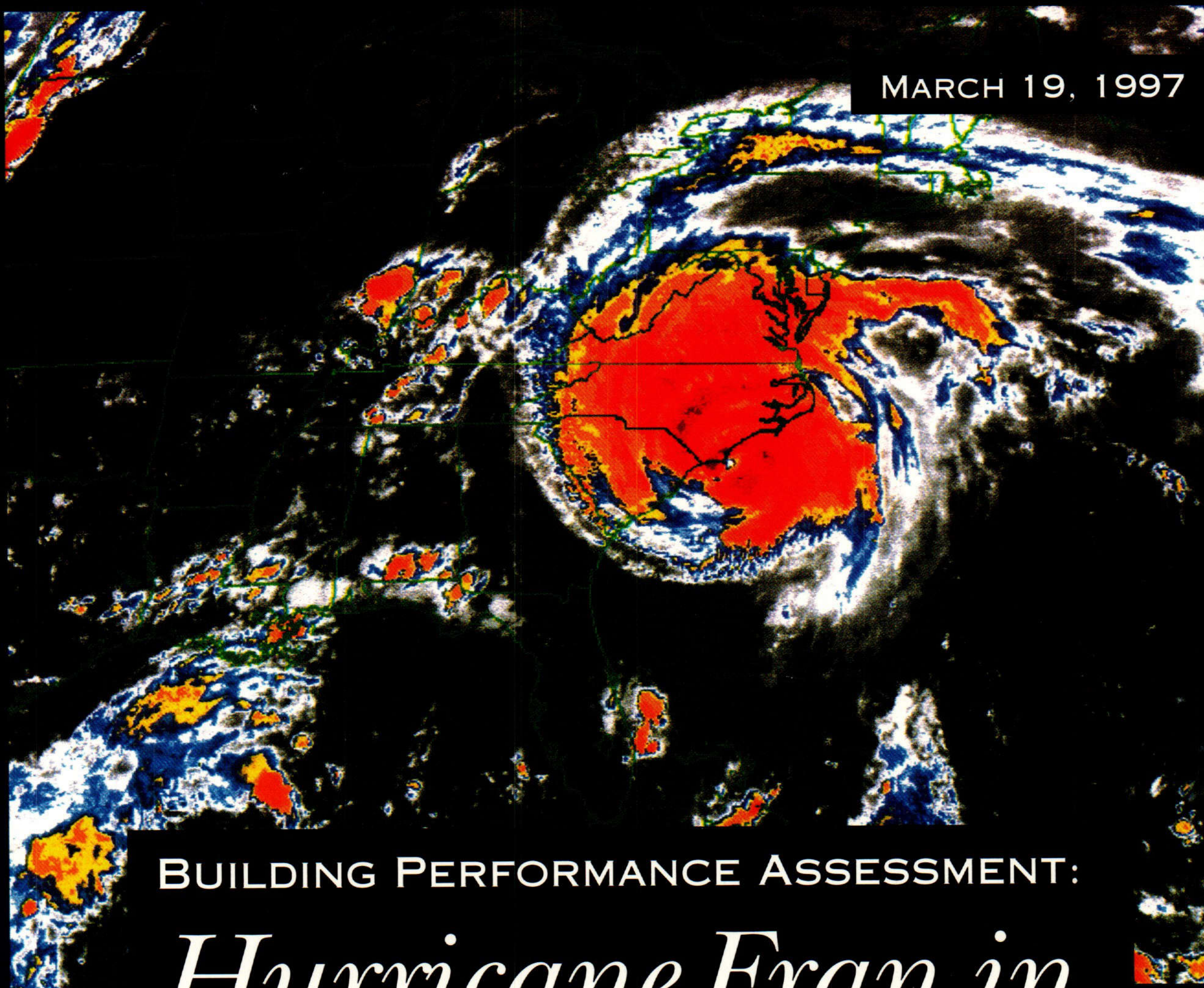
MARCH 19, 1997



BUILDING PERFORMANCE ASSESSMENT:

Hurricane Fran in North Carolina

OBSERVATIONS, RECOMMENDATIONS, AND TECHNICAL GUIDANCE

FEDERAL EMERGENCY MANAGEMENT AGENCY
MITIGATION DIRECTORATE

WASHINGTON, DC
AND
REGION IV
ATLANTA, GEORGIA

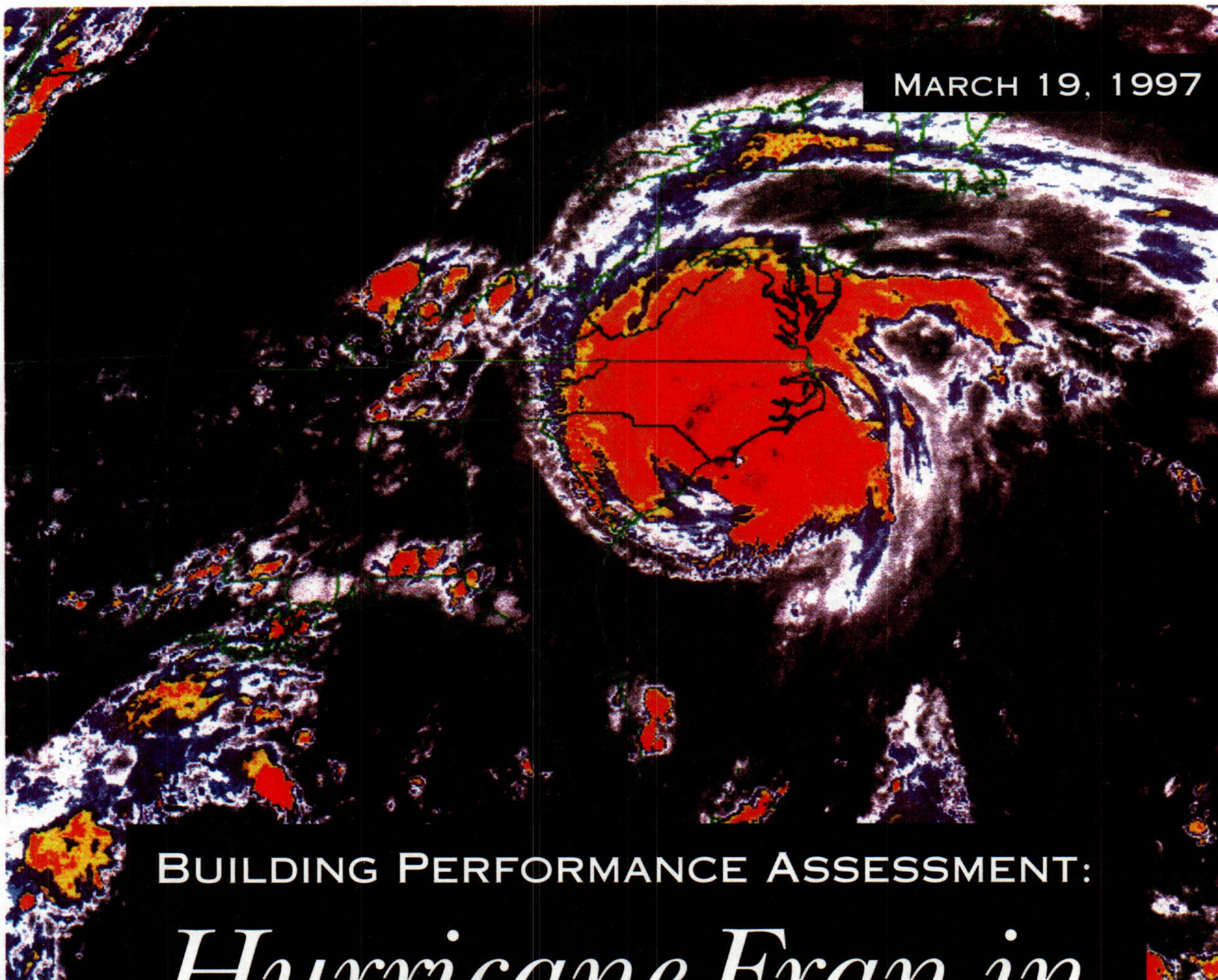
FEMA 290/*March 1997*

The Building Performance Assessment Team 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 sector 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.

Cover Photograph:

Hurricane Fran at landfall, September 5, 1996, 7:45 p.m., e.d.t. National Oceanic and Atmospheric Administration GOES-8 Color Enhanced IR photograph.



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Federal Emergency Management Agency
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Washington, DC
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Atlanta, Georgia

Preface

The Federal Emergency Management Agency (FEMA) Mitigation Directorate administers the floodplain management provisions of the National Flood Insurance Program (NFIP). The Federal Insurance Administration (FIA), also part of FEMA, administers the insurance provisions of the NFIP. Together, the Mitigation Directorate and FIA have been involved in assessing the performance of buildings affected by flooding. To date, FEMA has prepared over 25 building performance assessment, damage assessment, and flood hazard mitigation reports. A list of these reports is provided in Appendix A of this report. Over ten thousand copies of FEMA's report on Hurricane Andrew have been distributed, and the report has been cited by the national media and used by State and local governments and model building code organizations as the basis for changes to building codes and standards. The findings and recommendations of these reports have been used by all levels of government to enhance the performance of buildings subject to natural hazards.

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Executive Summary

On September 5, 1996, Hurricane Fran made landfall near Cape Fear, North Carolina (see Figure 1-1 in Section 1), and generated considerable rainfall, moderately high winds, and storm surge and waves along the coast. The National Oceanic and Atmospheric Administration estimated that Hurricane Fran generated 1-minute sustained winds of 115 miles per hour. Storm surge elevations approached or exceeded National Flood Insurance Program (NFIP) base flood elevations from Kure Beach North, Carolina, to North Topsail Beach, North Carolina, along approximately 50 miles of coastline. The recorded maximum high water, assumed to include wave effects, was 15.4 feet above mean sea level (m.s.l.) at Kure Beach. Although the storm generated high winds along the coast and well inland, severe damage to buildings was concentrated in those areas also impacted by the flood surge and waves. This report focuses on the damages along the North Carolina coast that resulted from flood surge, wave action, erosion, and scour.

On September 12, 1996, the Mitigation Directorate of the Federal Emergency Management Agency (FEMA) deployed a Building Performance Assessment Team (BPAT) to coastal North Carolina to assess damage caused by Hurricane Fran. The team was composed of FEMA Headquarters and regional engineers, a State representative, a consulting structural engineer, a consulting specialist in coastal construction and shoreline erosion, a consulting coastal engineer, the Chief Underwriter of the NFIP, and an engineer from the Insurance Institute for Property Loss Reduction. (See Appendix B for a list of team members.) Some members of the BPAT also represented the American Society of Civil Engineers (ASCE) Committee on Flood-Resistant Design and Construction.

The mission of the BPAT was to assess the performance of buildings on the barrier islands most directly affected by Hurricane Fran and to make recommendations for improving building performance in future events. Better performance of building systems can be expected when the causes of observed failures are determined and repair and reconstruction are undertaken in accordance with recognized standards of design and construction. The immediate goal of the BPAT process is to provide guidance to State and local governments for post-hurricane reconstruction. In addition, the BPAT's findings can enhance future coastal design and construction.

The BPAT made its assessments by conducting site investigations to observe the condition of buildings in selected areas affected by the storm. The scope of the BPAT process did not include recording the numbers of buildings damaged by the hurricane, determining the frequency of specific types of damage, or collecting other data that could serve as the basis of statistical analyses. Collectively, the team invested over 600 hours of effort conducting site investigations, inspecting damages, and preparing documentation. Documentation of observations made during ground-level and aerial surveys included field notes and photographs.

The BPAT assessed the performance of primary structural systems of buildings, i.e., systems that support the building against lateral and vertical loads experienced during a hurricane; building extensions, such as decks, porches, and roof overhangs; nonstructural building components such as breakaway walls and below-building concrete slabs; and on-site building support utilities such as electrical, water, and sewage services. The team focused its efforts on primary structural systems. It is extremely important to note, however, that damage to other portions of buildings often contributed to the damage incurred by the primary structural systems.

The building types observed were primarily one- and two-family, one- to three-story, wood-frame structures elevated on wood pilings. Other types of construction observed included one- and two-family wood-frame slab-on-grade houses, manufactured homes and permanently installed recreational vehicles (RVs) on dry-stack masonry foundations, and a small number of wood-frame structures elevated on solid-perimeter masonry walls. In general, wood-frame structures elevated on piling foundations outperformed structures on all other types of foundations (e.g., masonry pier, continuous masonry wall [crawl space], slab-on-grade) in resisting flood effects, including velocity flow from storm surge, wave action, debris impact, erosion, and scour. The team also observed two commercial structures: a hotel in which dry floodproofing measures helped protect the building from flood damage and a large oceanfront engineered concrete structure that performed well.

Coastal areas from Cape Fear to Cape Lookout experienced significant erosion and scour. Erosion caused by Hurricane Fran was exacerbated by the previous dune erosion caused by Hurricane Bertha, which made landfall in the same area only 2 months earlier. In many locations, especially from Topsail Beach to North Topsail Beach, localized frontal dunes were eroded and the beach profile was lowered 2 to 3 feet. Erosion of up to 4 to 6 vertical feet beneath oceanfront homes was measured in many locations. In addition, localized scour measured at vertical foundation members generally reached one to 1 to 1.5 times the diameter or width of the member. Measurements of combined erosion and scour commonly totaled 5 to 7 vertical feet at oceanfront homes in the area from Topsail Beach to North Topsail Beach. This erosion and scour, added to the average long-term erosion rate of 1 to 2 feet a year, left many oceanfront homes unable to withstand the loads experienced.

The combined effects of erosion and scour resulted in the collapse of well over 100 oceanfront homes with shallow piling foundation systems in the area from Topsail Beach to North Topsail Beach. Several similar oceanfront homes were lost in the Kure Beach-Carolina Beach area. The loss of supporting sand left many short pilings either completely exposed or embedded less than 2 feet. In either case, some pilings gave way. As a result, the remaining foundation pilings were overloaded and the elevated building collapsed. In those rare instances where oceanfront homes were constructed on slabs-on-grade, the loss of supporting sand coupled with the impact of velocity flow and breaking waves on the walls of the structures caused the structures to collapse.

The team observed very little damage in some areas, even oceanfront areas where velocity flows, wave action, and severe erosion occurred. The successful performance of buildings in these areas demonstrates the value of compliance with NFIP requirements regarding the elevation of buildings in coastal flood hazard areas and current State of North Carolina requirements regarding setback and piling embedment depth for oceanfront structures. The observations of the team and the findings of a separate study of piling embedment depth conducted for FEMA on Topsail Island (see Appendix C) suggest that the more stringent embedment depth requirements incorporated into the North Carolina State Building Code in 1986 helped reduce damage. The use of flood-resistant construction materials and techniques, such as in engineered concrete buildings was also effective. In addition, breakaway walls, although generally not installed properly, usually broke away as intended under the impact of flood forces and helped prevent structural damage.

Although the BPAT noted that breakaway walls generally performed as intended, three design and construction errors were observed that are worth noting:

- Breakaway wall panels were often installed immediately adjacent to and seaward of cross-bracing. When the panels broke away, they were pushed against the cross-bracing by flood waters. The resulting force on the vertical surface generated loads far in excess of the design strength of the cross-bracing. As a result, cross-bracing was broken or torn away.

- Utilities were installed on, through, or adjacent to breakaway wall panels. As a result, the panels were often prevented from breaking away cleanly under flood loads, and when they did break away, the utilities were damaged. Much of the utility damage observed was a direct result of improper installation.

- Sheathing was installed on the exterior of breakaway wall panels, continuously over the outside face of vertical foundation members. Sheathing installed in this way inhibits the ability of the breakaway wall panels to break away cleanly.

Most slabs-on-grade below elevated buildings broke apart under the hydrodynamic and impact loads imposed by flood waters and therefore did not transfer those loads to the foundation system. Also, the resulting slab fragments were usually small enough that when they became waterborne debris, they did not damage foundation system components. However, the BPAT observed some design and construction errors worth noting:

- In some instances, slabs were attached to vertical foundation members with steel dowels placed in the piling and cast into the slab. This practice resulted in the transfer of unanticipated loads to the foundation system and may have caused the failure of some foundations systems.

- The slabs observed generally did not have a sufficient number of contraction joints to promote the slab's breaking into small pieces. In one instance, a large section of a slab was observed to have been lifted by flood forces and to have come to rest against vertical foundation members. Although evidence of a cause and effect relationship was not directly observed, slabs that reacted in this way may have led to the failure of some buildings as well.

- The use of wire mesh cast into slabs further complicated matters by holding pieces of the slabs together after the slabs had fractured.

- Concrete collars were occasionally placed around pilings during the construction of slabs. Although the collars were intended to provide stability, they increased wave loads and scour by presenting larger obstructions to flow. Also, once the underlying sand was removed by erosion, the collars increased the dead weight of the pilings to which they were attached.

Utilities that were not installed in a manner that afforded the greatest extent of flood protection possible were damaged. Although portions of most utility services must extend below the flood level, many simple techniques are available to minimize or eliminate damages. Observed damage to water, sewage, electrical, telephone, and cable TV services could have been avoided. Septic tanks were routinely left exposed by storm-induced erosion and scour, and their connections to buildings were severed. The tanks were then filled with flood water and debris.

On oceanfront homes, many porches, decks, and roof overhangs supported on vertical foundation members collapsed or became structurally unsound. Similar failures occurred in the porches, decks, and roof overhangs attached to some inland homes. These failures were observed in both new and old structures. The vast majority of the vertical foundation members were found to have been embedded only 4 to 5 feet below existing grade without any regard for erosion or scour. In a few situations, undersized vertical support members, usually measuring 4 inches by 4 inches or 6 inches by 6 inches, were shattered, probably by the impact of waterborne debris.

Many manufactured homes and permanently installed RVs were installed on dry-stack masonry block foundations with metal tiedown straps attached to ground anchors. This method of installation performed very poorly. The failure of these foundations resulted in the loss of approximately 50 percent of the manufactured homes and RVs observed in the Surf City and North Topsail Beach areas. The causes of failure observed by the BPAT were undermining of the dry-stack block by scour resulting from relatively shallow velocity flow, failure of the tiedown straps due to corrosion from salt spray, and pullout of the ground anchors. Pullout of ground anchors occurred when the pullout resistance of the soil was exceeded because of improper anchor selection and/or saturation of the restraining sandy soil when the site flooded.

The BPAT developed recommendations for reducing future hurricane damage. The recommendations address areas of concern such as building materials (including corrosion protection for metal structural components, e.g., hurricane clips, straps, and fasteners), design practices, construction techniques, and quality of construction. The recommendations presented in this report are applicable in other communities that experience similar coastal flooding.

This report presents the BPAT's observations of the successes and failures of buildings that experienced the flood effects of Hurricane Fran, comments on building failure modes, and provides recommendations intended to enhance the performance of buildings in future hurricanes.

1 Introduction

1.1 Purpose

The purpose of this report is to present the observations of the Federal Emergency Management Agency's (FEMA's) Building Performance Assessment Team (BPAT) regarding the successes and failures of buildings that experienced the wind and flood effects of Hurricane Fran in North Carolina, to comment on the failure modes of damaged buildings, and to provide recommendations for improvements intended to enhance the performance of coastal buildings in future hurricanes.

1.2 Storm Conditions

On September 5, 1996, Hurricane Fran made landfall in the vicinity of the Cape Fear, North Carolina (see Figure 1-1). According to the National Hurricane Center, Fran was ranked as a Category 3 (major) hurricane on the Saffir-Simpson Scale. Hurricane Fran was the most intense hurricane to make landfall along the U.S. mainland during 1996. Although Fran's destructive storm surge, waves, and winds impacted the immediate coastal areas east and north of Cape Fear, heavy rainfall and high winds occurred well inland and resulted in riverine flooding and wind damage to residential and commercial buildings, manufactured homes, trees and crops, and power distribution systems in North Carolina, Virginia, West Virginia, and Maryland. Much of the wind-realted damage was not caused directly by the wind but by wind-downed trees. In areas where soils were saturated by the heavy rainfall, many trees were unable to resist the high winds and caused extensive damage when they fell.

The National Hurricane Center and the National Weather Service estimated that Hurricane Fran's maximum 1-minute sustained wind speed was 115 miles per hour (mph). It appears that Hurricane Fran may have reached design wind speeds (110 mph, fastest mile for 50-year return frequency) in a small area along the immediate oceanfront near Figure Eight Island. However, most coastal buildings in the study area appear to have received less than design wind speeds. A peak gust of 95 mph was recorded 940 feet from the ocean in Kure Beach. Although the storm generated high winds along the coast and well inland, severe damage to buildings was concentrated in those areas also affected by the storm surge and waves.

Independent of the BPAT process, FEMA's Mitigation Directorate and the Federal Insurance Administration conducted a high water mark survey in the wake of Hurricane Fran from just west and south of Cape Fear to just west of Cape Lookout. The goal of the survey was to determine and map approximate high water mark elevations that indicate the stillwater storm surge elevation and the combined effect of storm surge and waves in areas significantly affected by Hurricane Fran. The resulting historical record will prove useful to FEMA in the revision of Flood Insurance Studies and to the insurance industry in the settlement of claims regarding flood and wind damage. Selected elevation measurements made during this survey are shown in Figure 1-1. Storm surge elevations approached or exceeded National Flood Insurance Program (NFIP) Base Flood Elevations (BFEs) from Kure Beach to North Topsail Beach, along approximately 50 miles of coastline. As shown in the figure, a maximum storm surge elevation of 11.9 feet above mean sea level (m.s.l.) — as measured inside a structure — was recorded at Figure Eight Island, North Carolina. The

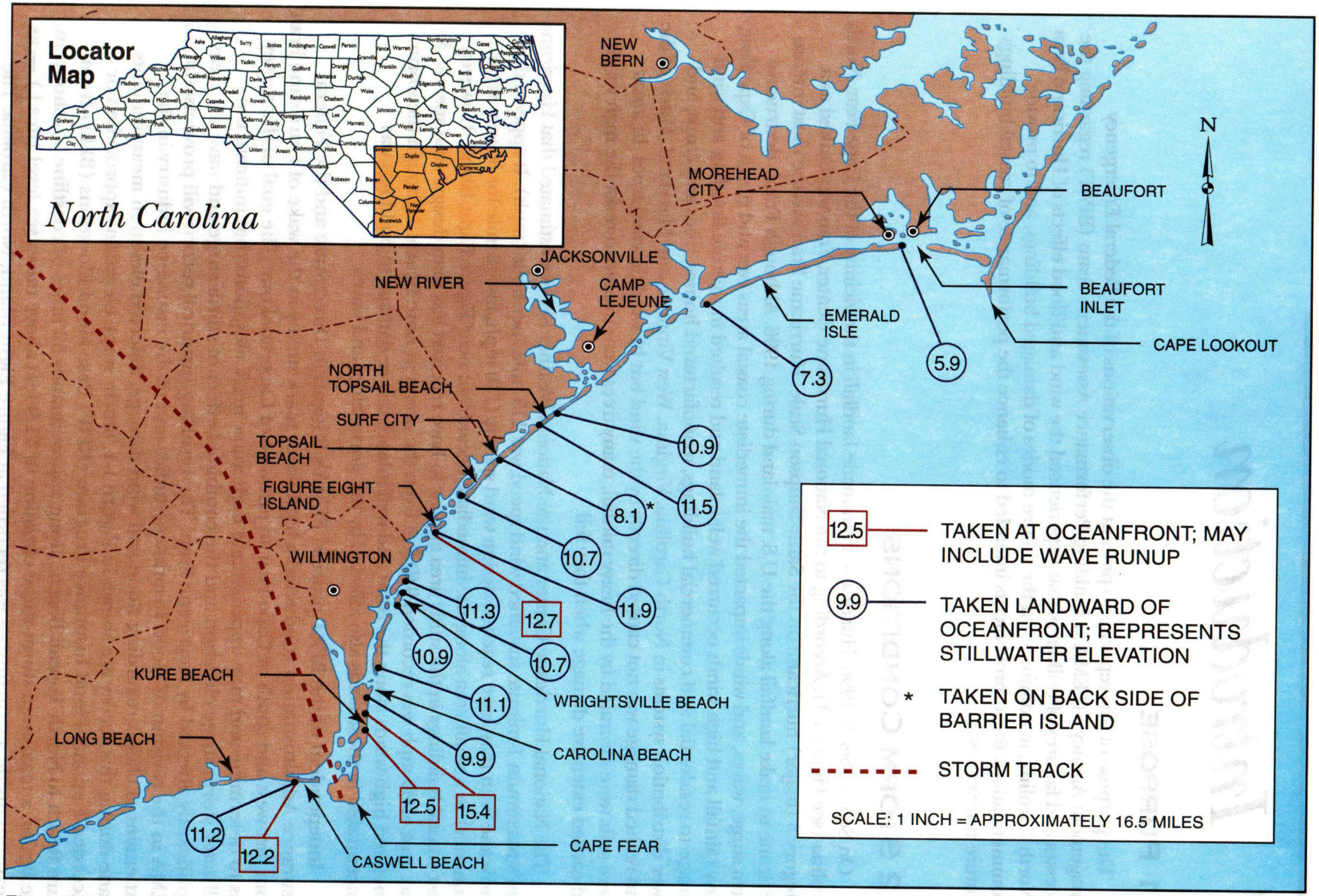

Figure 1-1 *High water mark elevations, in feet above Mean Sea Level, surveyed after Hurricane Fran.*

maximum recorded high water mark of 15.4 feet m.s.l. (assumed to reflect storm surge plus wave height) was at the southern end of Kure Beach, North Carolina.

