed on foundation systems that will resist flotation, collapse, and lateral movement. There are several ways to anchor the homes to these foundation systems. The support chassis of the home can be connected directly to the reinforced concrete or masonry piers by using metal "L" brackets or the home can also be anchored using straps. It should be noted that anchoring using straps would not be appropriate for homes elevated more than 3 to 4 feet where an engineered, permanent foundation may be required. Figure 7-10 shows the attachment of typical anchoring straps. Anchoring straps can be connected to the chassis by being wrapped around the support beam or the straps can be bolted to the support beam. The straps are connected to the ground by attaching to anchors encased in the concrete foundation or by attachment to earth auger or cross drive rock anchors.

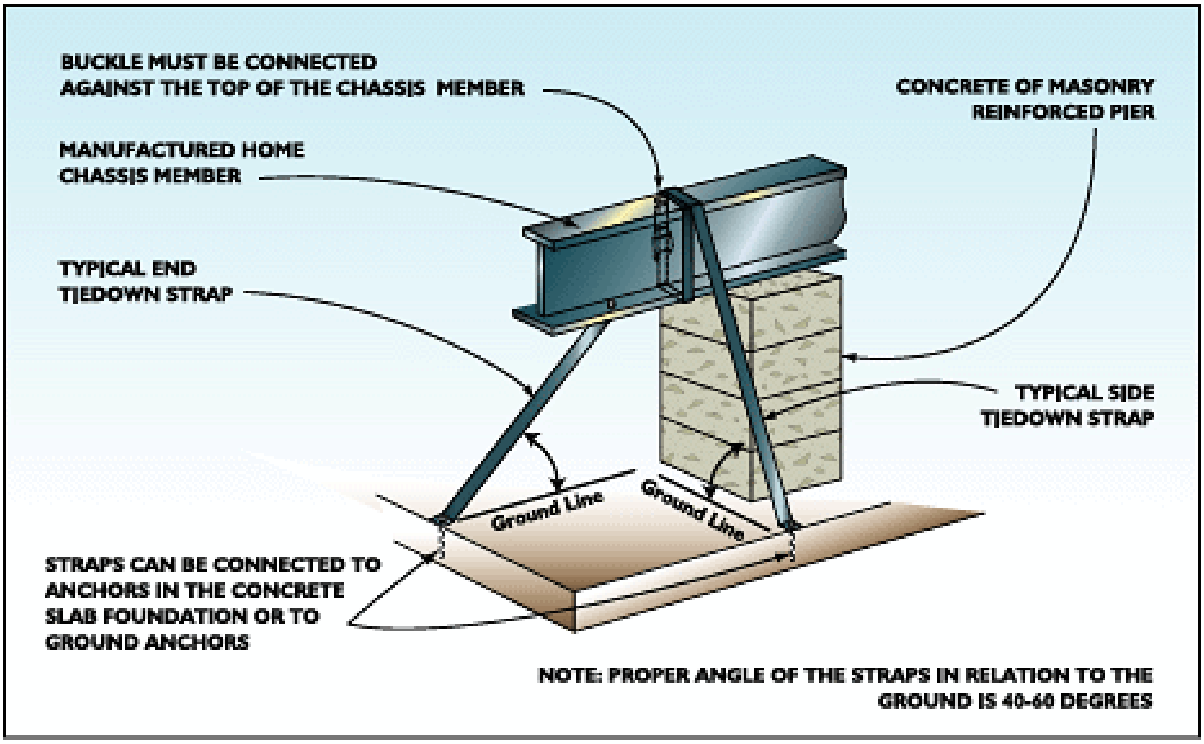


FIGURE 7-10 Typical manufactured home anchoring straps.

Chassis configuration varies among manufactured home manufacturers. Installation in a SFHA area may require manufactured homes to be installed on permanent, engineering foundations. Therefore, selection and installation of all anchoring systems must be performed in accordance with the manufacturer's installation instructions and/or engineered design criteria. In addition, anchoring straps must be properly installed by a qualified installer and in accordance with the strap manufacturer's installation instructions. As mentioned earlier straps may not be appropriate if the home is elevated more than 3 to 4 feet. Straps must also be properly tensioned and require periodic maintenance to ensure that proper tension is maintained. For these reasons it is preferred that the manufactured home be connected directly to the support piers using metal connectors. Any metal connectors used should be adequately protected from corrosion. Finally, metal connectors used in anchoring systems must be adequately protected from corrosion.