The severity of erosion of oceanfront sand dunes is closely related to the storm surge elevation at the shoreline. It is reasonable to assume that dune erosion due solely to Fran was a 100-year event. However, 2 months prior to Fran, Hurricane Bertha made landfall in the same area. Wind speeds and water levels were significantly less than those associated with Fran and significantly below design conditions. Storm-induced dune erosion is at least partly temporary, but there had been insufficient time for much recovery following Bertha's estimated storm surge of 6 to 9 feet m.s.l. The cumulative effect of back-to-back hurricanes appears to have caused dune erosion distances in excess of what would be expected to occur in a single 100-year storm surge.

This report focuses on the damages along the North Carolina coast that resulted from storm-induced flood surge, wave action, erosion, and scour.

1.3 Building Siting and Construction Regulations

Building construction regulations on the North Carolina coast have been established by the North Carolina Coastal Area Management Act (CAMA), the North Carolina State Building Code, and the NFIP. CAMA identifies ocean hazard areas, establishes oceanfront setback lines for new construction, and protects sand dunes. The State Building Code regulates most structural requirements. NFIP Flood Insurance Rate Maps (FIRMs) identify flood hazard areas and provide BFEs. BFEs are used to establish minimum floor elevations for buildings in 100-year flood hazard areas and other prescriptive and descriptive requirements of the NFIP. State requirements regarding most other construction criteria are more stringent than those of the NFIP.

1.3.1 North Carolina Coastal Area Management Act

In 1979 CAMA identified ocean hazard areas along the North Carolina coastline. All new buildings were required to be set back from the seaward line of stable dune vegetation at least 30 times the long-term erosion rate determined by the North Carolina Division of Coastal Management (see Figure 1-2 A). A minimum erosion rate of 2 feet per year was adopted. Additional setbacks were required on the largest primary or frontal sand dunes. On previously subdivided lots too small to meet the setback requirement, exemptions were allowed for single-family houses as close as 60 feet from the vegetation line. In 1985 the minimum setback distance for commercial buildings larger than 5,000 square feet was increased to 60 times the long-term erosion rate (see Figure 1-2 B), with additional exemptions where the rate is greater than 3.5 feet per year.

1.3.2 North Carolina State Building Code

The North Carolina State Building Code is based on the Standard Building Code with significant revisions adopted by the North Carolina Building Code Council. A separate Residential Building Code provides more prescriptive criteria for one- and two-family dwellings and is now based on the Council of American Building Officials (CABO) Code with substantial amendments by the Council. Most of the buildings observed near the coast had been constructed under the Residential Code, which was first adopted in the mid-1960's and has undergone several major revisions. After seven major hurricanes affected the North Carolina coast in the 1950's, the

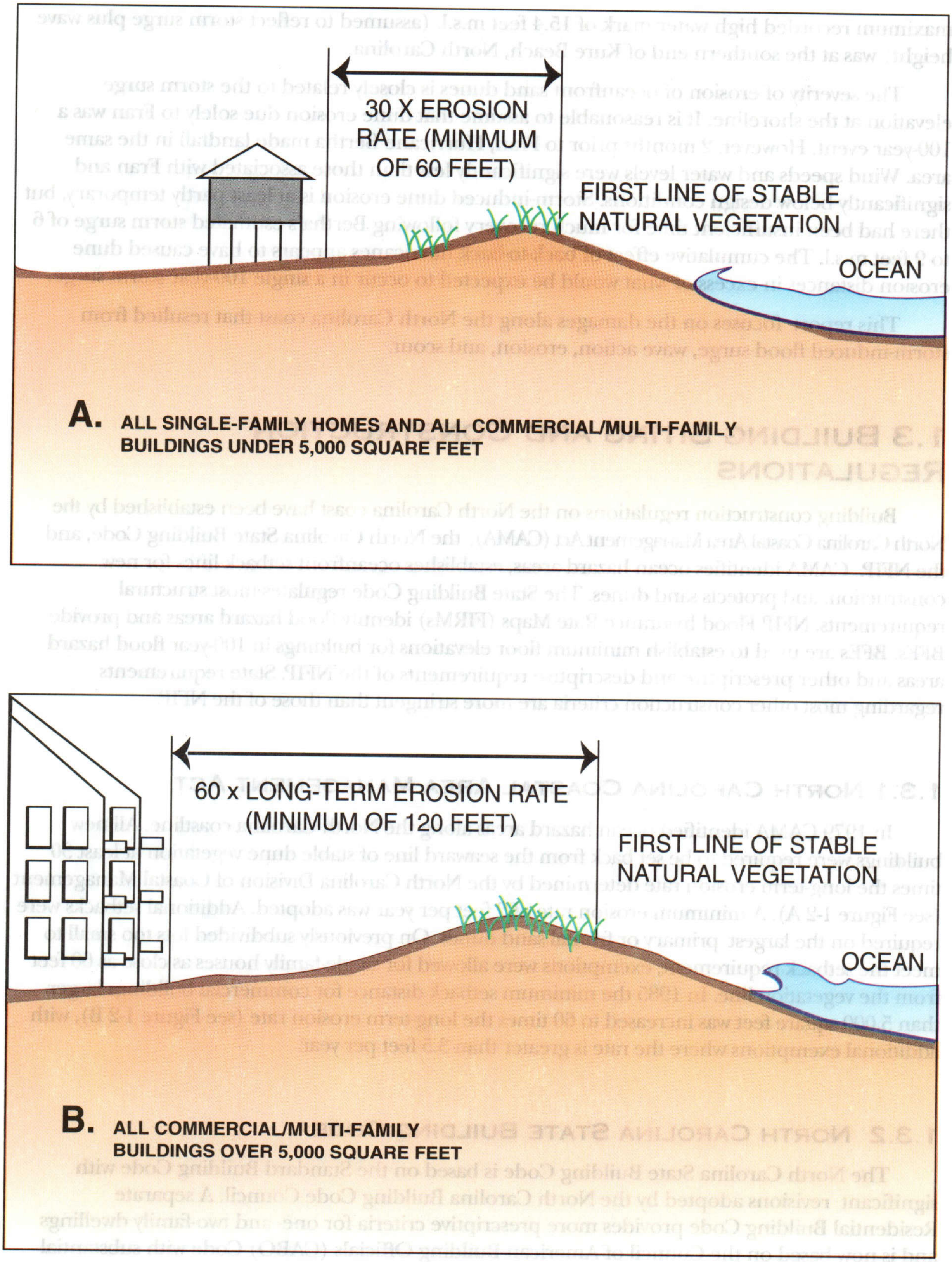

Figure 1-2 *Minimum oceanfront setback requirements under the North Carolina Coastal Area Management Act.*

Council adopted specific hurricane-resistant criteria for small residential buildings on the barrier islands. These were initially an optional appendix but soon became mandatory, with enforcement by local building officials. With a push from the State Building Code, building designs quickly shifted away from low floor elevations with shallow foundations to piling foundations elevated for underhouse parking. Since the 1960's, most houses on the barrier islands have been constructed on pilings.

The State Building Code initially required pilings to be embedded 8 feet below grade. Later, it became apparent that this piling penetration requirement was inadequate for erosion-prone oceanfront buildings. The Code was revised on January 1, 1986, to require piling foundations in all coastal high hazard areas (NFIP V zones) and ocean hazard areas (identified by CAMA). Buildings constructed closer to the seaward edge of the vegetation line than 60 times CAMA's long-term erosion rate are now required to have pilings extending to -5.0 feet m.s.l. or 16 feet below grade, whichever is less. At the same time, requirements for cross-bracing between pilings were added to improve wind resistance, making buildings with longer pilings readily distinguishable from older buildings on unbraced pilings with shallower embedment.

Wind-resistant construction techniques emphasizing improved connections from roof to foundation were in standard practice before 1970. Major increases in the wind criteria in the Residential Building Code have already been adopted and are scheduled to take effect sometime in 1997. The new criteria will, for the first time, apply up to 100 miles inland from the coast, rather than only on the barrier islands.

1.3.3 National Flood Insurance Program

All communities on North Carolina barrier islands participate in the NFIP. The NFIP was created by an act of Congress in 1968 to make flood insurance available to property owners in communities that agree to enact and administer floodplain management regulations that meet program requirements. The regulations require that new and substantially improved buildings in floodprone areas be built in such a manner as to reduce flood hazards and loss of life and property resulting from floods. In coastal areas, this means that buildings must be adequately elevated and protected from the effects of high-velocity flood flow. In V zones, buildings must be elevated on piling foundations and the lowest horizontal structural member of the lowest floor must be at or above the BFE. In addition, the area below the building must be free of obstructions or enclosed by non-supporting breakaway walls intended to collapse under wind an water loads without causing damage to the foundation or the elevated portion of the building. In coastal A zones, which are less likely to be affected by high-velocity flow, the lowest floor of the building must be at or above the BFE and the areas below the BFE can be enclosed with non-breakaway walls.

In the mid-1970's, FEMA issued a FIRM for each of the barrier island communities in North Carolina. When the communities began implementing their required floodplain management regulations in the late 1970's, the minimum lowest floor elevation requirements based on the BFEs shown on the FIRMs superseded the previous State Building Code requirement that the lowest floor be 2 feet above the highest known historical water mark. The resulting common use of piling foundations with underhouse parking generally placed the elevated floors well above minimum elevations required by the NFIP. However, finished underhouse enclosures constructed with non-load-bearing walls were common in older buildings and, in some communities, in new buildings.

Concerns about the accuracy of the information shown on FIRMs for areas near the ocean had been previously raised in North Carolina communities affected by Hurricane Fran. According to the FIRMs, many oceanfront lots are within B zones and C zones, outside the 100-year flood hazard area. In general, minimal elevation requirements at the building sites on these lots did not include consideration of waves above the stillwater flood elevation. The accuracy of the FIRMs and the steps being taken by FEMA in response to this issue are discussed in Section 2.10 of this report.

An important provision that communities participating in the NFIP must include in their floodplain management regulations is the requirement that substantially damaged buildings, if restored, meet the same requirements imposed for new buildings. The NFIP defines substantial damage as "damage of any origin sustained by a structure whereby the cost of restoring the structure to its before damage condition would equal or exceed 50 percent of the market value of the structure before the damage occurred." The BPAT observed several hundred buildings in the area between Kure Beach and North Topsail Beach that may have been substantially damaged. The vast majority of these were oceanfront residential buildings removed from their foundations by flood forces.

2 *Site Observations*

2.1 Assessment Team Approach

On September 12, 1996, the FEMA Mitigation Directorate deployed a BPAT to coastal North Carolina to assess damage caused by Hurricane Fran. The team was composed of FEMA Headquarters and regional office engineers, a State representative, a consulting structural engineer, a consulting specialist in coastal construction and shoreline erosion, a consulting coastal engineer, the Chief Underwriter of the NFIP, and an engineer from the Insurance Institute for Property Loss Reduction. (See Appendix B for a list of team members.) Some members of the BPAT also represented the American Society of Civil Engineers (ASCE) Committee on Flood-Resistant Design and Construction.

The mission of the BPAT was to assess the performance of buildings on the barrier islands most directly affected by Hurricane Fran and to make recommendations for improving building performance in future events. Better performance of building systems can be expected when the causes of observed failures are determined and repair and reconstruction are undertaken in accordance with recognized standards of design and construction. The immediate goal of the BPAT process is to provide guidance to State and local governments for post-hurricane reconstruction. In addition, the BPAT's findings can enhance future coastal design and construction.

The BPAT made its assessments by conducting site investigations to observe the condition of buildings in selected areas affected by the storm. The scope of the BPAT process did not include recording the numbers of buildings damaged by the hurricane, determining the frequency of specific types of damage, or collecting other data that could serve as the basis of statistical analyses. Collectively, the team did invest over 600 hours of effort conducting site investigations, inspecting damages, and preparing documentation. Documentation of observations made during ground-level and aerial surveys included field notes and photographs.

On Friday, September 13, 1996, the BPAT conducted an aerial survey along the North Carolina coast from Wrightsville Beach (in the south) to Emerald Isle (in the north). Ensuing ground observations were made in the area extending from Kure Beach (in the south) to North Topsail Beach (in the north). Figure 2-1 shows the areas where the aerial surveys and ground observations were made. Other communities in the studied area include Carolina Beach, Wrightsville Beach, Topsail Beach, and Surf City. Documentation of observations made during the ground and aerial surveys included field notes and photographs.

The BPAT assessed the performance of primary structural systems of buildings, i.e., systems that support the building against lateral and vertical loads experienced during a hurricane; building extensions, such as decks, porches, and roof overhangs; nonstructural building components such as breakaway walls and below-building concrete slabs; and on-site building support utilities such as electrical, water, and sewage services. The team focused its efforts on primary structural systems. It is extremely important to note, however, that damage to other portions of buildings often contributed to the damage incurred by the primary structural systems.

The building types observed were primarily one- and two-family, one- to three- story, wood-frame structures elevated on wood pilings. Other types of construction observed included one- and two- family wood-frame, slab-on-grade houses, manufactured homes and permanently installed recreation vehicles (RVs) on dry-stack masonry foundations, and a small number of

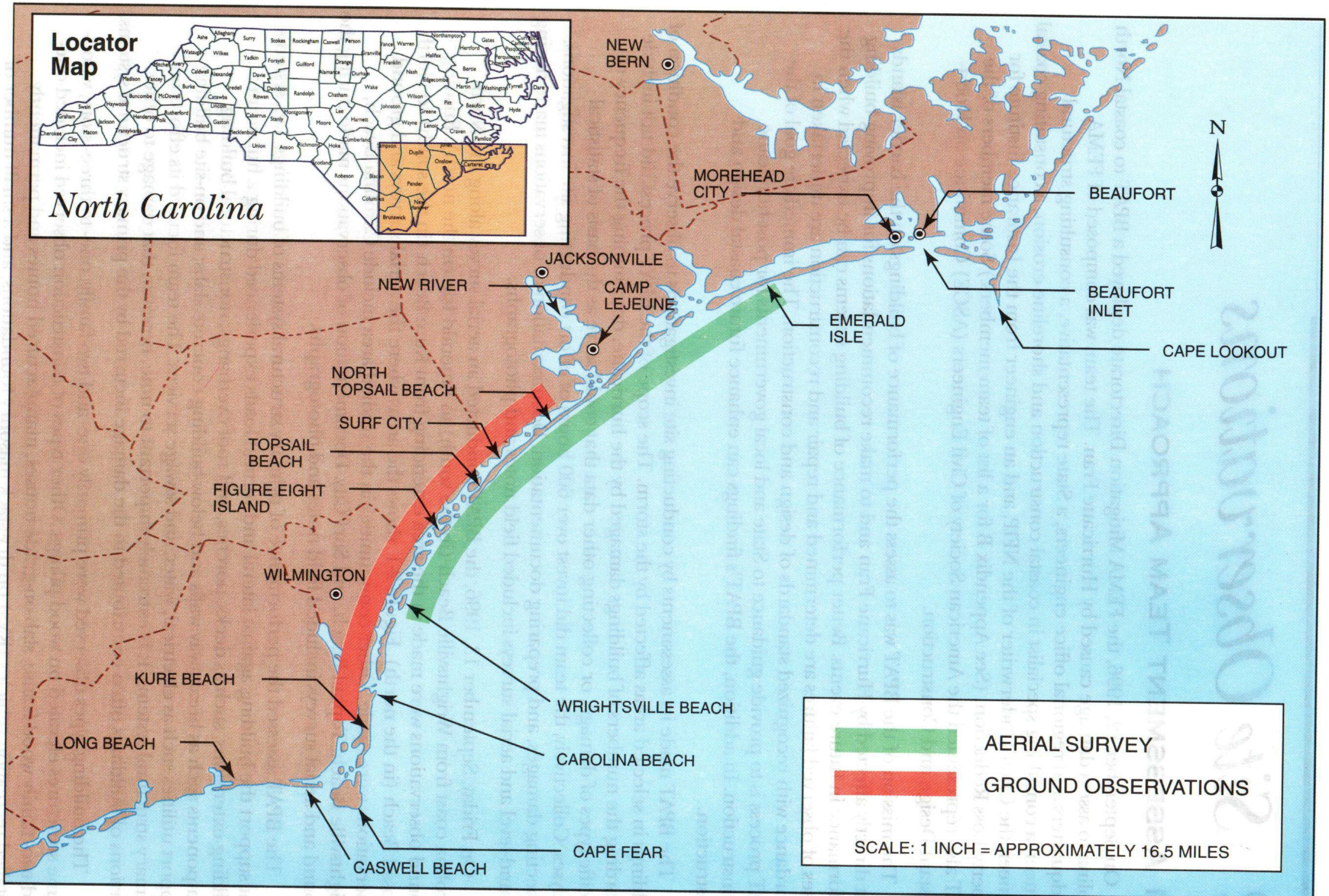

Figure 2-1 *Areas of BPAT aerial survey and ground observations.*

wood-frame structures elevated on solid perimeter masonry walls. In general, wood-frame structures elevated on piling foundations outperformed all other types of foundations (e.g., masonry pier, solid perimeter masonry wall [crawl space], slab-on-grade) in resisting flood effects, including velocity flow, storm surge, breaking waves, debris impact, erosion, and scour. The team also observed two commercial structures: a hotel in which dry floodproofing measures helped protect the structure from flood damage and a large oceanfront engineered concrete building that performed well.

2.2 Erosion and Scour

Oceanfront Residential Buildings

Coastal areas from Cape Fear to Cape Lookout experienced significant erosion and scour. In many locations, especially from Topsail Beach to North Topsail Beach, localized frontal dunes were eroded and the beach profile was lowered 2 to 3 feet. Erosion beneath oceanfront homes averaged 4 to 6 vertical feet (see Figure 2-2). In addition, erosion and localized scour at vertical foundation members was observed to have occurred.

A cursory study of localized scour was performed during the site investigation. Sand surrounding pilings was excavated to identify the maximum localized scour that occurred. From changes in sand color, texture, and bedding, the team determined that, in general, localized scour occurred to a depth of approximately 1 to 1.5 times the diameter or width of the piling (see Figure 2-3). The depth of scour around 8-inch-diameter round pilings and 8-inch x 8-inch square pilings supporting oceanfront structures was measured to be approximately 10 to 11 inches.

Figure 2-2 *Erosion resulted in significant loss of supporting sand, averaging 4 to 6 feet, under oceanfront buildings.*

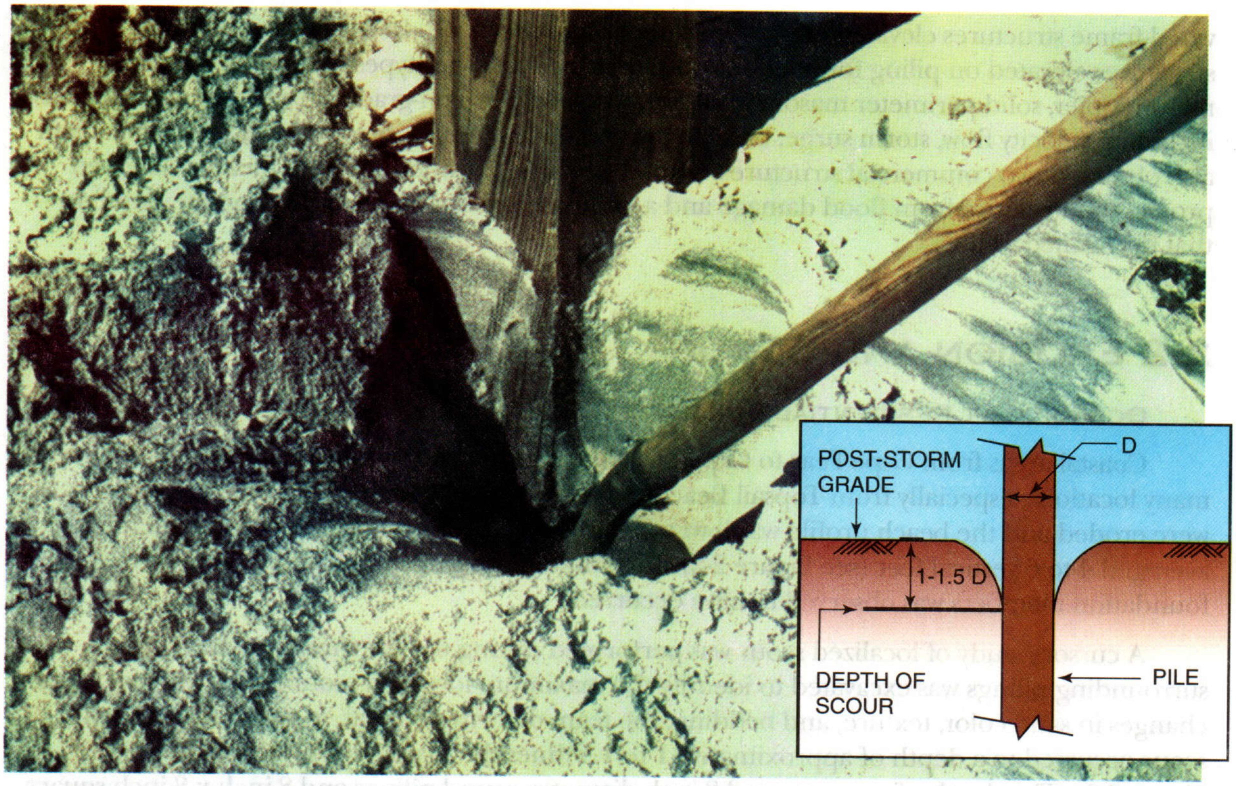

Figure 2-3 Determination of localized scour from changes in sand color, texture, and bedding.

Erosion and scour were commonly observed to total 5 to 7 vertical feet at oceanfront homes in the area from Topsail Beach to North Topsail Beach. This erosion and scour, added to the long-term erosion rate of an average 1 to 2 feet a year, left many homes unable to withstand the loads imposed by flood and wind forces acting simultaneously (see Figure 2-4).

Landward Residential Buildings

No evidence of general erosion was observed in the areas around landward structures, but evidence of localized scour around pilings and other obstructions was plentiful (see Figures 2-5 and 2-6). In general, scour did not result in the failure of the piling foundations of landward structures. However, scour around the vertical members supporting air conditioner platforms and building extensions such as decks, porches, and roof overhangs occasionally decreased the ability of the vertical members to withstand flood forces and led to their collapse.

Figure 2-4 *Loss of the frontal dune and the resulting erosion and scour left many coastal houses unable to resist wind and flood loads acting simultaneously.*

Figure 2-5 *Overwash of barrier islands generated high-velocity flows that caused extensive scour adjacent to large objects.*

Figure 2-6 *The disruption of velocity flows by large, non-breakaway objects generated extensive scour that undermined vertical foundation members and slabs-on-grade.*

2.3 Building Foundation Systems

In assessing the performance of structure foundation systems, the BPAT addressed a variety of issues related to the performance of oceanfront and landward structures: piling and column embedment for structures and their extensions (e.g., utility platforms, decks, porches, and roof overhangs), the grade of lumber used for vertical foundation members, elevation of structures in relation to the flood depth, cross-bracing of vertical support members, and solid perimeter foundation walls on continuous footings. The BPAT also assessed the performance of foundations under manufactured homes and permanently installed RVs.

2.3.1 Piling Embedment for Structural Support

Lack of sufficient embedment of vertical structural foundation members may well have contributed to the collapse of over 100 oceanfront residential buildings (see Figure 2-7). Of those that did not collapse, many were found to be leaning (see Figure 2-8). The majority of these structures met the pre-1986 requirement for an 8-foot embedment of pilings and columns (measured from existing grade). Many front-row houses were placed near or on the landward slope of the frontal dune, where the ground elevations were often 8 to 9 feet m.s.l. As a result, the bottoms of the pilings or columns were at approximately 0 feet m.s.l. (see Figure 2-9)

As noted in Section 1.3.1, the North Carolina State Building Code was revised in 1986 to require that vertical foundation members in erosion-prone areas be embedded 16 feet below existing grade or to -5 feet m.s.l., whichever is shallower. The 1986 requirement was generally successful in protecting structures in areas of low ground elevation, where pilings had to be embedded to -5 feet m.s.l. This is significant because most of the buildings undermined by

Figure 2-7 Over 100 oceanfront houses were washed off their foundations or completely destroyed.

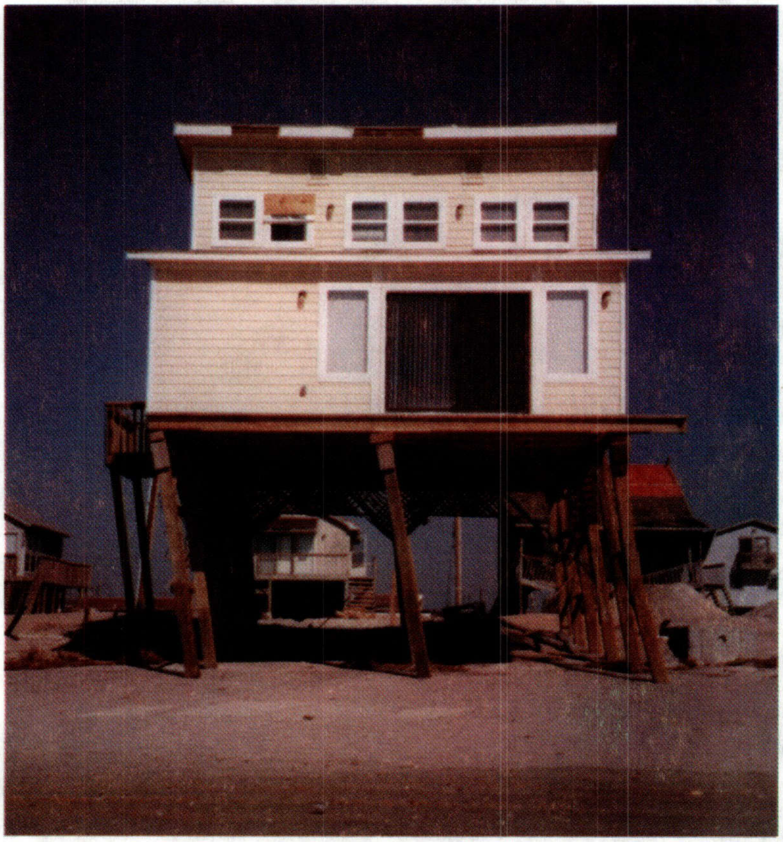

Figure 2-8
Many oceanfront houses built prior to current (1986) North Carolina State Building Code requirements were found to be leaning or destroyed.

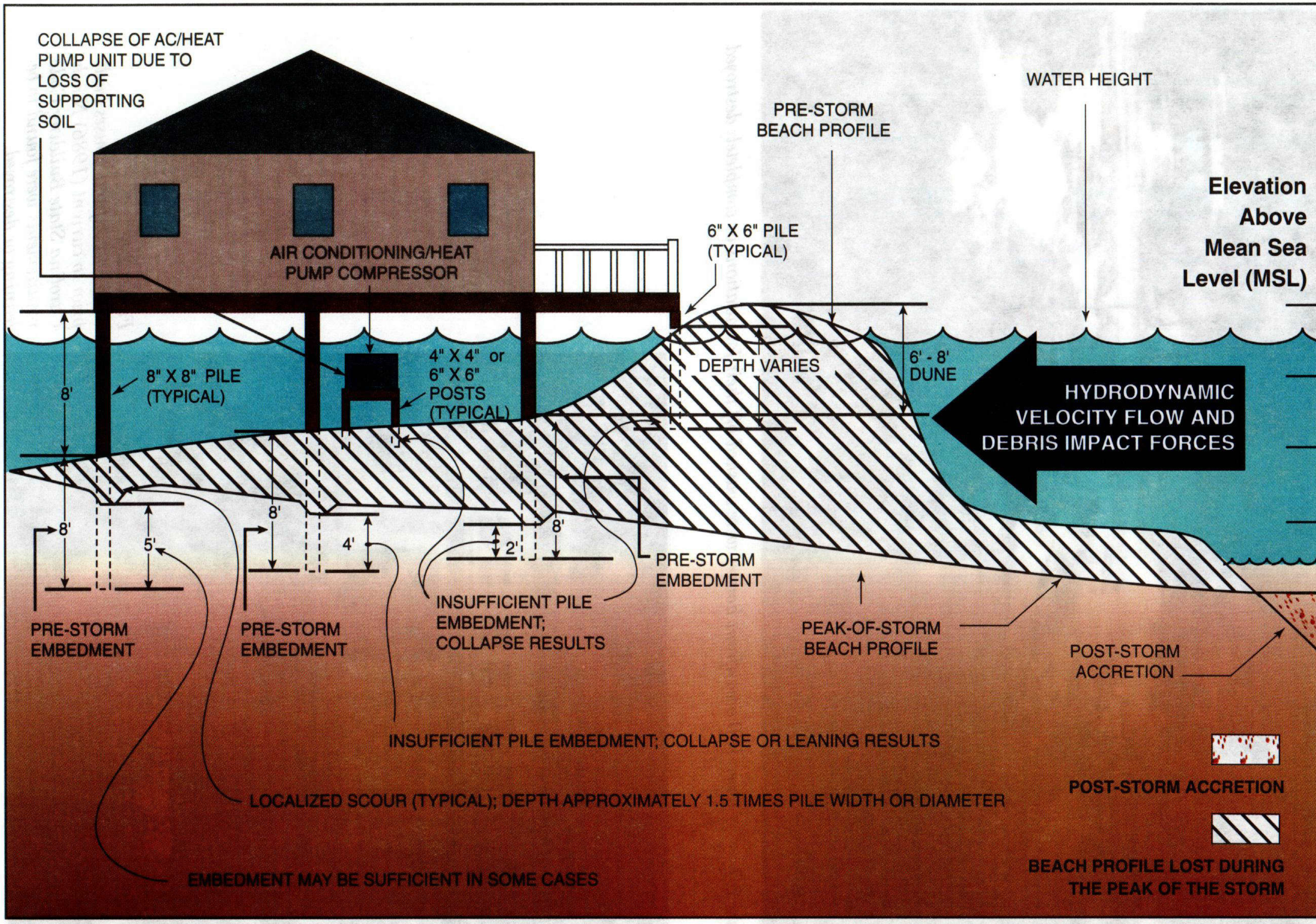

Figure 2-9 *Typical collapse mechanism of post-FIRM building based on pre-1985 embedment requirements in North Carolina coastal areas.*

erosion were in areas where the ground elevations were low. For structures on higher dunes (i.e., where ground elevations exceed 11 feet m.s.l.) the piling embedment requirement changes to only 16 feet below grade. This embedment depth is not sufficient to allow the pilings to survive a similar storm or continuing long-term erosion of moderate to high dunes.

Although post-1986 oceanfront structures generally performed better than oceanfront structures built prior to 1986, several foundations supporting oceanfront structures that were observed to be leaning were suspected of being post-1986 (see Figure 2-10). The remaining embedment depth of the foundation members beneath these structures was not determined by the BPAT; however, for example, with a pre-storm grade of 11 feet m.s.l., erosion of approximately 6 vertical feet to an elevation of approximately 5 feet m.s.l., and localized scour of an additional 1 vertical foot, the vertical foundation members should still have been embedded approximately 9 feet below grade during the height of the storm. This depth should have been sufficient to prevent leaning in many cases. One possible explanation is that the pilings under these leaning structures did not meet the current embedment depth requirement.

To follow up on this issue and investigate the effects of the current North Carolina State Building Code requirements on the performance of foundation pilings, FEMA contracted with Woodward-Clyde Federal Services (W-C) to determine piling embedment depths for oceanfront buildings on Topsail Island, North Carolina, where Hurricanes Bertha and Fran damaged a number of structures. Using aerial photographs, W-C identified 205 post-1986 oceanfront buildings. Of the identified buildings, 92 percent had not sustained any significant foundation damage. The remainder had pilings that were damaged or leaning. W-C conducted tests to determine the embedment depths of selected pilings under 11 of the identified buildings,

Figure 2-10 *One of several buildings observed to be leaning landward that were suspected of having been constructed to current North Carolina State Building Code requirements.*

including 7 leaning buildings, and found that over 80 percent of the tested pilings did not meet the 1986 embedment requirement. The testing procedure and the findings are presented in a separate report prepared by W-C. The Executive Summary from the W-C report is contained in Appendix C of this report. Recommendations based on W-C's findings are presented in Section 3.1.1.

2.3.2 Piling Embedment for Decks, Porches, and Roof Overhangs

Lack of sufficient embedment of vertical foundation members for decks, porches, and roof overhangs attached to oceanfront and landward residential buildings resulted in the collapse of several hundred of these building extensions (see Figure 2-11).

Oceanfront Residential Buildings

Vertical foundation members supporting unroofed decks did not have to meet the pre-1986 State Building requirement for 8-foot piling embedment, nor do they have to meet the post-1986 requirement for 16-foot embedment. Vertical foundation members for covered porches and roof overhangs are supposed to meet the criterion applied to the foundation members for the main structure. The BPAT found that vertical foundation members for decks, porches, and roof overhangs were often embedded to a depth of only 2 to 6 feet below existing grade (see Figure 2-12).

Decks, porches, and roof overhangs were often built on the seaward side of oceanfront structures and were therefore often embedded into the frontal dune (see Figure 2-9). With embedments of only 2 to 6 feet into the dune, the bottoms of the pilings or columns were often at elevations of 4 to 8 feet m.s.l. The remaining embedment depth of those deck, porch, and roof overhang supports that survived the hurricane appears to be as little as 1 to 2 feet in many cases.

Figure 2-11 ***The BPAT observed several hundred decks and porches that collapsed as a result of insufficient foundation support.***

Figure 2-12 *Example of building constructed to current North Carolina State Building Code requirements with insufficient embedment of piles/columns under two-story deck.*

Figure 2-13 *Embedment of deck supports into frontal dune was often shallow. After erosion of the dune, the bottom of the support for this deck was left several feet above grade.*

Since these supports are usually seaward of main structures, they are subject to amounts of storm surge, velocity flow, wave action, vertical erosion, and localized scour at least as great as those that affect the main structure (see Figure 2-13).

In the areas where decks, porches, and roof overhangs were observed, erosion was approximately 7 vertical feet, to an elevation of approximately 4 feet m.s.l. Localized scour of an additional vertical foot would result in total loss of embedment to an elevation of 3 feet m.s.l. during the peak of the storm (see Figure 2-9). When vertical foundation members lost their ability to support the structure above, the deck, porch, or roof overhang often collapsed, damaging the structure to which it was attached and becoming waterborne debris that was then carried into the main structure or nearby structures (see Figure 2-14). This damage may have contributed to the collapse of some buildings.

For decks, porches, and roof overhangs to have survived, their supporting vertical members would have to have had a post-storm embedment of approximately 8 feet below grade. The findings of the team regarding decks, porches, and roof overhangs are particularly important because it appears that the construction of multilevel decks and porches supporting roof overhangs is becoming increasingly popular in oceanfront architecture (see Figure 2-15). Usually, these building extensions are larger and more complex than required solely for building access.

Landward Residential Buildings

Decks, porches, and roof overhangs supported by vertical foundation members were observed to have been installed on many landward homes on barrier islands. In general, these building extensions were not protected from localized scour caused by velocity flow. The loss of

Figure 2-14 ***Storm-generated debris impacted nearby structure.***

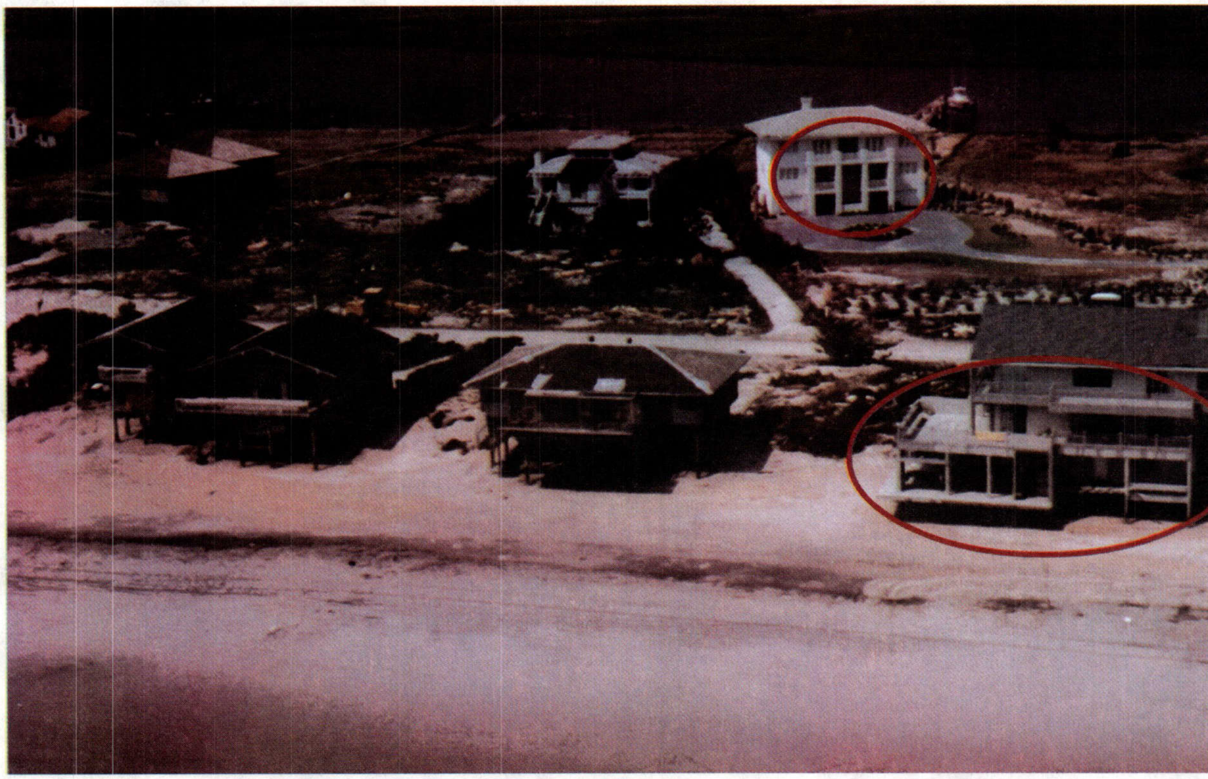

Figure 2-15 *As shown by this post-Fran photograph taken at Figure Eight Island, North Carolina, a current architectural trend is the construction of multistory decks supporting roof overhangs.*

supporting soil due to scour often left vertical foundation members of decks, porches, and roof overhangs unable to resist the velocity flow, wave action, and debris impact forces that occurred in coastal areas (see Figure 2-16). Vertical foundation members were found to not be embedded to the same depth as the main building supports. It was reported that the North Carolina State Building Code requires vertical supports for the main structure outside of a V Zone to be embedded 8 feet below existing grade, but that no such requirement was enforced for building extensions such as decks and, in some instances, porches and roof overhangs.

2.3.3 Debris Impact on Vertical Foundation Members

Debris observed by the BPAT included 8-inch x 8-inch pilings up to 20 feet long (see Figure 2-14), round 6-inch diameter posts, septic tank sections (see Figure 2-17), materials from collapsed adjacent houses, the remains of collapsed decks (from the house impacted and from adjacent and other nearby oceanfront houses — see Figure 2-18), and portions of collapsed fishing piers. An extreme example of debris impact is shown in Figure 2-19. Although debris impact generally was not suspected of causing significant failure of vertical foundation members, it did damage foundation cross-bracing, as discussed in Section 2.3.6.

2.3.4 Grade of Lumber Used for Timber Pilings and Cross-Bracing

To resist coastal flood forces, timber pilings depend largely on their dimensions and depth of embedment, but another important factor is the grade of lumber used. Lower grades of lumber may have knots, cracks, or other imperfections that contribute to failure when the piling is acted on by water and debris impact forces. For example, Figure 2-20 shows a failed timber

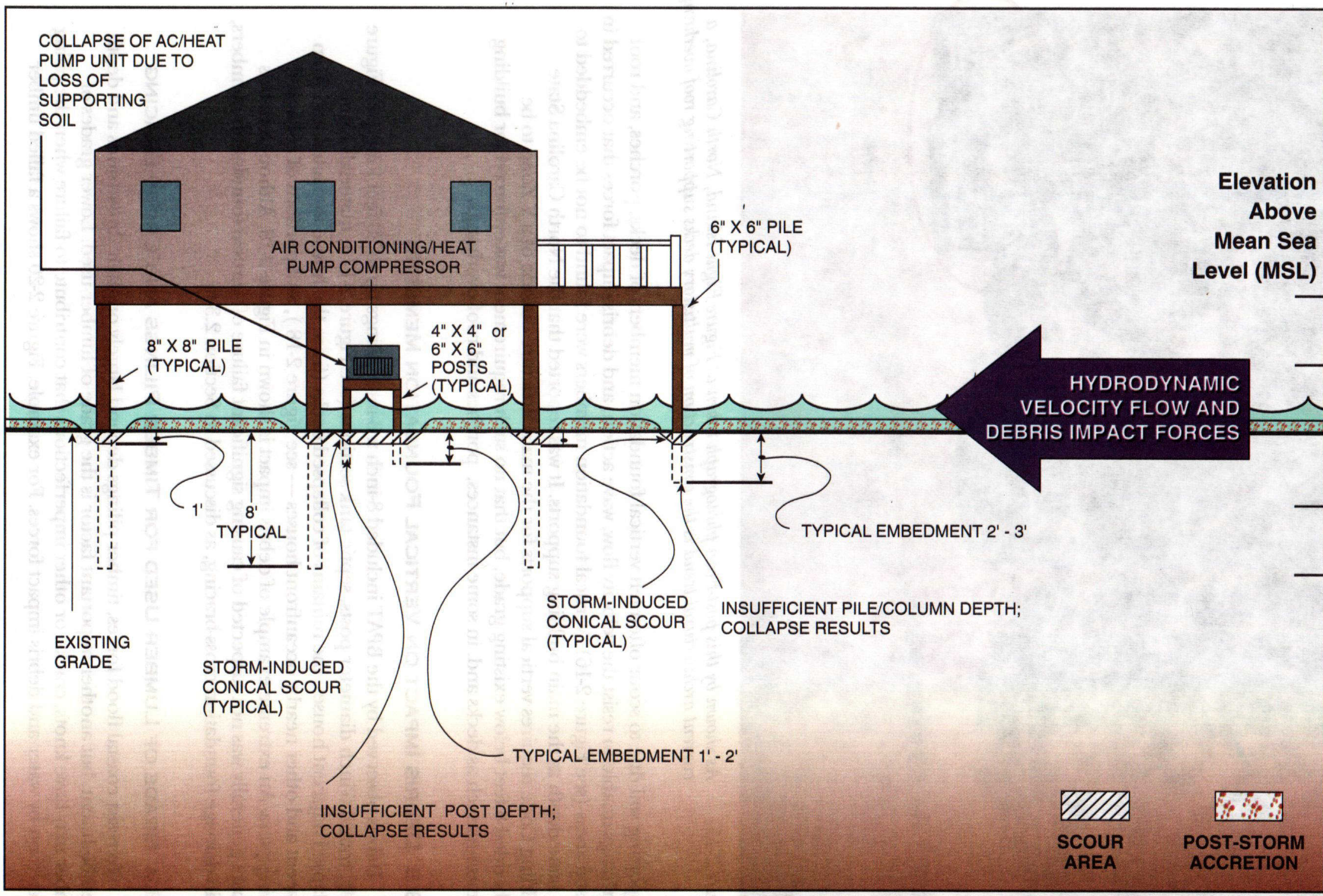

Figure 2-16 *Typical failure of deck / roof overhang and air conditioning / heat pump compressor platform for landward home.*

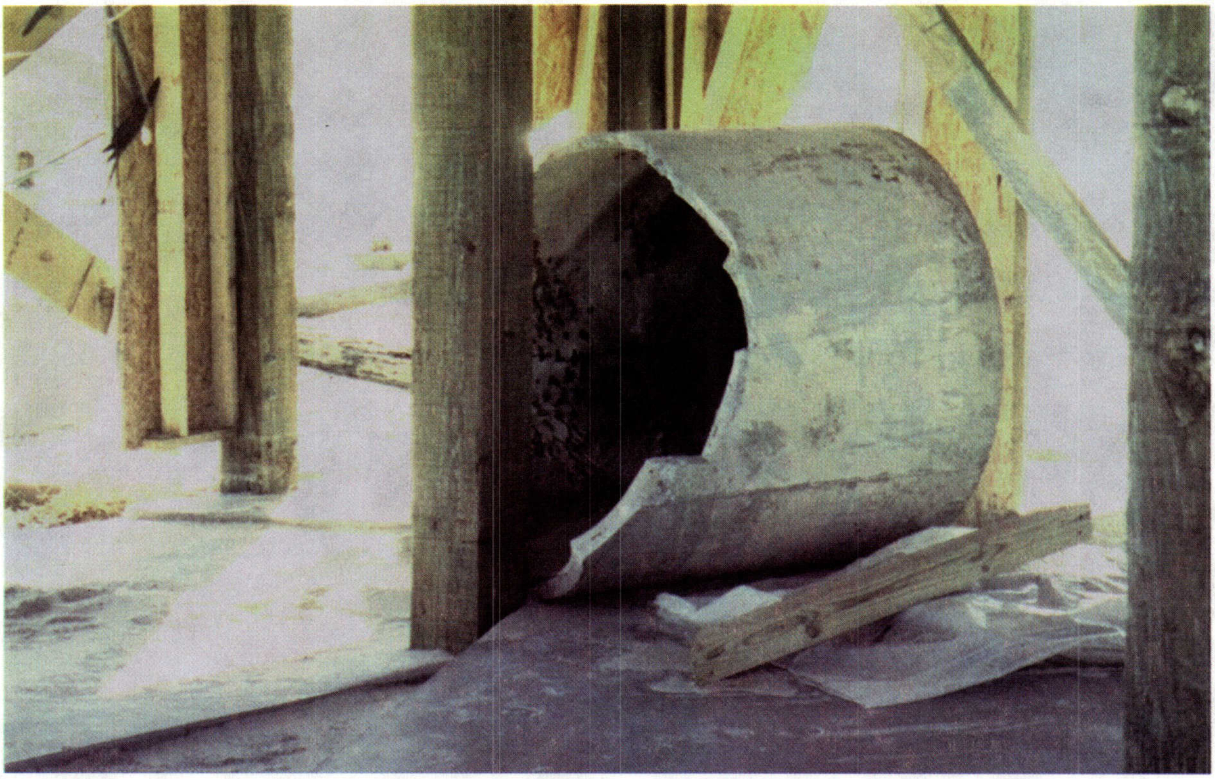

Figure 2-17 Precast concrete ring section of septic tank became waterborne debris, impacting building foundation members.

Figure 2-18 Impact of debris from a damaged deck appeared to have broken cross-bracing.

Figure 2-19 Example of extreme impact — two houses floated and pushed into another house.

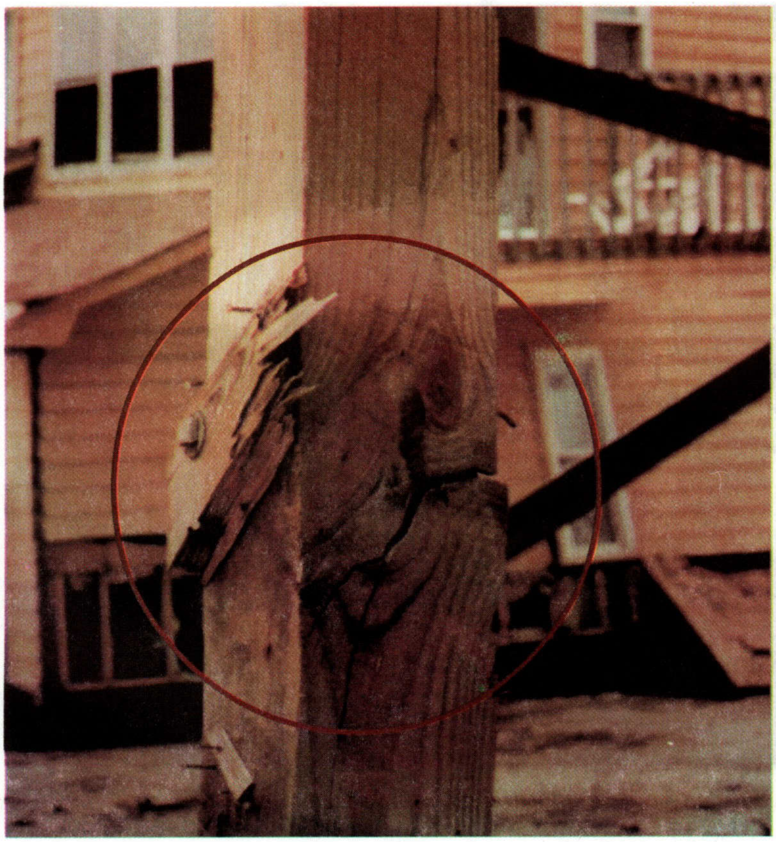

Figure 2-20
Example of broken piling. The piling broke at the location of several knots (circle), where cross-bracing was attached (note remaining bolt and piece of bracing).

piling whose strength was compromised by closely spaced knots. Failures of this type were not widely observed by the BPAT but, as indicated by Figure 2-20, are a potential problem that can lead to structure failure and even collapse.

2.3.5 Elevation of Buildings

NFIP regulations require that structures in Coastal High Hazard Areas (V zones) be elevated so that the lowest horizontal structural member of the lowest floor is at or above the BFE shown on the FIRM in effect at the time of construction. In the areas visited by the BPAT, structures in V zones appeared to have been built in compliance with this requirement. For structures in A zones, the NFIP regulations require that the lowest floor be elevated to or above the BFE; no requirements are imposed for structures in B, C, and X zones. Although elevating on open foundations with lowest horizontal structural members at or above the BFE is not required outside of V zones, this practice was widely observed in A, B, C, and X zones on the barrier islands within the study area (see Figure 2-21).

Homes in A, B, C, and X zones were often elevated 8 to 9 feet on embedded piling foundations to allow below-building parking and storage. This practice undoubtedly resulted in less damage than would have occurred if the lowest floors of these structures had been elevated only to the BFE in A zones and not elevated at all in B, C, or X zones. However, the areas below many of these elevated buildings had been enclosed with nonstructural wall panels and were being used for living space rather than solely for parking, storage, and building access. When acted on by velocity flows, the wall panels often collapsed. As a result, the affected buildings incurred extensive nonstructural damage.

Figure 2-21 *Survival of this properly elevated North Carolina State Park public rest room demonstrates the State's commitment to proper construction in coastal areas.*

2.3.6 Cross-Bracing Below Elevated Buildings

The BPAT found widespread damage to 2x cross-bracing, especially below oceanfront homes, including braces split along the grain, braces shattered across the grain, and pull-through of brace attachment bolts. (The term "2x" refers to lumber with nominal dimensions of 2 inches x 8 inches , 2 inches x 10 inches, etc.) Wave and debris impact appeared to have generated the greatest amount of damage. As noted in Section 2.3.3, the debris observed by the team included 8-inch x 8-inch pilings and 6-inch diameter posts, septic tank sections, and materials from collapsed houses, decks, and fishing piers. These types of objects can result in point-loading impacts that generate loads well beyond the material strengths of 2x cross-bracing. Although damage was most prevalent in areas where extensive debris was observed, no definitive cause and effect relationship could be established

Debris was also observed lying against or draped over cross-bracing. When exposed to the hydrodynamic loads imposed by flood waters, debris draped over or lying against cross bracing increases the drag coefficient and the area of the obstruction, thereby increasing the lateral loads transferred to the foundation. Although cross-bracing was frequently damaged, this damage did not appear to result in damage to the elevated building as long as the pilings were embedded deep enough to resist erosion.