7.4 Other Mitigation Guidance

Supplemental technical guidance for designers of coastal foundations can be found in the following documents:

- The ASCE standard *ASCE 7-95, Minimum Design Loads for Buildings and Other Structures*. This standard includes criteria for determining flood loads and for combining flood and other loads to determine load factors for buildings that experience simultaneous wind and flood loads. This standard meets, or exceeds, the minimum requirements of the NFIP for determining loads.
- The ASCE standard *ASCE 24-98, Flood Resistant Design and Construction*. This standard provides prescriptive requirements regarding the design and construction of buildings that are located in floodprone areas. This standard also meets, or exceeds, the minimum requirements of the NFIP.

- FEMA's *Coastal Construction Manual (FEMA 55).* This document provides further guidance on coastal foundation systems.
- FEMA's Technical Bulletin No.5, *Free-of-Obstruction Requirements for Buildings Located in Coastal Hazard Areas (TB 5-96).* This document provides information on NFIP-compliant design and construction practices that can prevent damage to coastal building caused by below-building obstructions.

Additional technical guidance and recommendations regarding design of breakaway walls, roofing systems, door and window protection, and other mitigation measures can be found in the following FEMA publications:

- *Building Performance Assessment: Hurricane Georges in Puerto Rico, Observations, Recommendations, and Technical Guidance,* March 1999 (FEMA 339).
- *Building Performance Assessment: Hurricane Fran in North Carolina – Observations, Recommendations, and Technical Guidance*, March 1997 (FEMA 290).
- *Hurricane Opal in Florida, A Building Performance Assessment,* August 1996 (FEMA 281).
- *Building Performance Assessment: Hurricane Iniki – Observations, Recommendations, and Technical Guidance*, January 1993 (FIA 23).
- *Building Performance Assessment: Hurricane Andrew in Florida – Observations, Recommendations, and Technical Guidance*, December 1992 (FIA 22).
- *FEMA's Technical Bulletin No. 2, Flood Resistant Materials Requirement for Buildings Located in Special Flood Hazard Areas*.
- *Homeowner's Guide To Retrofitting: Six Ways To Protect Your Home From Flooding*, June 1998 (FEMA 312).
- *Engineering Principals and Practices for Retrofitting Flood Prone Residential Buildings,* January 1995 (FEMA 259).

8 References

American Society of Civil Engineers, 1995. *ASCE 7-95, Minimum Design Loads for Buildings and Other Structures.* Washington, DC.

Associated Press, 1998. "Georges Pummels Caribbean, Florida Keys and U.S. Gulf Coast." September 30, 1998.

Federal Emergency Management Agency, 1986. *Coastal Construction Manual,* FEMA-55. February 1986. Washington, DC.

Federal Emergency Management Agency, 1996. *Hurricane Opal in Florida: A Building Performance Assessment,* FEMA-281. August 1996. Washington, DC.

International Code Council, 1995. *1995 International Private Sewage Disposal Code*.

National Hurricane Center, 1997. *Preliminary Report, Hurricane Danny.* August 1997. Miami, FL.

National Weather Service, 1998. *Preliminary Post Hurricane Report.* Hurricane Research Division. Miami, FL. NWS website.

National Weather Service, 1961. *Technical Paper 40.*

Pearman, Larry. Personal conversation. USGS, Mobile, AL.

United States Army Corps of Engineers, 1998. Hurricane Georges, Mobile District. September 1998. Mobile, AL. U.S. Corp of Engineers website.

United States Geological Survey, 1998. *Water Resources Investigations Report 98-4231*. 1998.

To order FEMA publications, call 1-800-480-2520, or write: FEMA Distributional Facility, P.O. Box 2012, Jessup, Maryland 20794-2012.

FEMA NFIP Technical Bulletins may also be downloaded from FEMA's website: www.fema.gov/mit/techbul.htm.

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