2.3.7 Solid Perimeter Masonry Foundation Walls Supported on a Continuous Footing

Solid perimeter masonry foundation walls supported by a continuous footing are not a prevalent form of construction on the barrier islands within the study area. Where this type of construction was found in areas of high-velocity flow, poor building performance was generally observed. High-velocity flood flows moving around the perimeter foundation walls generated localized scour that propagated to a depth greater than that of the bottom of the continuous footing supporting the perimeter foundation wall. Once the soil underlying the footing was lost, the footing and foundation wall collapsed, leaving the floor diaphragm unsupported (see Figure 2-22). This scenario occurred not just in oceanfront areas, but also in areas set back more than 600 feet from the ocean shoreline (see Figure 2-23). Even in areas of relatively shallow flooding (1 to 2 feet deep) and where deposition of beach sand had occurred, scour and collapse of solid perimeter foundation walls was observed.

2.3.8 Manufactured (Mobile) Home and Permanently Installed RV Foundations

Many manufactured homes and RVs were significantly damaged by Hurricane Fran. The vast majority of manufactured homes and RVs were anchored on top of dry-stack masonry block piers and anchored with metal straps and helical anchors (2 feet long with 3-inch helical plates) embedded into the sand (see Figure 2-24). While most were exposed to relatively shallow flood depths (1 to 3 feet), many were moved 50 feet or more laterally and flipped over by wind forces acting alone or in conjunction with flood forces (see Figures 2-24 and 2-25).

The team observed depressions from 1 to 2 feet deep left by localized scour within the original footprint of the structure (see Figure 2-25). The scour may have been caused by numerous factors, including a discontinuity between the stabilizing root mat provided by grass surrounding the site and the corresponding loss of unprotected sand beneath the home, the creation of a large obstruction by the solid skirt surrounding the foundation system, and localized scour around the dry-stack masonry piers supporting the structure.

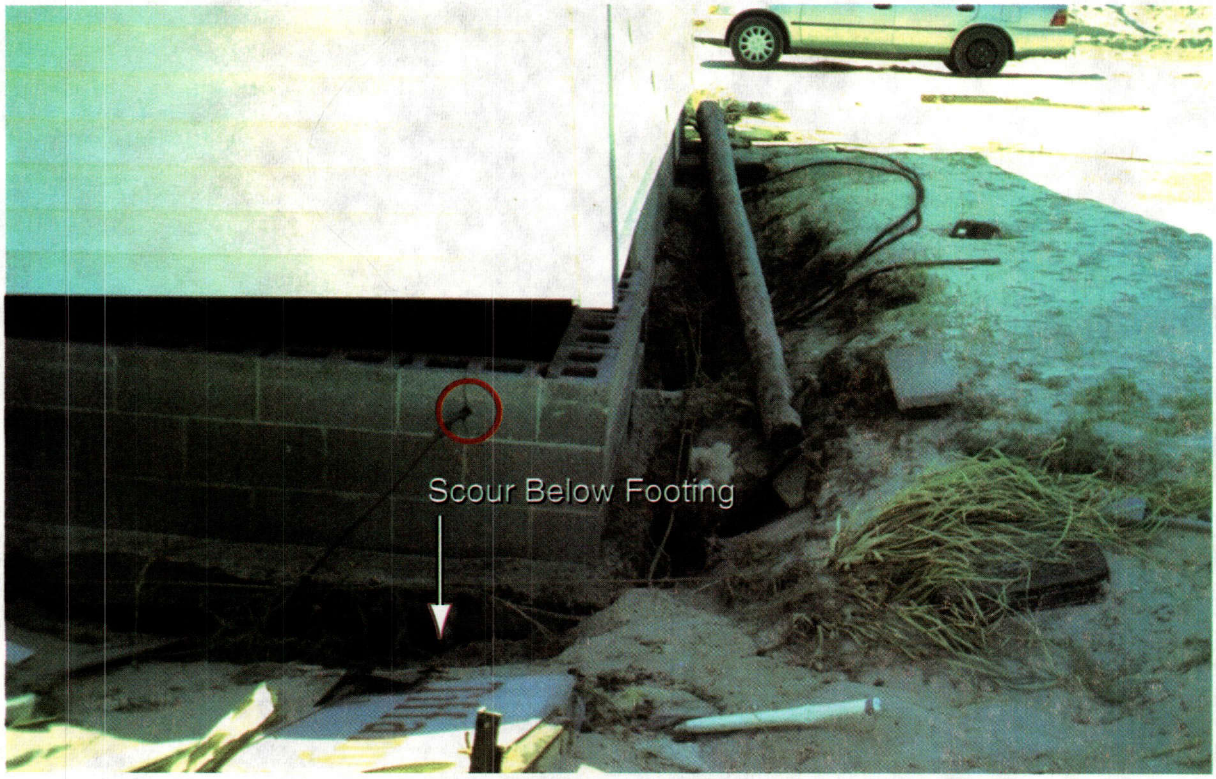

Figure 2-22 *Collapse of footing and foundation wall under elevated wood-frame building. Collapse resulted because obstruction of flow by building caused scour to extend below the bottom of the footing (arrow). Note propane gas line (circled) extending through foundation wall.*

Figure 2-23 *Catastrophic failure of landward building constructed on masonry wall and slab-on-grade foundation. Failure resulted because obstruction of flow by building caused extensive scour. Note compressor collapsed into scour hole.*

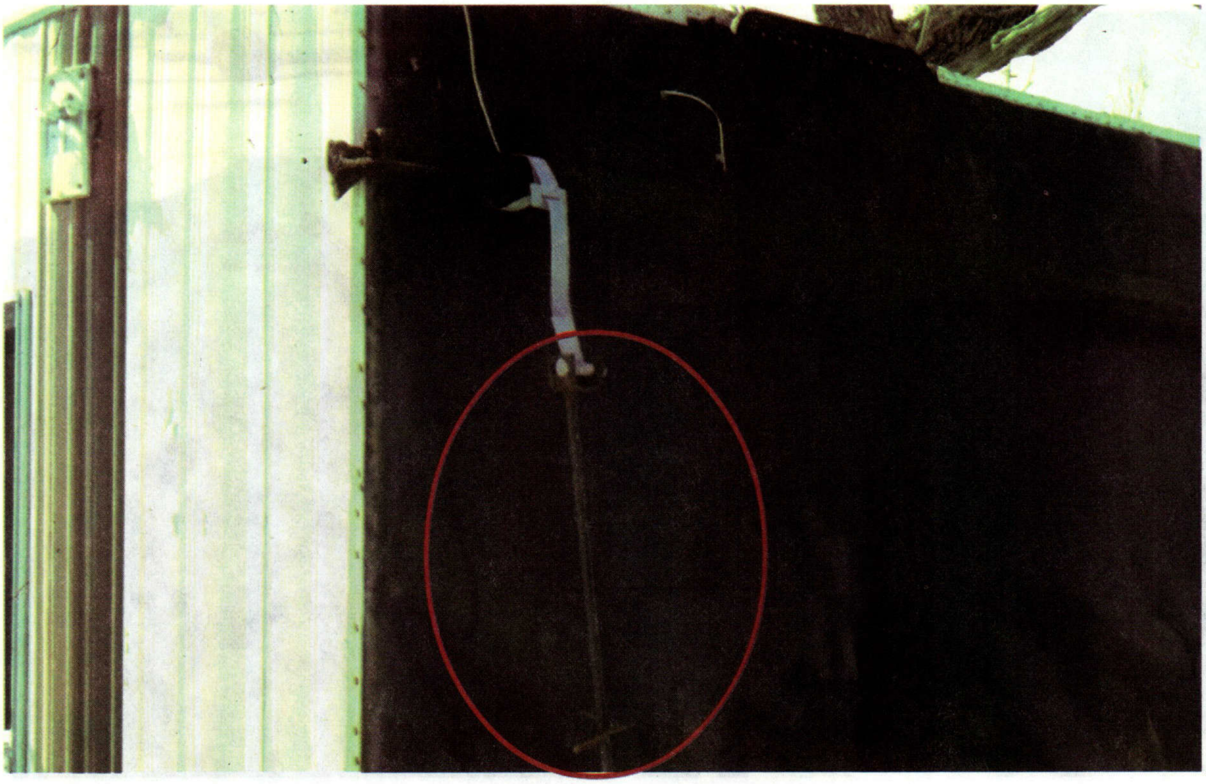

Figure 2-24 *Permanently installed RV overturned as a result of anchor pullout. Anchor (circled) is 2 feet long.*

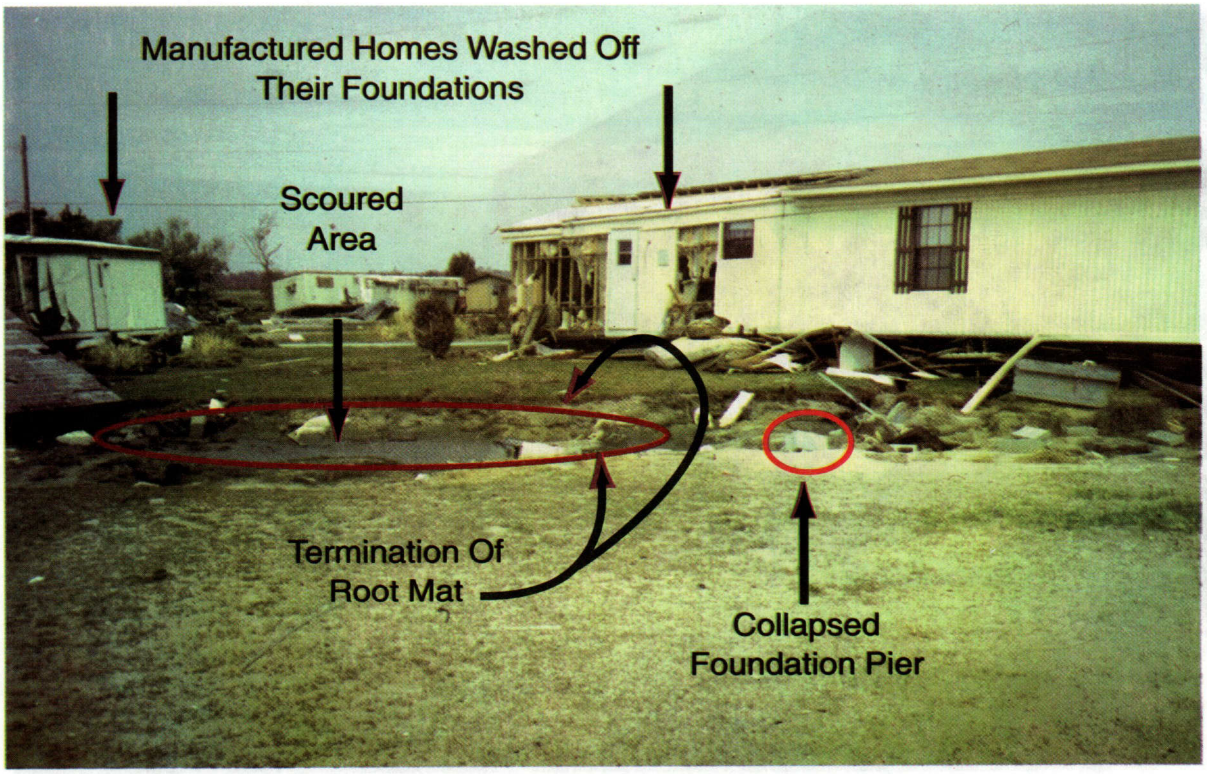

Figure 2-25 *Localized scour beneath pre-storm footprint of manufactured home. Note the collapsed dry-stack block foundation and termination of root mat, which otherwise would have helped stabilize the adjacent ground.*

Even units tied down with straps and helical anchors were displaced from their foundations because of pier undermining and subsequent collapse, strap failure, or anchor pullout. Strap failure may have occurred when the tensile strength of the strap was exceeded. Anchor pullout occurred when the resisting force of the surrounding soil was exceeded. Both strap failure and anchor pullout occurred in several scenarios, which include the following:

- Collapse of the supporting dry-stack masonry foundation due to localized scour. When the foundations gave way, the unit fell onto the ground, exposing the seaward face to the full force of the velocity flow and debris impact.

- Failure of the strap due to corrosion. Several corroded straps were observed to have failed when they were exposed to minimal tensile loading. The coastal environment, where salt and moisture are present, can accelerate the rate of corrosion. Straps that are exposed to salt spray and that are not periodically cleansed by rainfall can lose much of their design tensile strength in a little as 3 to 5 years.

- Pullout of the anchor due to soil saturation. All anchors observed had been embedded in sand. During flooding conditions, sand can quickly become saturated and thereby loose it capacity to resist pullout of the helical anchor plates. Because anchors that had pulled out were observed to have small-diameter helical plates and shallow embedments, it is assumed that soil saturation played at least a contributing role in anchor pullout.

In addition, the use of anchors of the wrong size and the installation of anchors not in accordance with manufacturers' recommendations may have contributed to the observed failures.

2.4 Breakaway Walls Below Elevated Buildings

Many of the areas below BFE beneath elevated structures observed by the BPAT had been enclosed with wall panels intended to break away under the impact of hydrodynamic flood forces. Under the NFIP, this practice is permitted. When properly installed, these wall panels break away under the impact of hydrodynamic flood forces and therefore do not transfer loads to the foundation of the structure and the structure frame. Although the BPAT observed that breakaway wall panels generally performed as intended, some problems are worth noting. The placement of exterior sheathing of breakaway panels continuously over adjacent vertical foundation members, the improper attachment of breakaway panels to foundation members, and the improper position of the panels in relation to foundation cross-bracing were often found to affect their performance. These issues are discussed in the following sections.

2.4.1 Placement of Exterior Sheathing Over Pilings

On some structures, exterior sheathing consisting of oriented strand board (OSB) had been installed over breakaway wall panels in such a way that it traversed adjacent panels and the faces of intervening vertical foundation members. Sheathing installed in this fashion is not in conformance with breakaway wall designs recommended by the NFIP. It interferes with the function of the breakaway panels because it must fail before the panels can break away (see Figures 2-26 and 2-27). The OSB installed across breakaway panels and foundation members did not appear to have caused structural damage; however, when acted on by flood forces, it can potentially place unnecessary and unanticipated lateral loads on vertical foundation members.

2.4.2 Improper Attachment of Breakaway Wall Panels to Foundation Members

In general, the BPAT observed that breakaway wall panels had been attached to structure foundation members with an excessive number of fasteners (nails). The BPAT did not observe any instances of structural failure or structural damage that appeared to have resulted from this practice. However, when an excessive number of fasteners are used between the structural members and the perimeters of the breakaway wall panels, the loads necessary to make the panels break away increase significantly, far beyond the flood load expected to cause the panel to break away. Another example of improper attachment is shown in Figure 2-28. Placing anchor bolts through the sill plate of the breakaway wall panel prevents it from breaking away until the forces on it have increased significantly beyond those under which the wall is intended to break away.

2.4.3 Placement of Breakaway Wall Panels Seaward of Cross-Bracing

On a few structures, breakaway wall panels were observed to have been installed directly seaward of cross-bracing (see Figure 2-29). When the panels broke away under the loads imposed by flood waters, they moved back and came to rest vertically against the cross-bracing. As a result, the vertical surface exposed to velocity flow, breaking waves, and debris impact increased tremendously and so did the corresponding loading on the cross-bracing. For cross-bracing installed across a typical 8-foot span between pilings, the resulting loading far exceeds the bending moment capacity of 2x or 3x wood braces in the narrow dimension. As a result, the cross-bracing often failed.

Figure 2-26
Exterior sheathing of breakaway wall spanned piling.
Note torn sheathing (arrow).

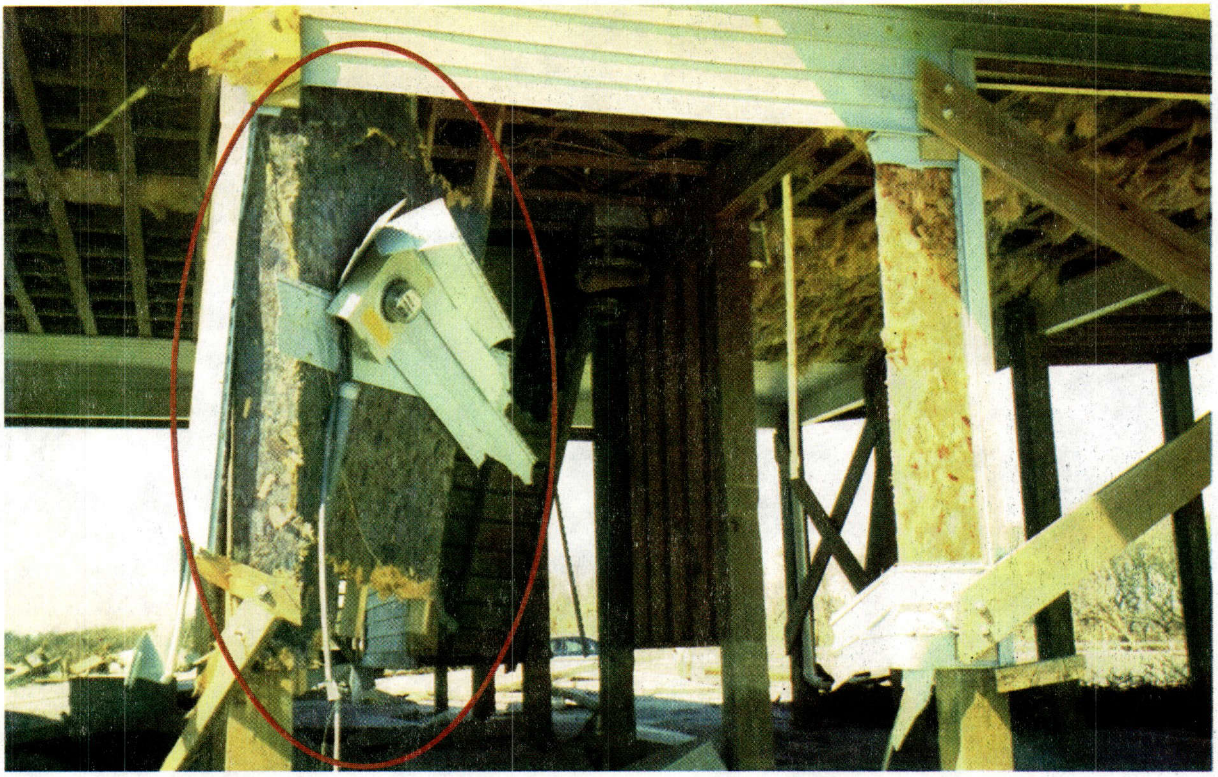

Figure 2-27 *Breakaway wall panel failed to function as designed because continuous sheathing was installed across pilings. No structural damage was observed; however, note damage to utility components installed on breakaway wall panel.*

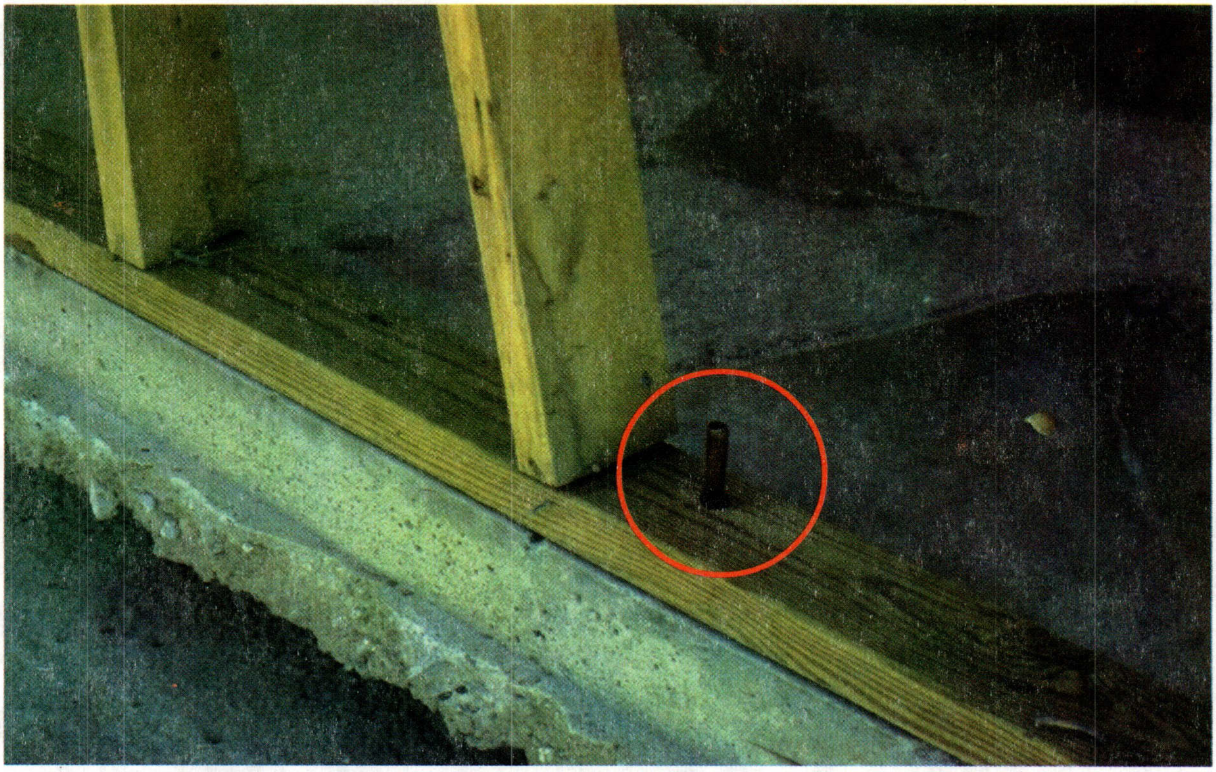

Figure 2-28 *Use of anchor bolts through the sill plate of a breakaway wall is improper. Even though this bolt does not have a nut and washer, it prevented the wall from breaking away laterally.*

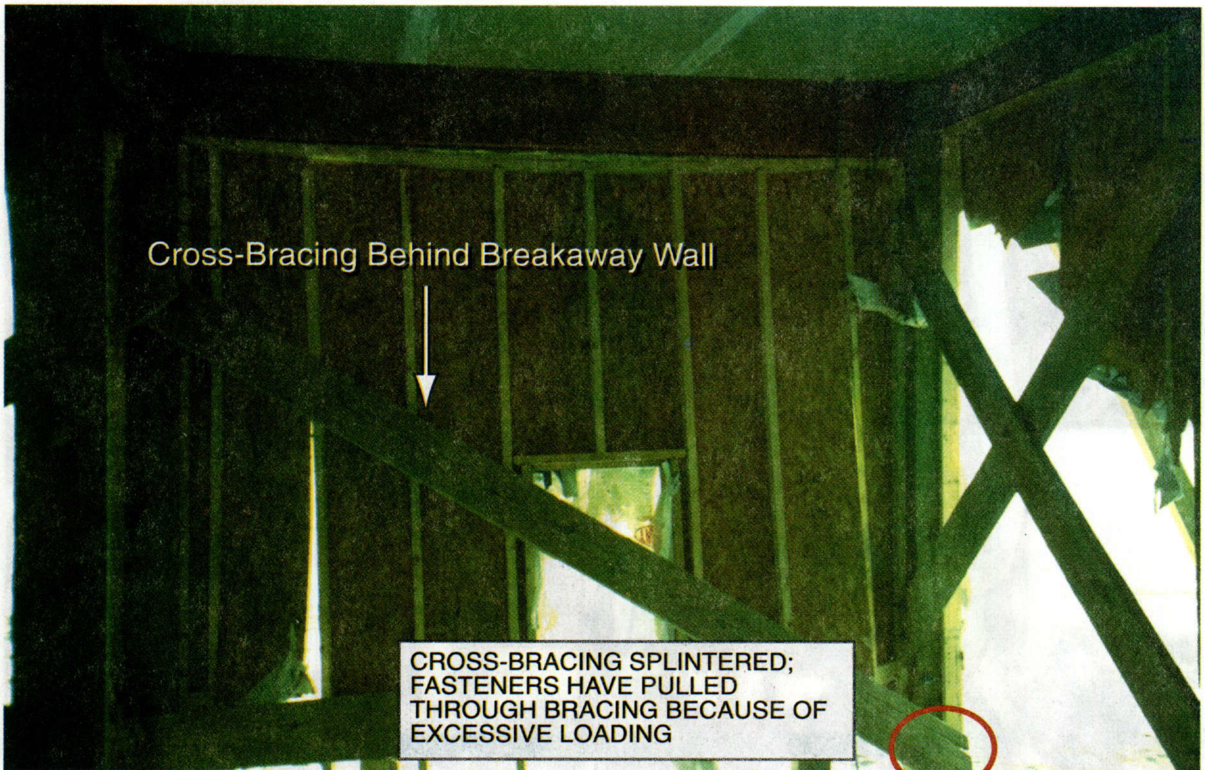

Figure 2-29 Improper installation of breakaway walls (on the seaward side of cross-bracing) resulted in failure of cross-bracing. Note breakaway wall pushed against cross-bracing.

2.5 Below-Building Concrete Slabs

With some minor exceptions, below-building concrete slabs generally performed as intended. Because some of the exceptions resulted in building damage, they are worth noting.

2.5.1 Slab Thickness

Slabs thicker than 4 inches were observed to have caused two problems:

- The thicker the slab, the greater the force needed to break the slab and therefore the greater the load transferred to the building foundation system until the slab breaks free of the foundation (see Figure 2-30).
- The thicker the slab the more it weighs per square foot of surface area. When a thicker slab breaks apart, the sections weigh more than those of the same size from a thinner slab and they create greater impact loads when they are thrown up against the building foundation by velocity flow and wave action.

2.5.2 Slab Joints

Three general types of joints are used in concrete slabs under elevated buildings: tooled and sawcut contraction (crack control), expansion, and isolation:

- Contraction joints are cut into the surface of the slab after the slab is poured and floated level. The joints become vertical planes of weakness that are intended to control cracking. These planes of weakness can serve a dual purpose by creating a frangible slab, since they are also the planes along which the slab is expected to break during a coastal erosion and scour event such as a hurricane or Nor'easter.

Figure 2-30 Example of unnecessarily thick slab.

- Expansion joints are set in place before the slab is poured. They separate independent slab sections and are filled with a compressible material that allows the sections to expand and contract in response to changes in temperature. They also help create a frangible slab.

- Isolation joints are used to separate the slab from structural members, such as vertical foundation members, and other slab penetrations. These joints are similar to expansion joints in that they are filled with a compressible material and are set before the slab is poured. When used in frangible slabs, they help ensure that the slabs will break away cleanly from the vertical foundation members and other slab penetrations such as sewer riser pipes.

The problems associated with slab joints involved the number of contraction joints and the effect of reinforcing wire mesh. In the slabs beneath many structures, the number of contraction joints was observed to be insufficient to make the slabs frangible. When the slabs broke up, the pieces were too large and generated unnecessary impact loads on the foundation system. Occasionally, the lack of an adequate number of contraction joints prevented the slab from breaking up. Figure 2-31 shows a large, unbroken section of a below-building slab-on-grade that was flipped up, probably by wave action, and came to rest against two vertical foundation members. The flipped slab created an obstruction that increased the flood loads on the foundation. In fact, the vertical foundation members behind the slab in Figure 2-31 were found to be leaning landward.

2.5.3 Wire Mesh

The BPAT observed that wire mesh was used in most slabs. The mesh is laid out before the concrete is poured. It usually extends across contraction joints but usually does not extend across expansion joints . The BPAT observed that where wire mesh was present , it usually had been

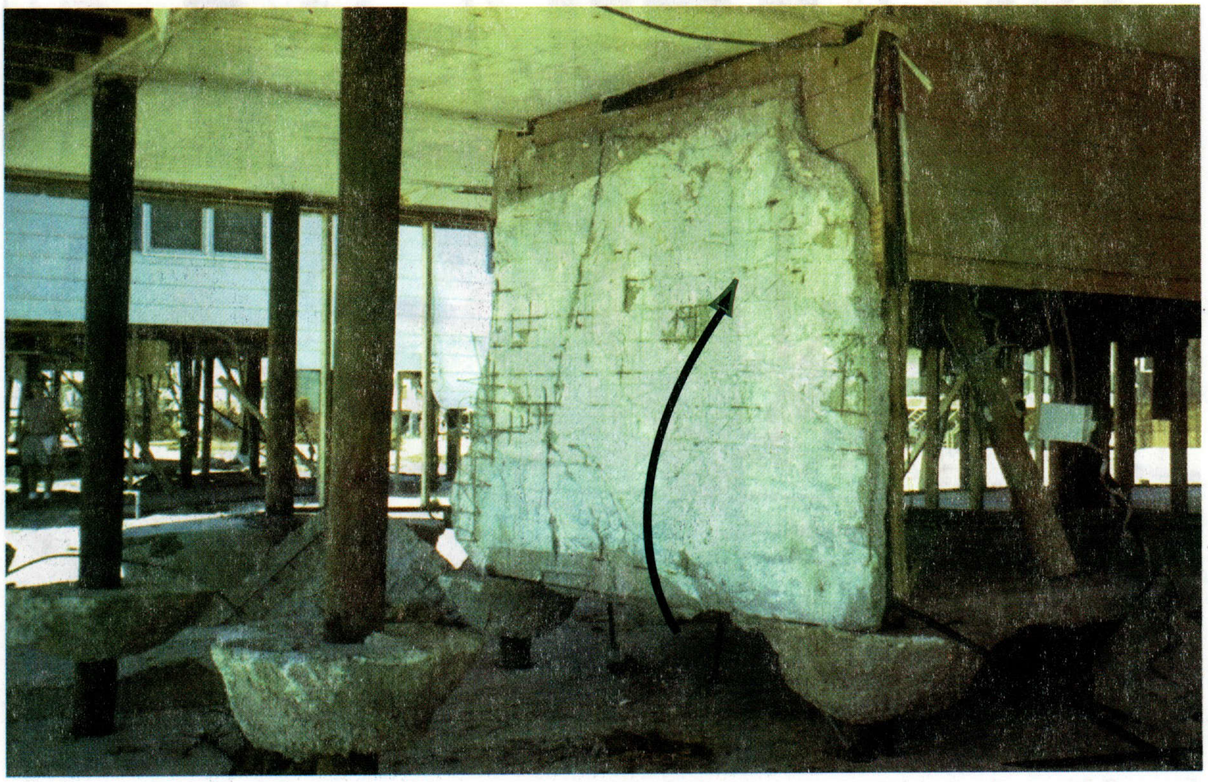

Figure 2-31 *Concrete slab-on-grade flipped up, probably by wave action, came to a rest against two foundation members, generating large, unanticipated loads on the foundation. Note slab is supported on concrete collars around piles and contains wire mesh.*

installed improperly (i.e., at the bottom rather than in the middle of the slab). Even so, the team observed that when reinforced slabs broke apart, broken sections were held together by the wire and came to rest against , or became wrapped around, vertical foundation members. As a result, large, unanticipated loads were transferred to the foundation system.

2.5.4 Connecting the Slab to the Vertical Foundation Members

Some engineers and architects may have specified, or contractors chose to use, dowels to connect concrete slabs-on-grade to vertical foundation members. The dowels, intended to help prevent the differential settlement of the slabs, were inserted into or through the vertical foundation members before the slab was poured. They caused serious problems when the slabs broke apart under flood loads. The dowels made it more difficult for the slab to break into small pieces and separate cleanly from the vertical foundation members. Even when the slabs broke into small pieces, the dowels acted like pins in a hinged connection, keeping the slab connected to the vertical foundation members (see Figure 2-32). As a result, unnecessary and unanticipated flood loads were transferred to the vertical foundation members.

Although the BPAT was unable to define a cause-and-effect relationship, several buildings with this slab-to-foundation pin detail were found to be leaning. The team members believe that the inability of the slab to break free of the vertical foundation members was at least partially responsible the failure of the vertical foundation members to remain plumb.

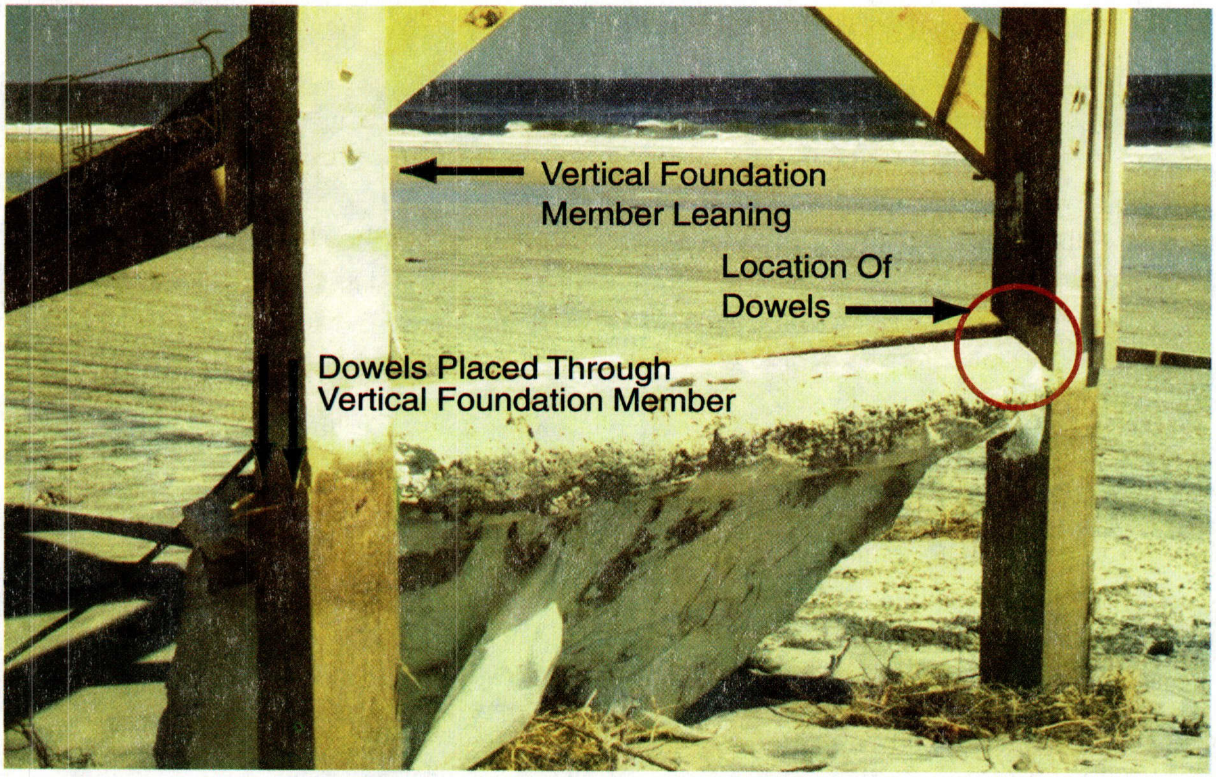

Figure 2-32 *Use of steel dowels to tie slabs to vertical foundation members prevented the proper breakup of slab. A portion of the slab was left attached to the piling, resulting in large, unanticipated loads on foundation members. Note leaning vertical member, on right.*

2.5.5 Casting Concrete Grade Beams and Slabs-on-Grade Monolithically

Some concrete grade beams and slabs-on-grade were poured monolithically in a continuous concrete pour. As a result, large loads were transferred to the foundation system when velocity flow, breaking waves, and debris forces were applied to the sections of slabs attached to the grade beam. Although the BPAT was unable to define a cause-and-effect relationship, several buildings with this monolithic grade beam and slab detail were found to be leaning. The team members believe that the inability of the slab to break free of the vertical foundation members and grade beam was at least partially responsible for the failure of the vertical foundation members to remain plumb.

2.5.6 Concrete Collars

The BPAT observed that concrete collars were often poured around foundation pilings in conjunction with the construction of below-building concrete slabs (see Figures 2-14 and 2-31). Although intended to provide stability, these collars presented a large obstruction to flow, therby increasing flood loads on, and scour around, the pilings to which they were attached. the increased scour resulted in a loss of sand supporting the foundation (see Figure 2-31). As shown in Figure 2- 14, collars did not prevent piling failure.

2.6 On-Site Utility Systems

Building performance issues concerning on-site utility systems usually involved air conditioning / heat pump compressors and their supporting platforms, the placement of utility system components in relation to breakaway wall panels and vertical foundation members, and septic tanks.

2.6.1 Air Conditioning / Heat Pump Compressor Platforms

The majority of air conditioning and heat pump compressor platforms supported by posts collapsed when acted on by flood forces. The posts were generally observed to be embedded only 1 to 2 feet. Once platforms were dislodged, they often collasped, leaving compressors submerged in flood water (see Figure 2-23. Many compressors were observed to have become waterborne debris. Occasionally, when a platform survived, the compressor was insufficiently elevated and was inundated with salt water and sand. Once inundated, the compressor is no longer salvageable and must be replaced.

Oceanfront Residential Buildings

When post-supported platforms adjacent to oceanfront houses collapsed, the cause was almost always erosion and scour combined (see Figure 2-33). Erosion in the areas where the platforms were set was generally 2 to four 4 feet in depth, often exceeding the embedment depth of the support posts. Cantilevered platforms, which do not depend on vertical support members, escaped the scour- and erosion-induced damage incurred by post-supported platforms. Compressors installed on adequately elevated cantilevered platforms were not subject to flood-related damages, including inundation, but were still subject to wind damage when they were not adequately anchored (see Figure 2-34).

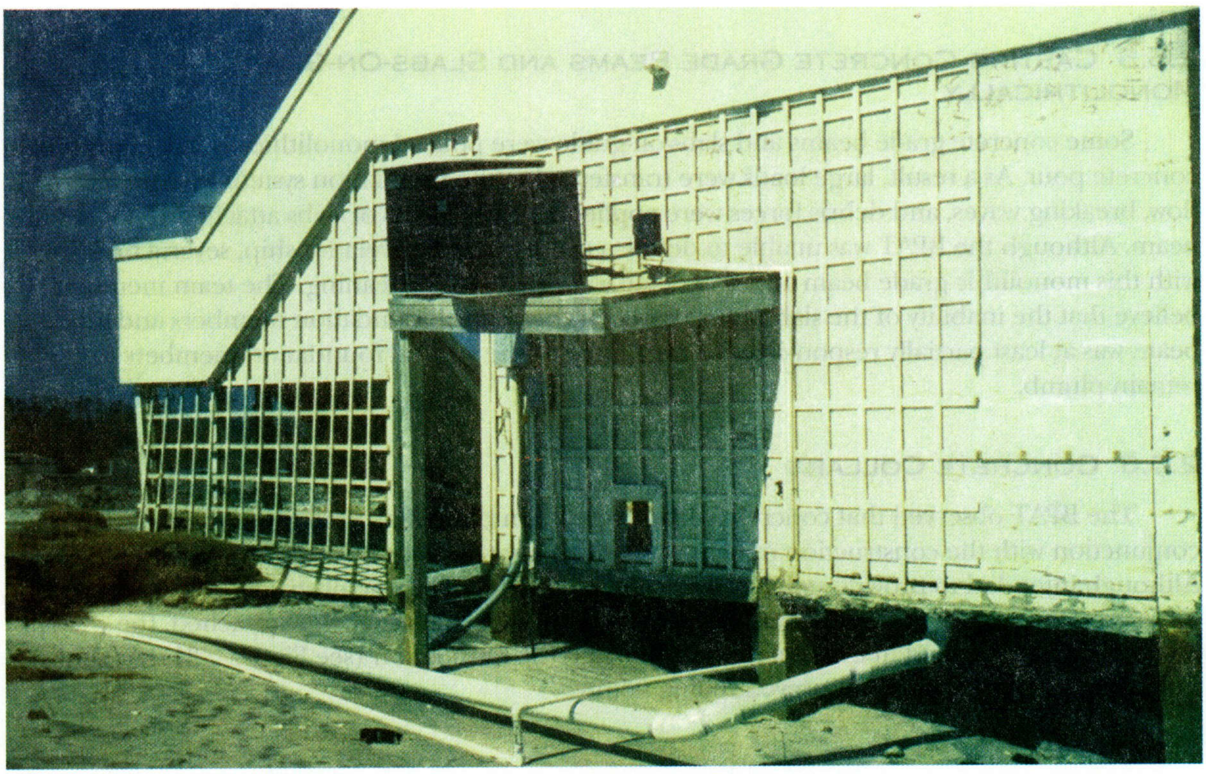

Figure 2-33 *Air conditioning / heat pump compressor platform leaning because erosion and scour caused loss of one supporting column.*

Figure 2-34 *Although the air conditioning/heat pump compressor platform on this oceanfront house was adequately elevated with cantilever bracing, the compressor was almost pushed off the platform by wind because of the lack of the necessary attachment.*

Landward Residential Buildings

Many of the post-supported compressor platforms adjacent to homes landward of the oceanfront row collapsed as a result of localized scour due to velocity flows (see Figures 2-23 and 2-35). Localized scour of approximately 1 foot in depth was generally observed. Where posts were embedded only 1 to two 2 feet, localized scour allowed the velocity flow and debris impact forces to dislodge the platform. Platforms with properly embedded posts performed much better. Often, the only damage sustained by landward residential buildings was the loss of the compressor unit due to water or wind damage.

2.6.2 Placement of Utilities on, Through, or Adjacent to Breakaway Wall Panels

In the vast majority of structures with breakaway wall panels observed by the BPAT, utilities were improperly placed on, through, or adjacent to breakaway wall panels.

The BPAT observed electric meter boxes, telephone service boxes, cable TV boxes, sewer service lines, and domestic water service feeds all mounted on breakaway wall panels (see Figures 2-27 and 2-36). Utilities placed through breakaway wall panels included telephone and cable TV lines, the electric feed from the back of the meter box to the electric panel box, and water service feeds (see Figure 2-37). Under the effects of flood forces, these utilities either were torn out or prevented breakaway wall panels from breaking away cleanly. Another deficiency observed was the placement of utilities adjacent to or near breakaway wall panels (see Figure 2-38). These utilities were damaged when flood forces caused the panels to break away.

Figure 2-35 *Air conditioning / heat pump compressor platform leaning because scour caused loss of two supporting posts.*

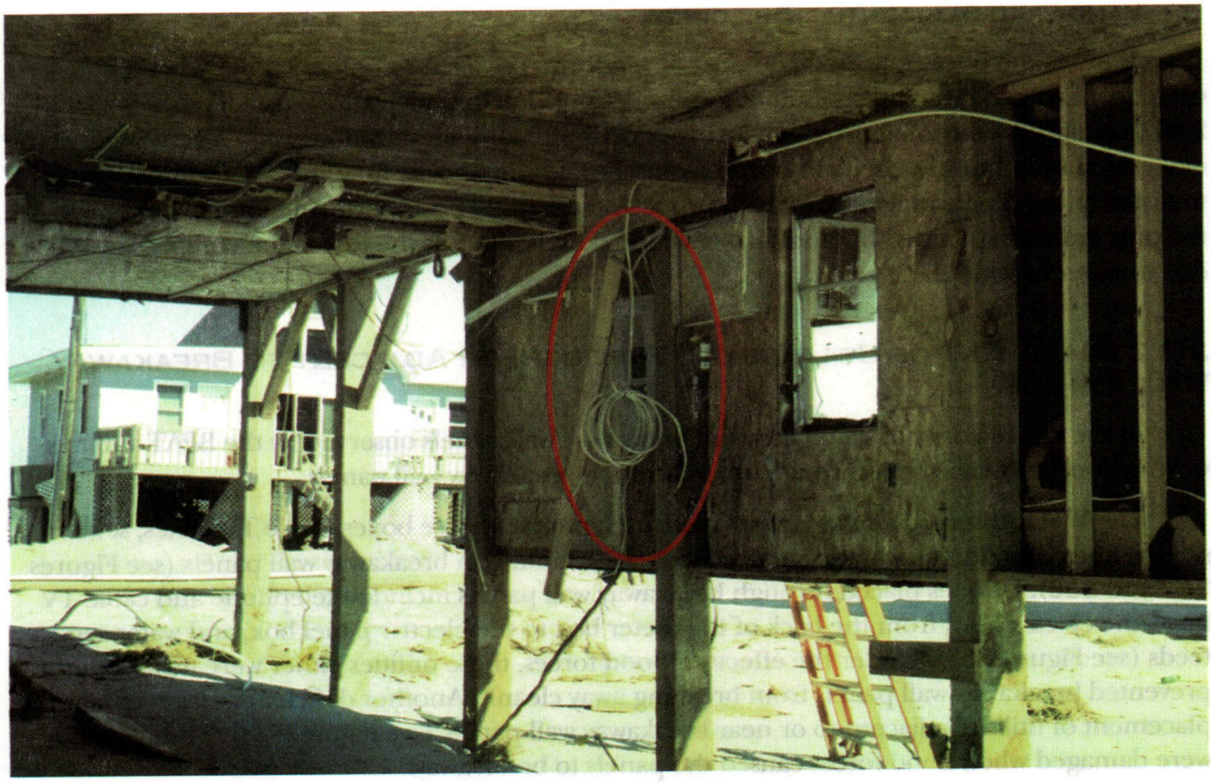

Figure 2-36 *Example of utility component (electric panel box) installed on a breakaway wall panel.*

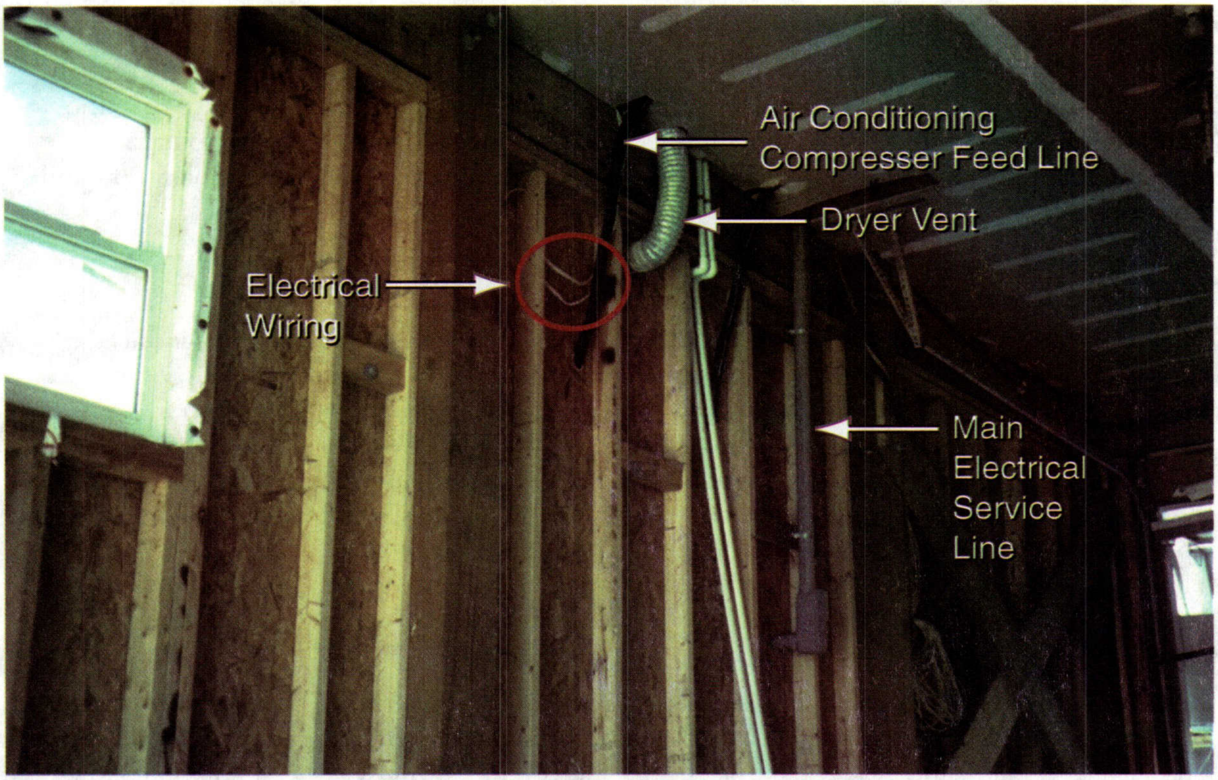

Figure 2-37 *Utility components (dryer vent, air conditioning compressor feed line, main electrical service line out of meter box, and electric wiring) penetrating breakaway wall panel.*

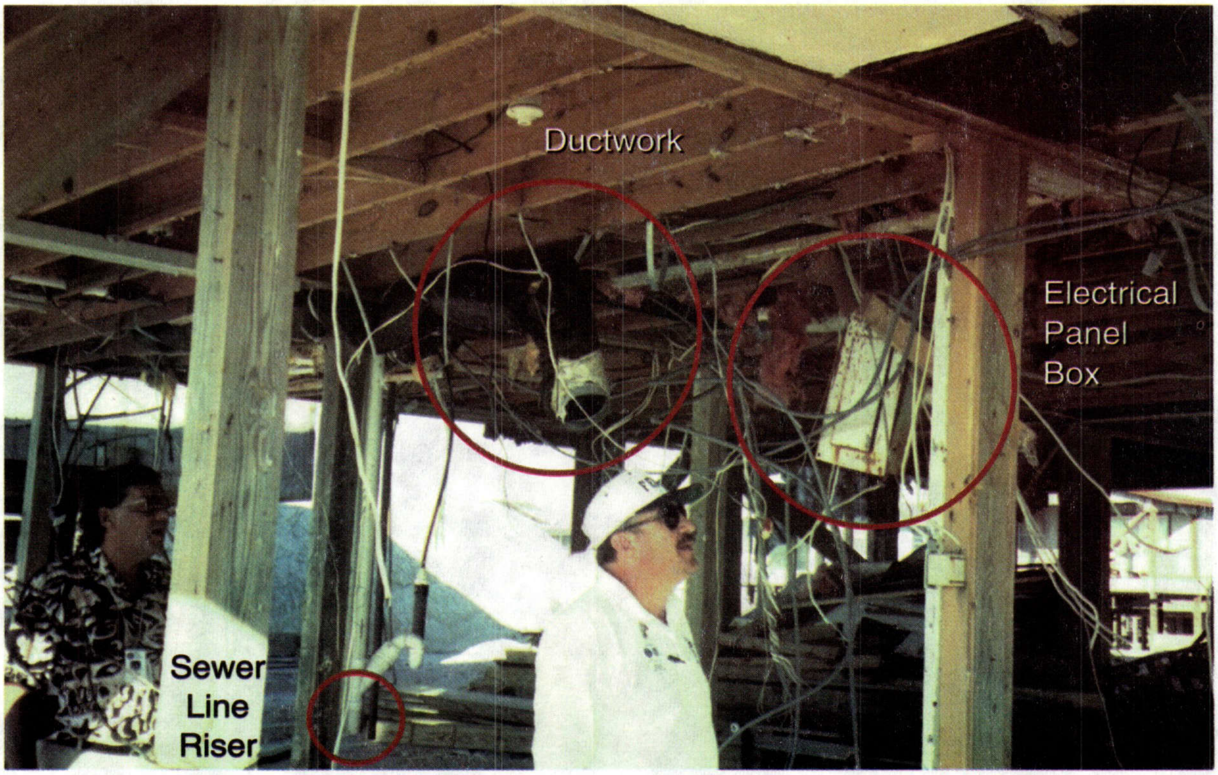

Figure 2-38 *These utility components (wiring, electric panel box, ductwork, and sewer line) were installed adjacent to breakaway wall panel and were damaged when the walls broke away. Note broken sewer line riser pipe on seaward side of piling.*

2.6.3 Placement of Utilities Adjacent to Vertical Support Members

Utilities on the vast majority of structures were found to be in locations exposed to velocity flow and debris impact, e.g., mounted to vertical foundation members on sides other than the landward side (see Figure 2-38). Utilities installed on the landward side of vertical foundation members generally survived since the foundation member shielded them from velocity flow and debris impact.

2.6.4 Septic Tanks

Septic tanks installed near oceanfront homes were often left exposed by storm-induced erosion and scour (see Figure 2-39). Occasionally, thin-walled septic tanks made of precast concrete rings were observed to have become waterborne debris. Concrete ring sections were found dislodged and under elevated structures (see Figure 2-17). When a tank was exposed, the sewer line from the home was usually severed. On many exposed tanks there were openings where the access lid was missing and where the connection to the sewer line from the house was exposed when the pipe broke away. The openings allowed sewage to leak out and flood water and debris to enter the tank. Homes that were otherwise not significantly damaged had been posted "Unoccupiable" by the local building official because of the lack of an operating sanitary disposal system.

The State of North Carolina has established regulations concerning the installation of septic tanks and leach fields in areas subject to coastal flood hazards. When a new building is constructed, the tank and leach field must be installed on its landward side. When repairs to an existing septic system located on the seaward side of a building become necessary for any reason, the tank and leach field must be moved to the landward side of the building.

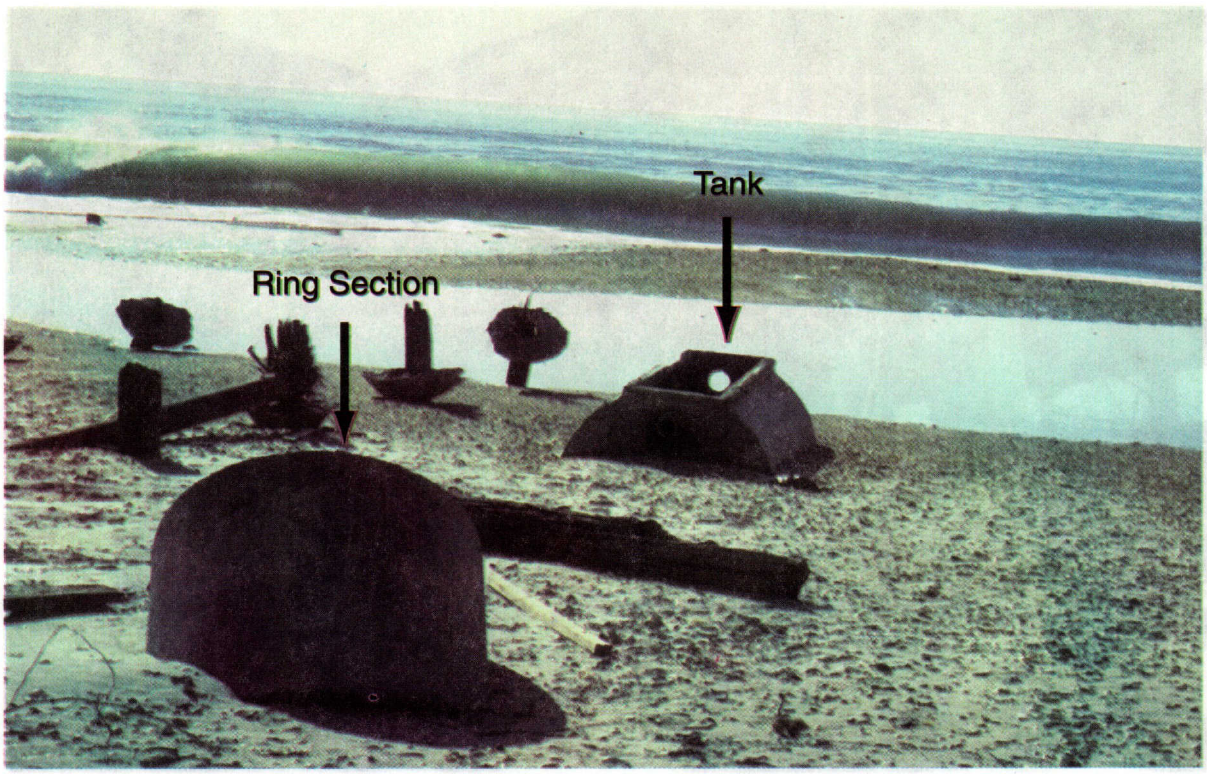

Figure 2-39 *Oceanfront erosion and scour unearthed and damaged septic tanks and systems. Note precast ring section and precast tank.*

2.7 Dry Floodproofing in Coastal A Zones

One unusual building in Wrightsville Beach is worth noting. The building is a slab-on-grade hotel that was renovated several years ago. During the renovation of the conference rooms, the owner reconstructed the exterior walls to make them watertight and installed tracks in the door openings for the placement of removable flood shields (see Figure 2-40). The flood shields were approximately 3 feet high and were manufactured by a firm that specializes in producing flood shields. Each shield was equipped with a pneumatic gasket that could be inflated to seal the gap between the track and the edge of the shield (see Figure 2-41). Construction of a solid masonry wall inside the exterior walls of the conference rooms completed the floodproofing.

The BPAT interviewed the hotel manager and engineer during the site investigation. Both were directly involved in the renovation of the hotel. Both said that the floodproofing was worth the effort but that they wished the shields had been 1 foot higher. While the shields prevented the storm surge from entering the protected area, some water splashed over the tops of the shields. The water that passed over the top flooded the conference rooms to a depth of 4 inches. It damaged the carpeting and mildewed the wall paper. However, in the remaining portions of the hotel, which were not floodproofed, the depths of flood waters reached 18 inches. In these areas, the water damaged the sheetrock and left over 2 inches of sand on the floor. Both the manager and the engineer stated that keeping sand out of the conference area was, in itself, justification for the expense of the floodproofing.

Figure 2-40 *Engineered flood shield installed over opening to large dry floodproofed commercial building.*

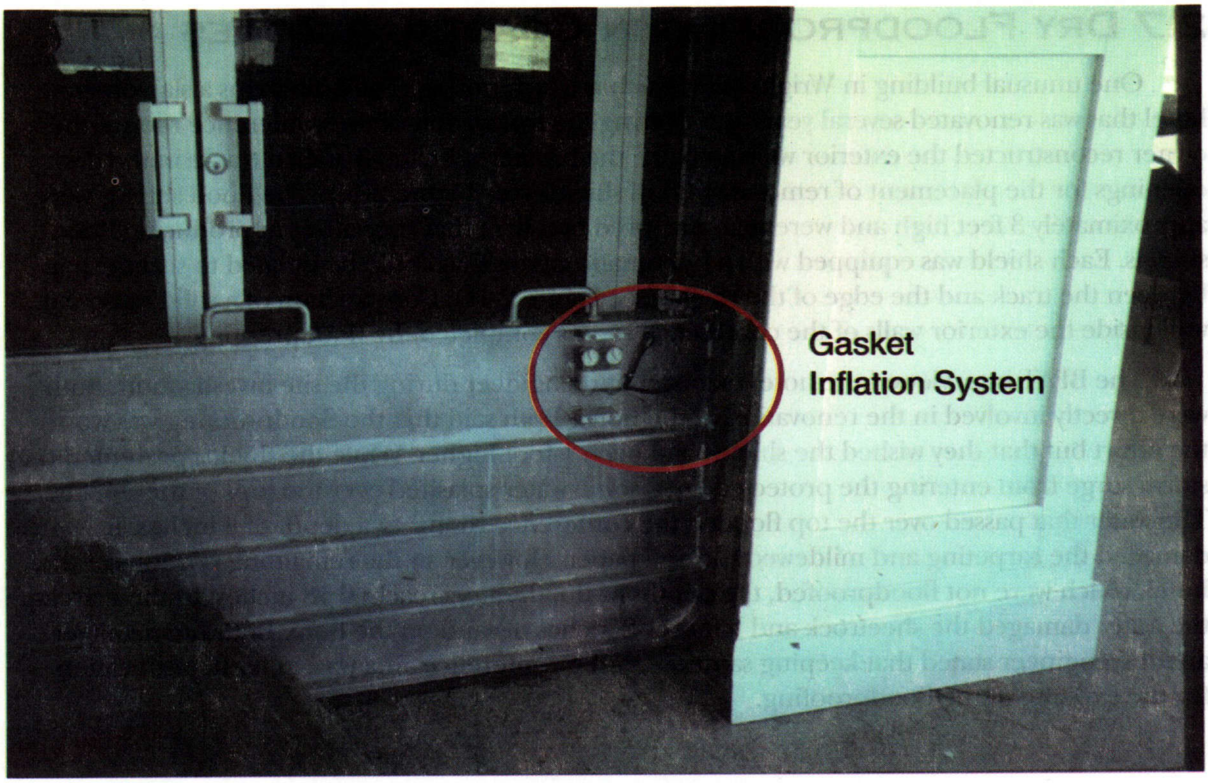

Figure 2-41 *Buildings that are floodproofed require extensive engineering detailing. Note that this flood shield is sealed with a pneumatic gasket.*

Although flood shields and other elaborate floodproofing measures can be quite effective, they often require extensive human intervention to function properly (see Figure 2-42). It should be noted that very few floodproofed buildings in coastal A zones are known to be subject to wave action. Floodproofing in areas known to be subject to wave action presents special challenges that must be addressed in the design, installation, and operation of the components of the floodproofing system.

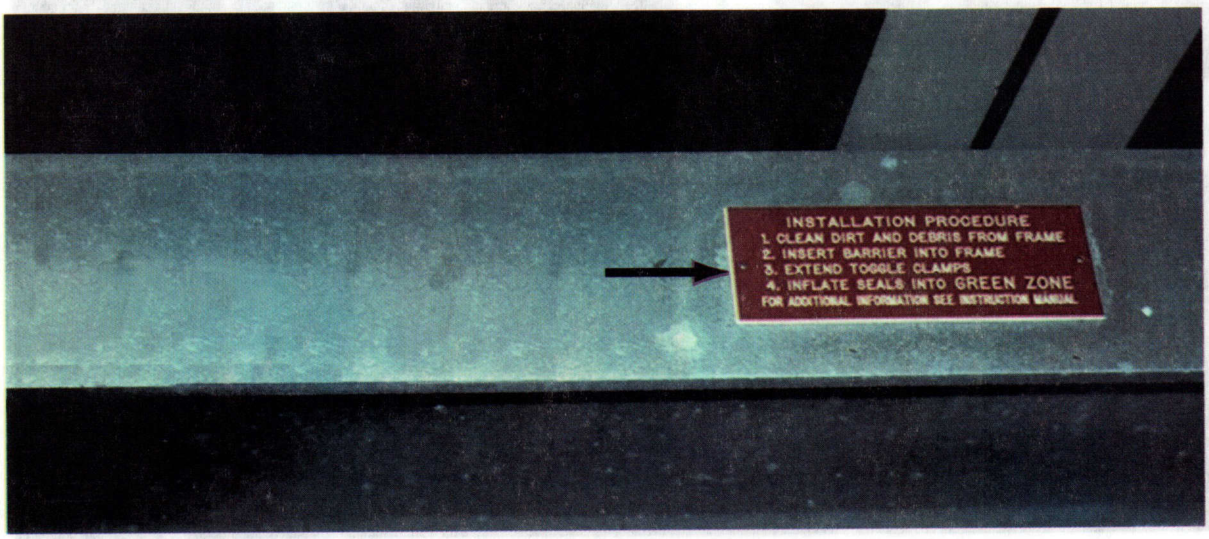

Figure 2-42. *Dry floodproofing often requires extensive human intervention. Note the detailed instructions affixed to this flood shield.*

2.8 Wind Damage

Although the BPAT focused on flood damage, the team also observed wind damage to many buildings. Porch roofs and large overhangs often failed because of poor connections, particularly base and roof connections of support columns. Porch and overhang failures often caused severe damage to otherwise well-connected main roofs. An additional contributor to observed wind damage was the failure of corroded metal connectors.

2.9 Corrosion of Structural Metal Components

The BPAT continued to see a trend toward the increased use of partially exposed metal structural components, such as hurricane straps and clips, stamped metal plates on floor diaphragm trusses, and manufactured home and RV tiedowns (see Section 2.3.8), in coastal structures. With this trend, comes a trend toward an increase in the observed corrosion of these components. Components that are partially exposed, i.e., those that are exposed to direct contact with ambient exterior air but not cleansing rainfall, continued to show the highest rate of corrosion.

Examples of such components are shown in Figures 2-43, 2-44, and 2-45. The presence of rust indicates an obvious loss of galvanization on metal components observed in both oceanfront and landward structures in the study area and may indicate that the connectors are nearing the end of their useful life.

As noted in Section 2.8, the team observed wind damage to some structures that was due in part to the failure of corroded metal connectors.

2.10 Concerns Regarding the Effective FIRMs for North Carolina Coastal Communities

Throughout the damaged oceanfront area, the effective FIRMs for the affected communities do not account for the effects of dune erosion, wave setup, or wave runup. Prior to Hurricanes Fran and Bertha, the V-zones were located on the ocean beach, well seaward of building locations. Oceanfront dunes were identified as B and C zones, outside the influence of 100- and 500-year flooding. Fran caused severe erosion in the oceanfront row of buildings and allowed waves greater than 3 feet high to extend several rows of buildings farther landward. Smaller waves swept the entire barrier island in many locations.

In addition to the false sense of safety that results when erosion is neglected, the FIRM deficiencies allowed finished underhouse enclosures in oceanfront B and C zones to be constructed on slab foundations not supported by the piling foundation. In areas like Kure Beach, erosion and wave damage caused significant damage to the finished enclosures. Without the application of FEMA models for dune erosion, wave setup, and wave runup, the wave model used in the preparation of the existing FIRMs underestimates the wave heights above the stillwater elevations. This results in BFEs that are lower than those needed to avoid wave damage to coastal construction.

[Editor's note: FEMA Region IV in Atlanta has issued advisory flood hazard maps for several communities severely impacted by Hurricane Fran and has begun the preparation of revised FIRMs. The communities have adopted the advisory maps and will use them until FEMA issues the revised FIRMs.]

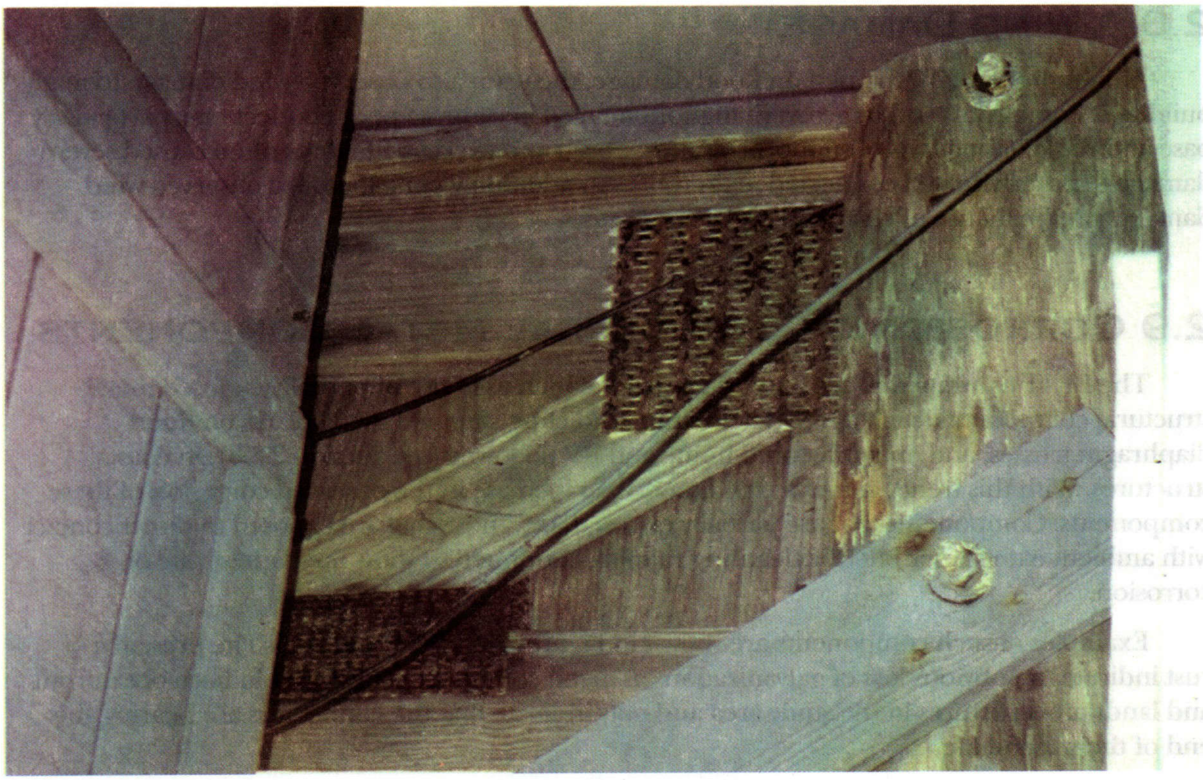

Figure 2-43 Corrosion of galvanized floor truss plates was observed in many buildings.

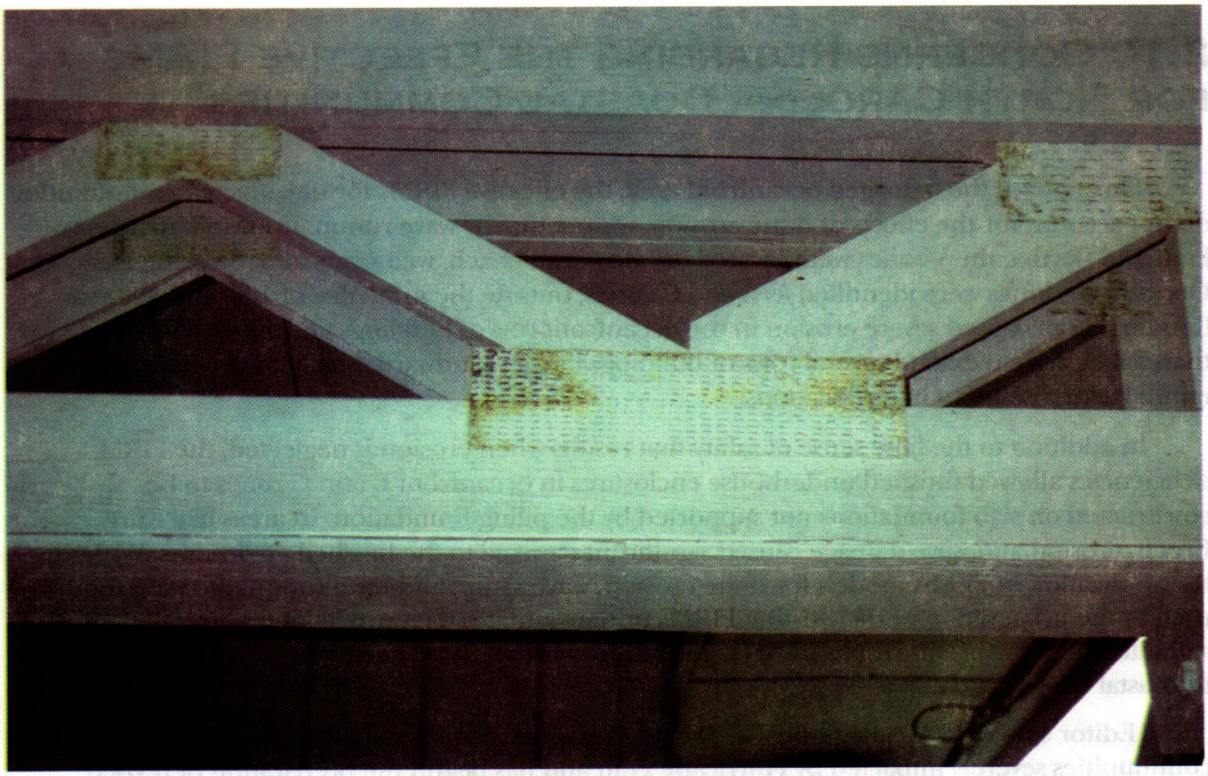

Figure 2-44 Corrosion of galvanized floor truss plates was observed in many buildings. Note that painting does little to slow the process of corrosion in coastal environments

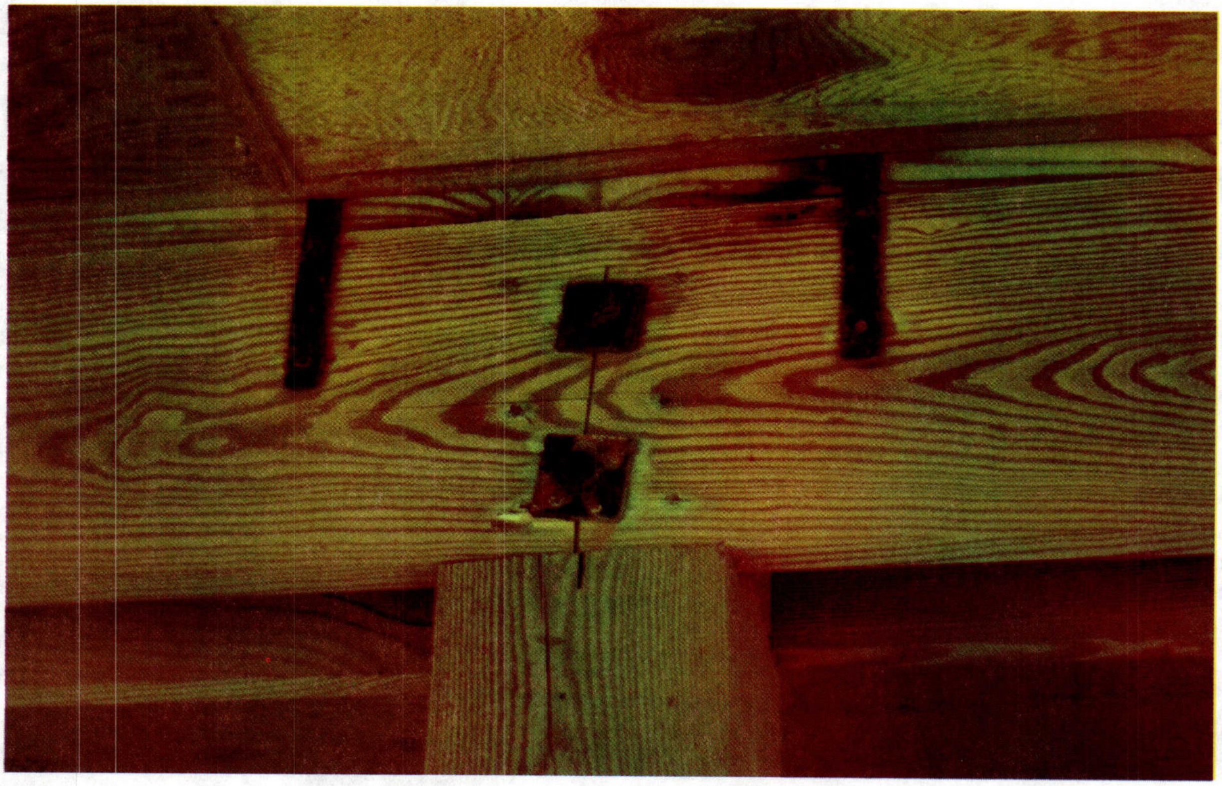

Figure 2-45 Corrosion of hurricane straps and steel plates was also observed in many locations.

2.11 Building Performance Successes

The shift in construction from low floor elevation with shallow footings to elevated piling foundations with underhouse parking, as described in Section 1.3.1, significantly reduced the flood damage to buildings landward of any erosion. Where not subject to erosion, second row and more landward buildings on pilings consistently survived wave heights of at least 3 feet and overwash deposition of up to 3 feet of sand under the building. The use of 8-inch x 8-inch square pilings embedded 8 feet below grade was successful in protecting landward three-story buildings elevated up to 10 feet above grade. Outside of areas impacted by erosion, the BPAT did not observe a single piling failure. Since most landward building sites in the beach communities are not subject to erosion, the piling standards initiated by the by the State Building Code in the 1960's were extremely successful. However, underhouse non-load-bearing enclosures below the elevated floor were regularly flooded and when used as finished living space were often severely damaged.

The shift in the State Building Code to require longer pilings for erosion-prone buildings along the ocean was generally successful. As noted by W-C (see Appendix C), of the 205 post-1986 oceanfront structures on Topsail Island, over 90 percent sustained no significant foundation damage. Only a few were seriously damaged or destroyed. In comparison, adjacent oceanfront houses on shallow pilings were often destroyed when the foundation was undermined by erosion. The current requirement is for piling embedments to -5.0 feet m.s.l. or 16 feet below grade, whichever is less. As noted in Section 2.3.1, the natural grade on most of the eroded lots was relatively low, allowing the -5.0-foot m.s.l. requirement to control the design. In those conditions, the piling standard was usually adequate. However, on higher dunes where the requirement for

16 feet below grade applies, the required depth is too shallow to keep buildings stable after erosion of the dune and beach profile.

It is also important to note that the BPAT observed few situations in which the performance of breakaway walls below an elevated building may have resulted in structural damage to the building. Successful building performance during Hurricane Fran also demonstrates the value of compliance with elevation and setback requirements, the use of flood-resistant construction materials and techniques, such as in engineered concrete buildings, and compliance with other coastal design and construction requirements (see Figures 2-46, 2-47, and 2-48).

Beach nourishment with construction of a hurricane protection dune substantially reduced damage in Wrightsville Beach and Carolina Beach. In these areas, the manmade dune eroded but prevented erosion failures and reduced wave damage to structures. Such dunes are considered expendable but require periodic maintenance and replacement after the worst storms.

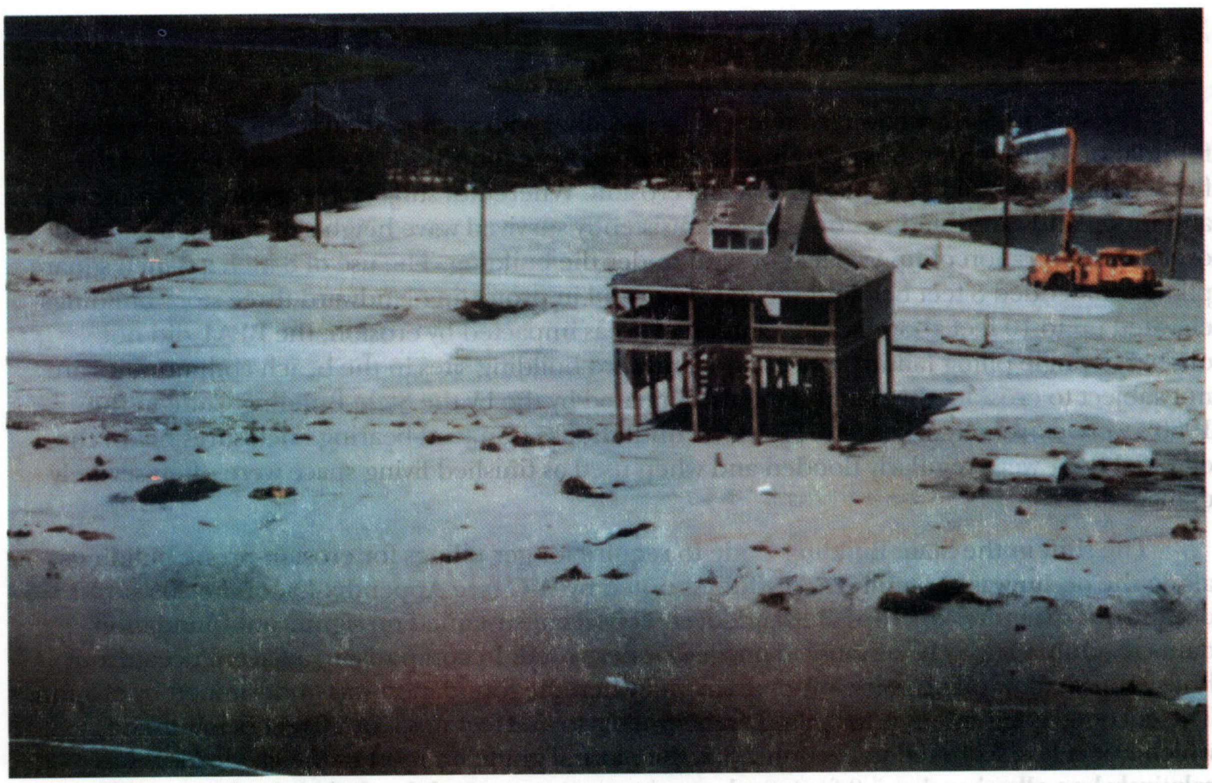

Figure 2-46 *While this house experienced 6 feet or more of vertical erosion and scour, as well as the loss of breakaway wall panels, the foundation and superstructure performed as designed.*

Figure 2-47 *As shown by this post-Fran photograph taken at Emerald Isle, North Carolina, proper elevation and setback from the oceanfront in conjunction with substantial protection afforded by dunes resulted in little or no flood damage to the oceanfront row of buildings.*

Figure 2-48
This large, engineered oceanfront structure performed as designed.

Recommendations

3.1 Building Foundation Systems

3.1.1 Piling Embedment for Structural Support

It is critical that coastal foundations be designed to survive the anticipated amount of erosion and scour. Erosion and scour combine to impact coastal piling foundations in three distinct ways. First, in the absence of cross-bracing, the loss of soil adjacent to a thin vertical foundation member 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. The loss of friction reduces the ability of the piling to resist uplift loads from wind.

For the concerns discussed above to be adequately addressed, designs of coastal foundation systems must account for the conditions expected to occur during the base flood (100-year flood) and long-term erosion for the life of the building. The following documents offer guidance to designers of coastal foundations:

- The ASCE standard *ASCE 7-95, Minimum Design Loads Building and Other Structures.* The 1995 version of this standard includes, for the first time, criteria for determining flood loads (Chapter 5) and for combining flood and other loads to determine combined load factors (Chapter 2) for buildings that experience simultaneous wind and flood loads. This standard is available from ASCE. Portions, if not the whole standard, may well be incorporated by the model building code organizations into future versions of model building codes. This standard also meets, or exceeds, the minimum requirements of the NFIP for determining loads.
- The ASCE standard *Flood Resistant Design and Construction Practices.* This standard is currently in development and should be completed in 1997. It will be available from ASCE. This new standard will provide descriptive as well as prescriptive requirements regarding the design and construction of buildings that are to be located in floodprone areas. The draft of this standard presents the recommendations of some of the Nation's leading experts in coastal construction and 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. It recommends that pilings be embedded to a depth of -10 feet m.s.l.
- FEMA's Technical Bulletin No. 5, *Free of Obstruction Requirements for Buildings Located in Coastal High Hazard Areas.* This document provides information on NFIP-compliant design and construction practices that can prevent damage to coastal buildings caused by below-building obstructions.

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, pilings for structures in areas subject to erosion and scour be embedded to -10 feet m.s.l. In areas with terminating strata that inhibit erosion and scour, and areas with rocky shorelines, foundation systems with shallower depths may be justified.

The findings of the W-C study suggest that in coastal areas of North Carolina where the ground elevations are at or below 11 feet m.s.l. the current requirements of the State Building Code regarding piling embedment depth may have been adequate to prevent foundation failure during Hurricane Fran. However, given the limitations of that study (as discussed in Appendix C), and the anticipated revisions to BFEs for North Carolina coastal communities as discussed in Section 2.10 of this report, it may be appropriate for the state to consider the need for piling embedment depth requirements more stringent than those in its current Code. These issues are discussed below.

All of the structures tested by W-C were located where the ground elevation was 11 feet m.s.l. or less. To meet the applicable code requirement, the pilings for these structures had to be embedded to a minimum of -5 feet m.s.l. In areas where the grade is greater than 11 feet m.s.l., pilings will meet the State Code if they are embedded 16 feet below average original grade. As a result, the bottoms of the pilings in these areas will be above -5 feet m.s.l. This embedment depth may not be sufficient for structures built on or directly behind frontal dunes, where extensive erosion and scour can cause the loss of the entire dune or remove so much of it that piling support becomes inadequate. There are areas within the state where this situation can occur. For structures in these areas, the state may want to consider revising the Code to require that piling embedment depth be -5 feet m.s.l. or 16 feet below grade, whichever is greater.

As noted in Section 2.10, FEMA is preparing revised FIRMs for several North Carolina communities affected by Hurricane Fran. Because the revised FIRMs are expected to include BFEs higher than those shown on the current FIRMs, new structures and substantially damaged structures that are reconstructed will have to be elevated higher to meet minimum NFIP requirements. As a result, these structures may be subject to different wind and flood loads than structures built previously, when lower elevation requirements applied, and increased piling embedment may be necessary.

In addition, the findings of the W-C study suggest that the State of North Carolina needs to emphasize the importance of inspection and code enforcement to ensure that all structure pilings meet current and any future Code requirements.

3.1.2 Piling Foundations for Decks, Porches, and Roof Overhangs

The design criteria for vertical foundation members for building extensions such as porches, decks, and roof overhangs must be equal to those for the foundation system of the main structure.

Oceanfront Residential Buildings

The vertical foundation members for decks, porches, and roof overhangs must be designed and constructed to maintain their ability to support the structure above. These building extensions are often on the ocean side of oceanfront structures, where they are exposed to amounts of storm surge, velocity flow, wave action, vertical erosion, and localized scour at least as great as those that affect the main structure. The foundation requirements for these building extensions should never be less stringent than those for the building itself. Because of the damage caused to the main structure when building extensions collapse and the debris they generate once they collapse, they should not be considered sacrificial. The only exceptions would be stairways and narrow walkways required for building access.

In areas subject to erosion and scour, embedment of vertical foundation members for building extensions should be based on a depth related m.s.l., not a depth below existing grade.

The BPAT recommends that in these areas, the requirements applied to the main building support system also be applied to the piling foundations for decks, porches, and roof overhangs. This recommendation is based on the observed performance of coastal buildings in many hurricanes, including Hurricane Fran.

Landward Residential Buildings

In landward areas also, vertical foundation supports for building extensions such as decks, porches, and roof overhangs should meet the same requirements applied to the main building support system. In areas not subject to erosion but subject to localized scour, embedment of these foundation members may be based on a depth related to existing grade. From the observed performance of landward coastal buildings and building extensions, the continued use of an embedment depth of 8 feet is recommended for all vertical foundation members.

3.1.3 Grade of Lumber Used for Timber Pilings and Cross-Bracing

The requirements of the North Carolina State Building Code regarding the quality of wood materials used in the construction of residential building foundations, including wood piles and dimensional lumber, are set forth in Section R-309 of the Code. Section R-309 specifically addresses protection against decay. It states that all pressure-treated wood foundation members must bear the quality mark of a quality control inspection agency for pressure-treated wood that has been approved by the State Building Code Council. It does not contain any explicit requirements regarding grades of lumber used for vertical foundation members or cross bracing. Contractors and inspectors must therefore depend on their judgment in determining acceptable grades of lumber for these applications. To help avoid situations in which foundation strength is compromised by the use of lower-quality wood materials (as depicted in Figure 2-20), the State should consider amending the Code to include prescriptive language regarding the grade of wood materials used for vertical members and cross bracing in structure foundations.

3.1.4 Proper Elevation of Coastal Buildings

Buildings constructed in Coastal High Hazard Areas (V zones — as shown on NFIP FIRMs) must be elevated so that the lowest horizontal structural member of the lowest floor is at or above the BFE and the area below the building is free of obstructions. These requirements are intended to allow velocity flows and waves to pass freely under the building. When a building in a V zone meets these requirements, its lowest floor is usually 12 inches or more above BFE, because of the thickness of the floor diaphragm and the supporting beams. FIRMs for coastal communities usually show A zones landward of V zones. In A zones, a building's lowest floor must be elevated to or above the BFE, and areas below the BFE may contain obstructions. In B, C, and X zones, no elevation requirements apply.

The practice of elevating buildings on open foundations and ensuring that the lowest horizontal structure member is above the BFE was widely used in A, B, C, and X zones on the barrier islands impacted by Hurricane Fran. Homes in these zones were often elevated 8 to 9 feet on embedded piling foundations to allow below-building parking and storage. This practice undoubtedly resulted in much lower damages than would have occurred if the lowest floors of these homes had been elevated to the BFE in A zones and not elevated in B, C, and X zones. The practice of requiring V zone construction standards in coastal A zones exceeds NFIP minimum requirements. Coastal A zones subjected to velocity flow and wave action are not distinguished from other A zones on FIRMs. Communities on barrier islands may want to consider adopting stricter standards in areas of known high coastal hazard, whether or not they are currently identified as V zones.

A building elevated so that its lowest floor is above BFE can qualify for an extremely favorable flood insurance rate. Rates for buildings in both Zone A and Zone V are lowered incrementally for each 1-foot increase in the height of the lowest floor above the BFE, up to a maximum of 4 feet. For buildings at this height, the rate reduction is 33 percent in Zone A and 60 percent in Zone V. Rate reductions are justified because a building that exceeds the minimum elevation requirements generally has a low risk of being significantly damaged by flooding. Therefore, in the design process for a new building, elevating above the BFE is well worth considering. Local insurance agents can provide information concerning the flood insurance rates associated with elevating above the BFE.

3.1.5 Cross-Bracing Below Elevated Buildings

Whenever possible, piling foundations should be designed to withstand simultaneous wind and flood loads without the use of cross-bracing. Alternatives to cross-bracing that may provide the necessary stability include incorporating a structural, unroofed deck into the building design to increase the building footprint; using pilings that are larger, longer, or both; and reducing piling spacing. When cross-bracing is necessary, its use should be minimized to the extent possible, especially where it would be perpendicular to velocity flow, wave action, and debris impact. Whenever cross-bracing is used, regardless of its orientation, it must be designed to withstand the anticipated wind and flood loads.

3.1.6 Solid Perimeter Masonry Foundation Walls Supported on a Continuous Footing

The use of solid perimeter foundation walls in coastal flood hazard areas should be scrutinized carefully. Since these foundations create large obstructions to velocity flow and are usually backfilled with the native sandy material, they are extremely susceptible to extensive localized scour. This condition was observed to have occurred even in overwash areas where accretion of sand occurred. Scour occurred where the velocity flow was disrupted at the seaward face of the obstruction and where the flow reconverged at the landward face of the obstruction.

Only where an engineering analysis of potential scour has been completed by a professional engineer should coastal communities consider allowing solid perimeter wall foundation systems in landward areas subject to high-velocity flow. Engineering solutions to this problem could include backfilling the foundation excavation with soil that is resistant to scour and installing the footing at a depth that is below the expected depth of scour (see Figure 3-1). The preferred solution is to construct piling foundations in landward areas subject to high-velocity flow. Of course, solid perimeter walls should never be used in oceanfront areas and are not permitted in V Zones.

3.1.7 Manufactured (Mobile) Home and Permanently Installed RV Foundations

Manufactured (mobile) homes and permanently installed RVs are usually supported on dry-stack masonry foundations. When manufactured homes and RVs are installed, steps should be taken to protect them from the damage caused by foundation collapse due to scour, anchor strap failure due to corrosion, and anchor strap pullout due to the use of the wrong size or type of anchor.

Protecting the foundation from localized scour requires either controlling scour or providing a foundation that extends to a depth that is below the expected depth of scour. For example, controlling scour may involve excavating the area under the footprint of the home and replacing the excavated soil with a non-scourable soil or installing a geotextile fabric beneath the home. If a fabric is installed, it must be keyed-in around the edges so that the scour will not undercut the

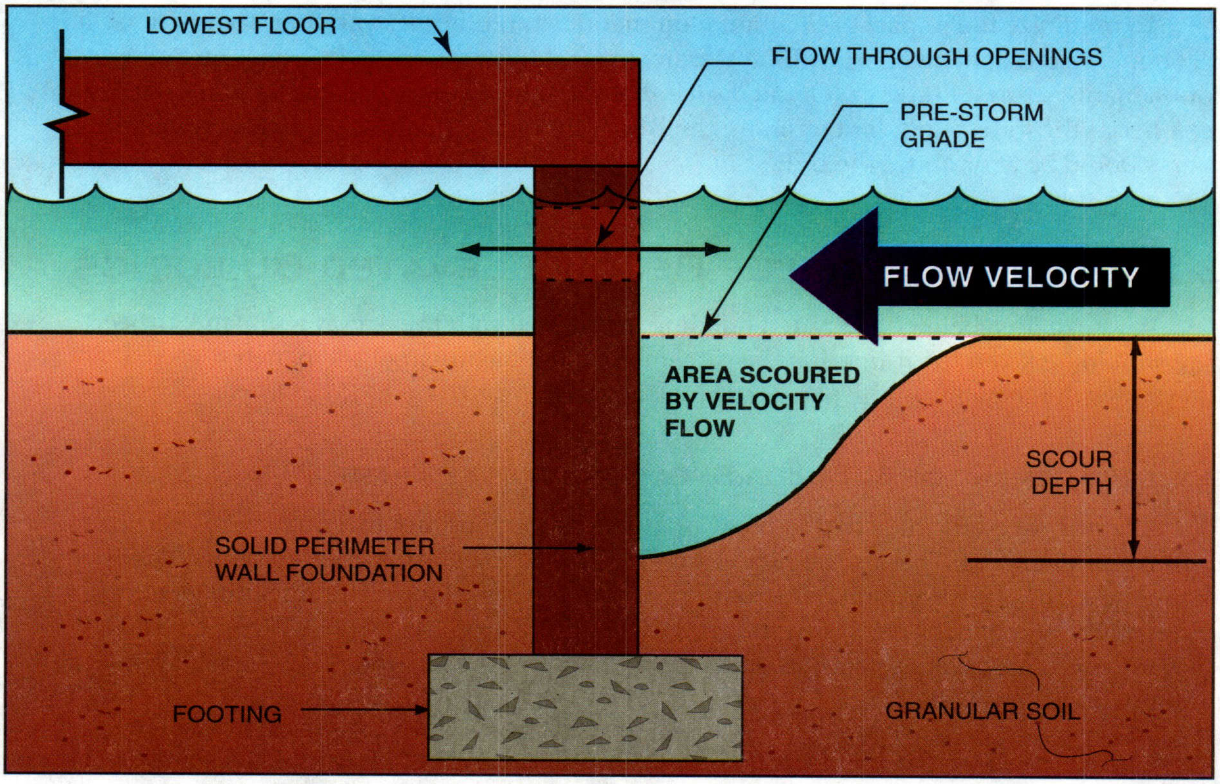

Figure 3-1 Deepening foundation to account for scour.

fabric. Providing a deep foundation can be done at minimal expense. A power-driven auger can be used to drill holes to a depth that exceeds the depth of the scour. The augured holes should be at least 1 foot in diameter and should exceed the expected scour depth by at least 1 foot. The deep foundation can consist of a wood post or cast-in-place concrete footing.

Metal straps used to tie down manufactured homes and RVs can become loose over time. In coastal areas, metal straps are also subject to higher rates of corrosion. Loose or corroded straps exposed to the loads imposed by high winds and flood waters are prone to failure, which can lead to damage to the foundation and home. It is critical that straps be checked periodically for both proper tension and corrosion. Checks for tension should be made frequently throughout the hurricane season and are especially important after high-wind events. All loose straps should be tightened according to the manufacturer's specifications. Straps that show visible signs of corrosion should be replaced. In coastal areas, metal straps have been shown to exhibit signs of corrosion after 3 to 5 years of exposure.

Pullout of anchors to soil saturation can be minimized through the use of the proper size and type of anchor. Anchors used in sandy soils prone to saturation by flood waters must either be long enough that the helical plates extend to a depth below the saturated soil, into soil that can resist anchor pullout, or be designed to work properly in saturated soil. In coastal areas subject to high-velocity flow that have loose to medium-dense sands and other granular soils, anchors should be at least 4 feet long and 3/4 inch in diameter and should have helical plates at least 6 inches in diameter. Major anchor manufacturers provide guidelines for selecting and installing the appropriate anchor according to the size of the home, the soil type at the installation site, and other conditions that can affect anchor performance. The manufacturer's specifications and recommendations should always be followed in the selection and installation of anchors.

To minimize the impact of tidal surge on manufactured homes and their foundations, it is recommended that in all Special Flood Hazard Areas subject to coastal flooding, including A zones, manufactured homes be elevated such that the bottom of the lowest horizontal structural member of the lowest floor is at or above the BFE. This means that the bottoms of the chassis I-beams would be at or above the BFE.

3.2 Breakaway Walls Below Elevated Buildings

When an area below an elevated building is enclosed with breakaway wall panels, special care should be taken to ensure that the placement and attachment of the panels does not interfere with the ability of the panels to break away when acted on by flood forces.

3.2.1 Placement of Exterior Sheathing Over Pilings

Exterior sheathing attached to breakaway wall panels must not extend over the vertical foundation members. This also applies to wire mesh used in exterior stucco systems. There should be a free and clear joint between the panels and vertical foundation members so that unnecessary lateral loads are not transferred to the foundation (see Figures 3-2 and 3-3). FEMA's *Coastal Construction Manual* provides guidance on how to fabricate wood-frame, metal-frame, and masonry breakaway panels.

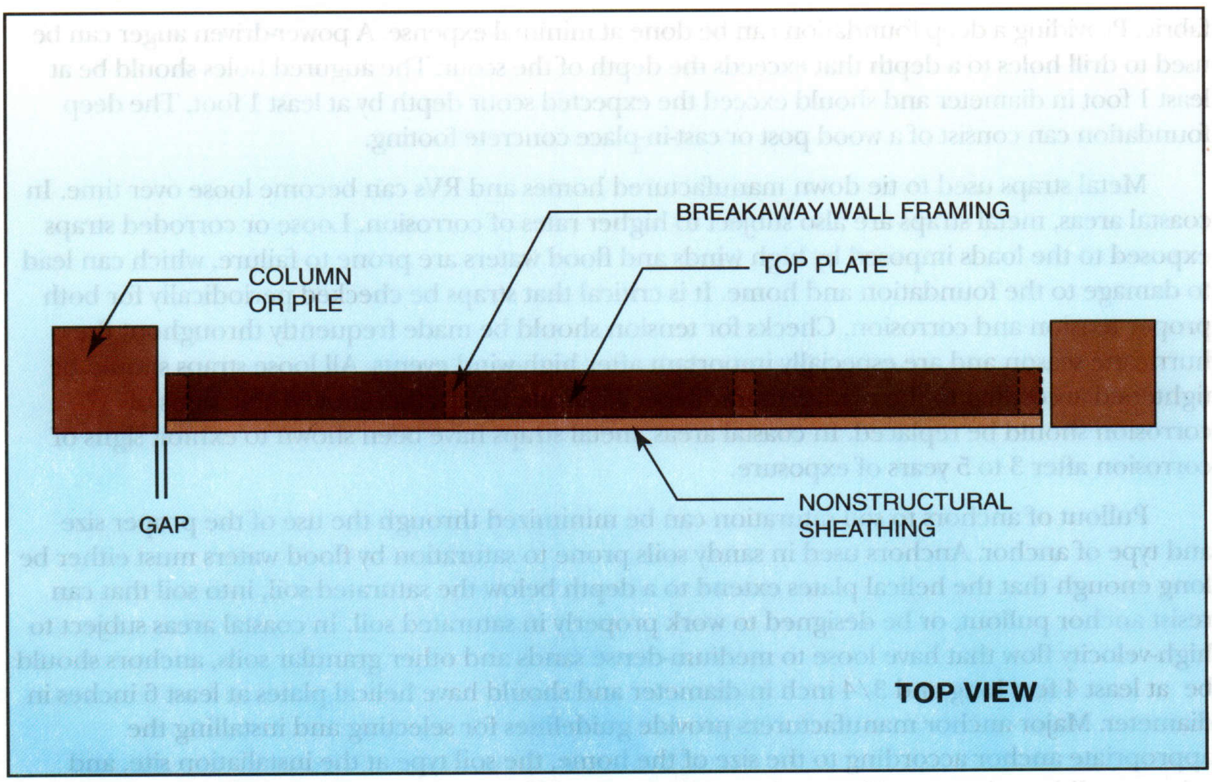

Figure 3-2 Recommended practice for breakaway wall sheathing.

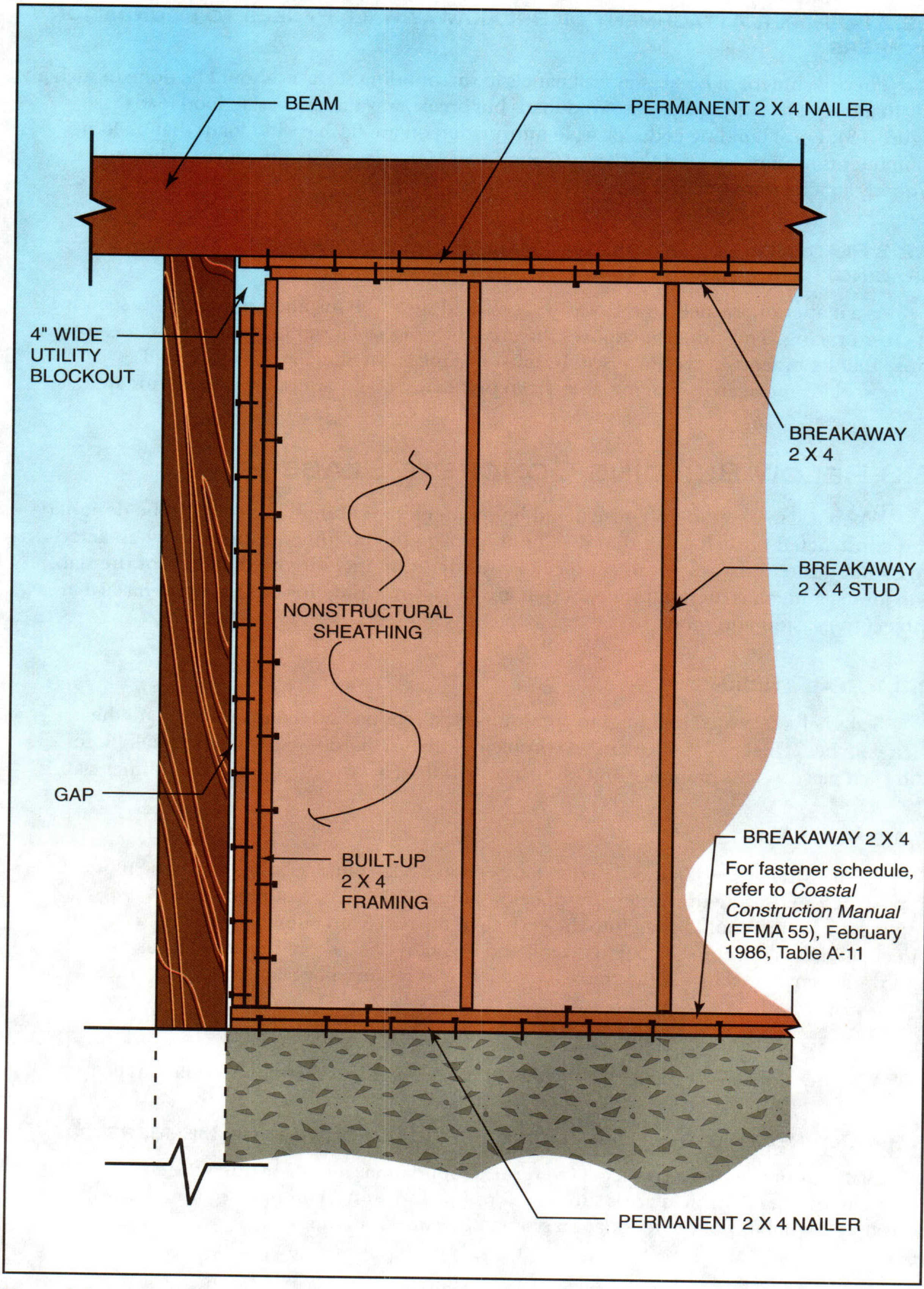

Figure 3-3 *Recommended breakaway wall attachment.*

3.2.2 Improper Attachment of Breakaway Wall Panels to Foundation Members

The attachment of breakaway wall panels to surrounding surfaces should be done in such a way that the panels will safely resist wind loads but break away under coastal flood loads (see Figure 3-3). Local building codes provide information on applicable wind loads that building components must resist. FEMA's *Coastal Construction Manual* provides guidance on how to properly attach breakaway wall panels.

3.2.3 Placement of Breakaway Wall Panels Seaward of Cross-Bracing

As a matter of practice, breakaway walls should never be installed immediately seaward of cross-bracing. This practice exposes the cross-bracing to lateral loads that far exceed those that 2x bracing is able to resist. In most instances, an alternative is to install latticework or move cross-bracing away from breakaway wall panels, into an interior area.

3.3 Below-Building Concrete Slabs

When a slab-on-grade is constructed below an elevated building, it should be designed and constructed in such a way that it will not damage the building foundation when acted on by flood forces. 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.

3.3.1 Slab Thickness

Slabs below elevated buildings in areas subject to erosion and scour should be no thicker then 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.

3.3.2 Slab Joints

Of the three types of joints described in Section 2.5.2, contraction joints are the most important for ensuring the frangibility of below-building slabs. As shown in Figure 3-4, 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.

3.3.3 Wire Mesh

Wire mesh retards the ability of the slab to break apart and therefore should not be used.

3.3.4 Connecting the Slab to the Vertical Foundation Members

Slabs should never be connected to vertical foundations 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.

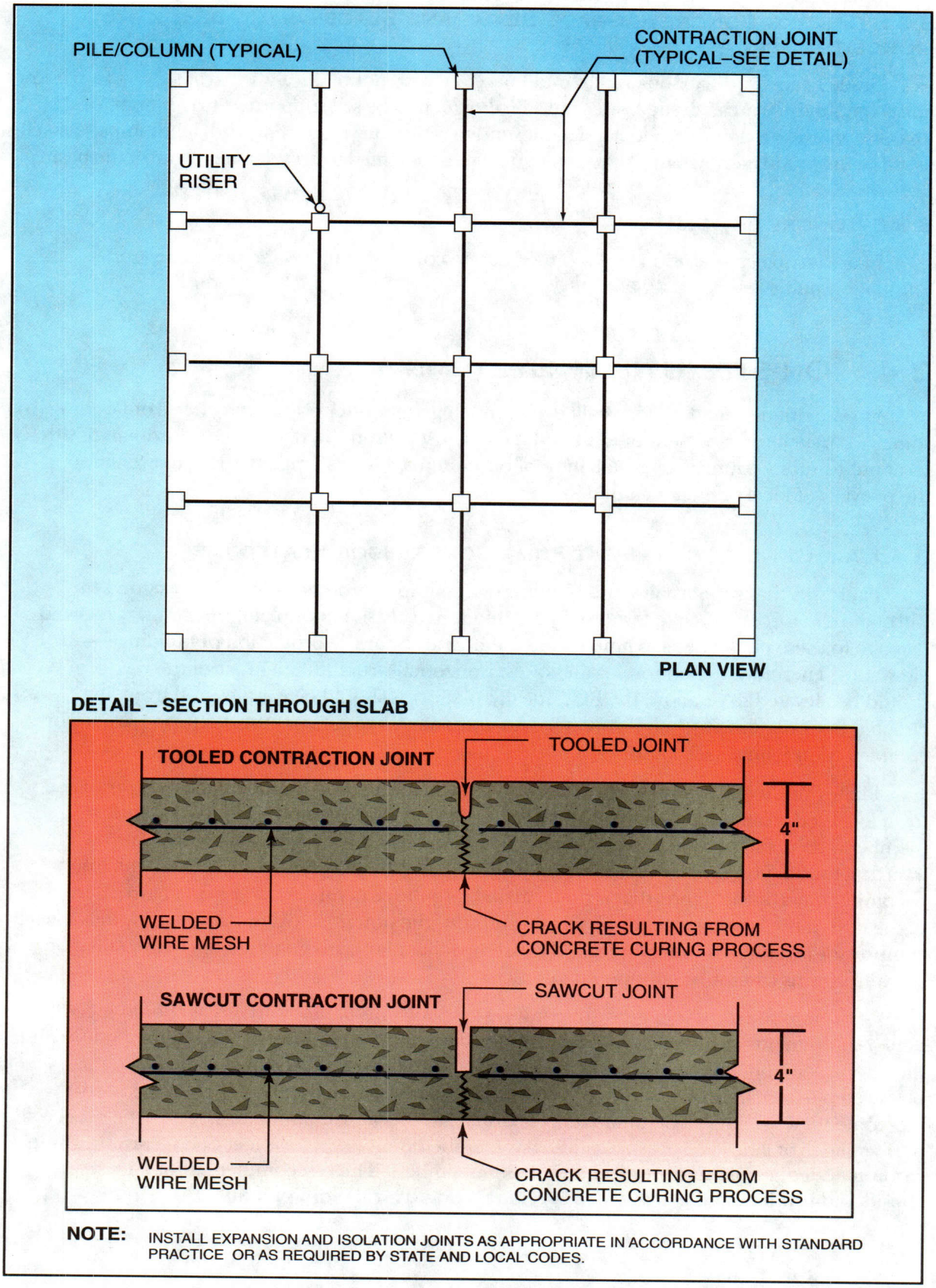

Figure 3-4 *Recommended contraction joint layout for frangible slab-on-grade below elevated building.*

3.3.5 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 designed to act separately from grade beams.

3.3.6 Concrete Collars

In areas subject to erosion and scour, concrete collars should not be placed around foundation pilings.

3.4 On-Site Utility Systems

On-site utilities need to be installed with much greater attention to the effects of flooding. In some cases, such as placement of electrical meters, installation will need to be coordinated with local public utility companies. Installation of other items, such as septic systems, may fall under the purview of local or State health departments.

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 a coastal floodplain, 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, platforms should be cantilevered from an elevated floor diaphragm (see Figure 3-5). An alternative is to support the platform partially or completely on pilings (see Figure 3-6).

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 looses it ability to support the platform, the platform collapses, becoming waterborne debris that is then carried into the structure or nearby structure. Because of the cost of the compressor (often $2,000 and up), the potential loss of habitability when the compressor is rendered inoperable, and the debris that platforms generate once they collapse, these platforms cannot be considered sacrificial.

Vertical foundation members for compressor platforms in landward areas should meet the same requirements as the main building support system. In areas subject to scour, embedment of these foundation members should be based on a depth related to existing grade. From the observed performance of oceanfront buildings, an embedment depth of -10 feet m.s.l. is recommended for all vertical foundation members for oceanfront buildings. From the observed performance of landward coastal buildings, an embedment depth of 8 feet below existing grade is recommended for platform vertical foundation members. These recommendations are considered prudent in the absence of specific State and local requirements.

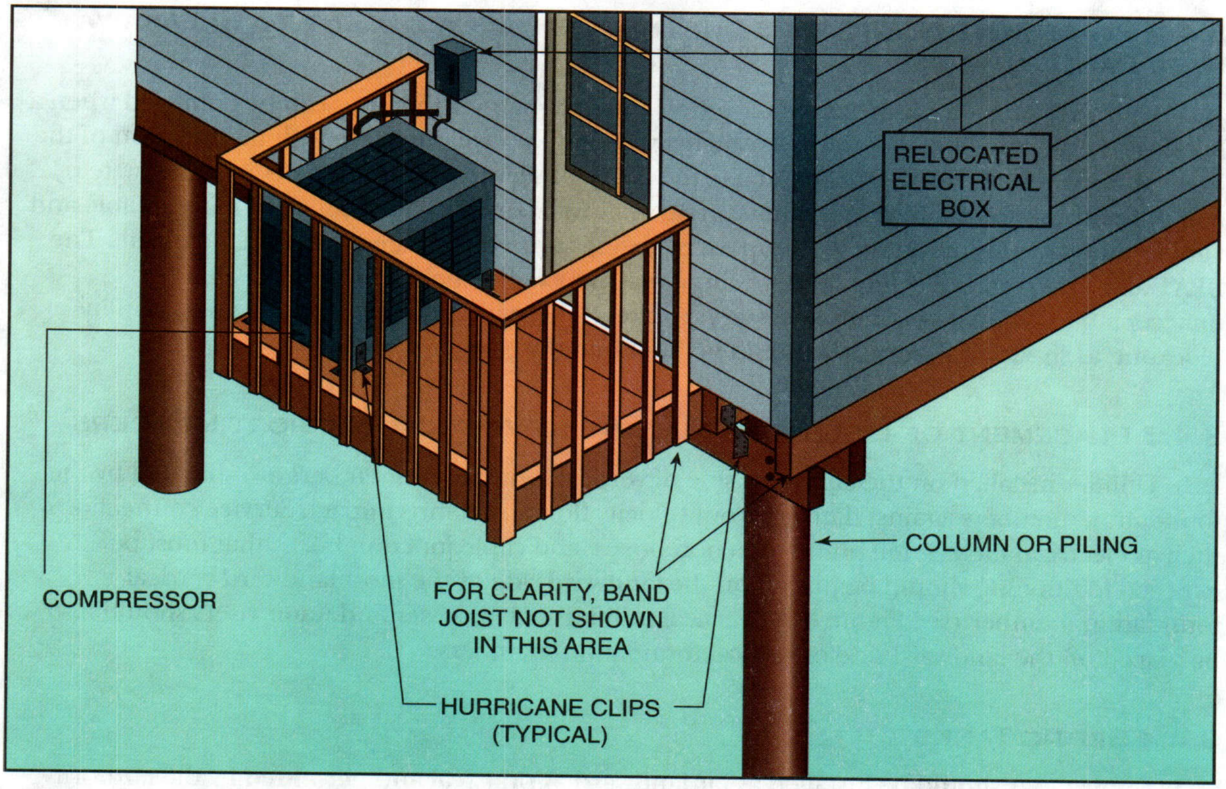

Figure 3-5 *Cantilevered mechanical platform.*

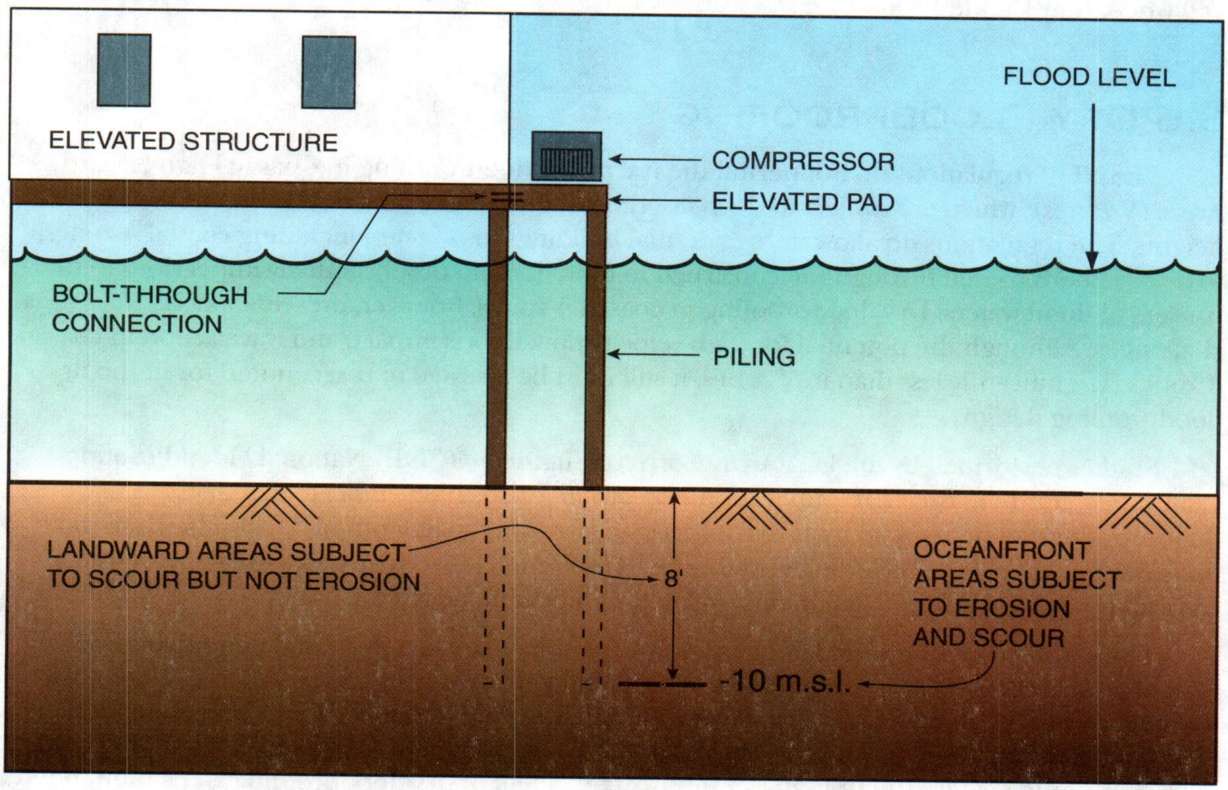

Figure 3-6 *Mechanical platform supported by pilings.*

3.4.2 Placement of Utilities On, Through, or Adjacent to Breakaway Wall Panels

Utility services should never be placed in a such a manner that they can be damaged when a breakaway wall panel breaks away or in such a way that they will interfere with the function of the breakaway panels. As noted in Section 2.6, the BPAT observed numerous types of utility system components mounted on or adjacent to breakaway wall panels. This practice is unacceptable and almost always results in the utility components being severely damaged during a hurricane. The BPAT also observed utility lines penetrating breakaway wall panels. This practice is also unacceptable. When it becomes necessary to extend these lines through a wall panel, a utility blockout, as shown in Figure 3-3, should be built into the wall.

3.4.3 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 (see Figure 3-7). Vertical utilities such as sewer and water risers should also be placed on the landward side of vertical foundation members.

3.4.4 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 having regulatory control should be consulted concerning whether such tanks are permissible and how and where they should be installed.

3.5 Dry Floodproofing

The NFIP regulations do not permit the use of dry floodproofing in Coastal High Hazard Areas (V zones), which are subject to deep flooding, high-velocity flow, debris impact, and wave heights. The regulations do allow nonresidential buildings in A zones, including coastal A zones, to be dry floodproofed through the construction of walls that are substantially impervious to the passage of flood waters. Dry floodproofing in coastal A zones, however, presents special challenges. Although the potential for high-velocity flow, debris impact, and wave action in coastal A zones is significantly less than in V zones, it still must be assessed and accounted for in the dry floodproofing design.

Studies performed by the U.S. Army Corps of Engineers (COE) National Flood Proofing Committee, found in the COE publication *Floodproofing Tests*, 1988, indicate that dry floodproofing can be used in areas that experience flooding to a depth of 3 feet. The COE did not study coastal effects, including wave action. Wave action, especially waves breaking on the vertical dry floodproofing components, will add significant loads to the floodproofing system.

Therefore, it is recommended that dry floodproofing be used in coastal floodplains only where the stillwater depth is no more than 2 feet above grade during the base flood. Where the stillwater depth is 2 feet, the wave crest elevation will be approximately 1 foot above the stillwater elevation, and wave breaking and overtopping will reach even higher. To protect a building from wave overtopping where the stillwater depth is 2 feet, 4 feet of dry floodproofing is recommended (see Figure 3-8). In no case should the increase in floodproofing height be used to compensate for higher stillwater depths without a detailed engineering analysis.

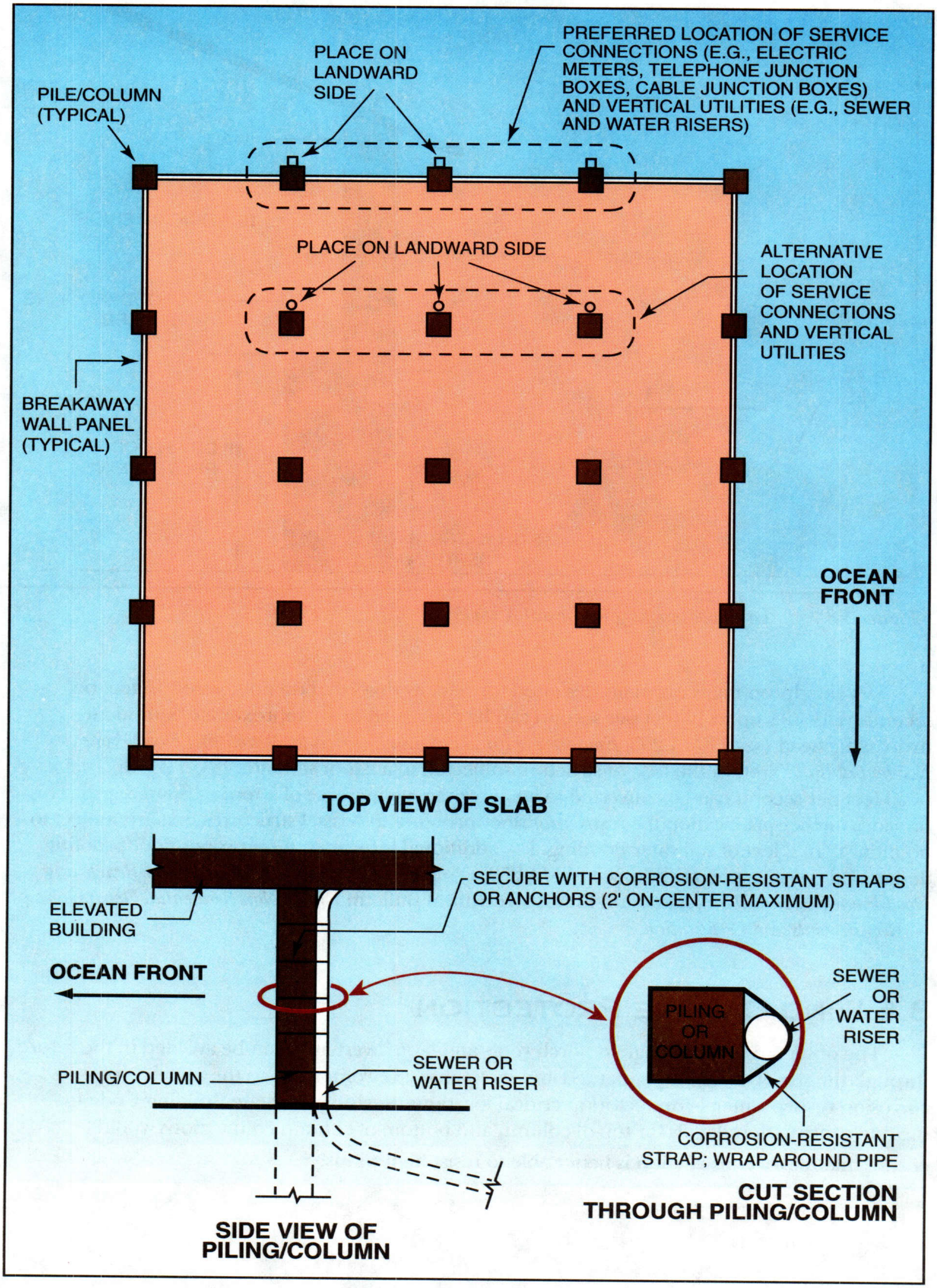

Figure 3-7 Proper location of utilities.

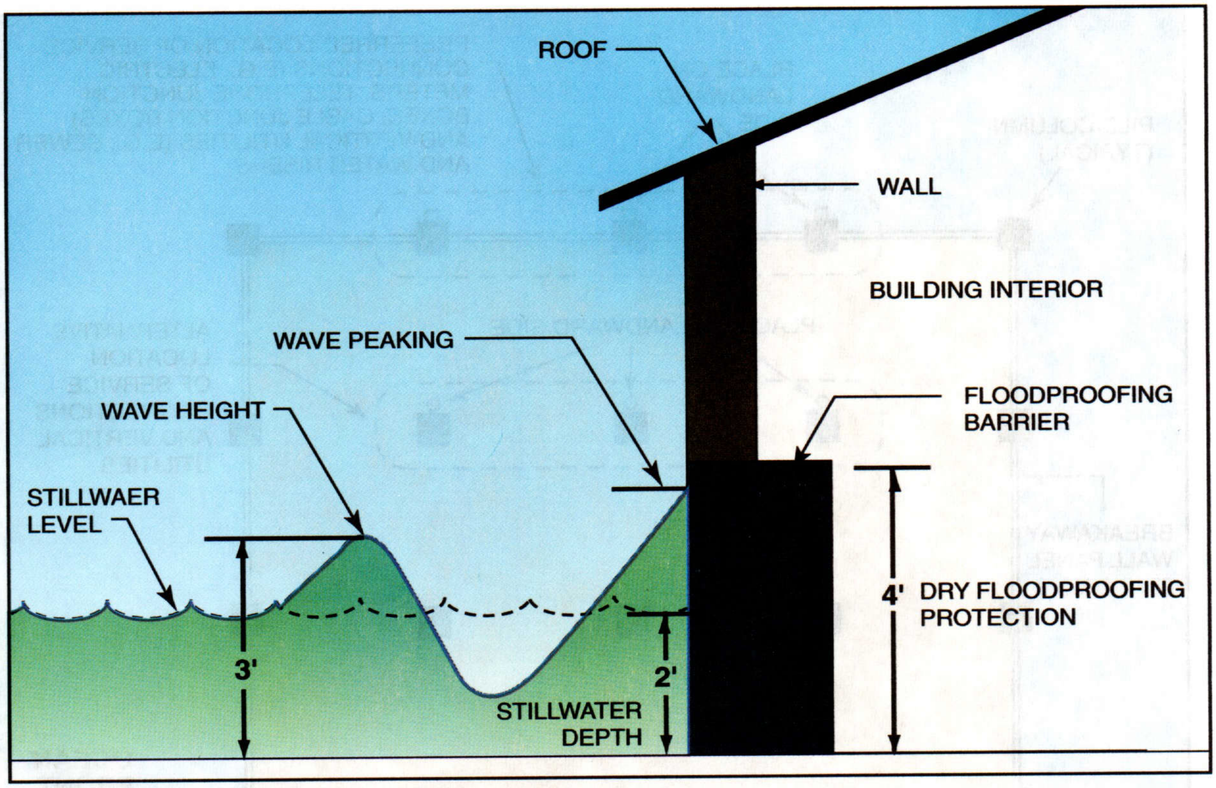

Figure 3-8 *Dry floodproofing in coastal A zones.*

Dry floodproofing is normally designed for velocity flows that do not exceed 10 feet per second. Velocities up to 10 feet per second can be converted to an approximate equivalent hydrostatic head (see FEMA 259: *Engineering Principles and Practices for Retrofitting Flood Prone Residential Buildings*). In the case of structure subjected to a 2-foot stillwater flood depth, a velocity of 10 feet per second can be converted to an approximate increase of 1 foot of flood depth. This provides further justification for restricting floodproofing to coastal structures that are subject to no more than 2 feet of stillwater flooding. For additional information on proper floodproofing design and construction criteria, see FEMA 259, *Engineering Principles and Practices for Retrofitting Flood-Prone Residential Structures,* and FEMA's Technical Bulletin No. 3, *Non-Residential Floodproofing — Requirements and Certification.*

3.6 Wind Damage Protection

The observed wind damage to porch roofs and large overhangs can be avoided in the future through the use of easily implemented and inexpensive retrofits, such as the addition of corrosion-resistant metal connectors at critical locations. Revising the State Building Code to include construction details for top-of-column and bottom-of-column connections would help ensure that future construction is better able to resist high winds.

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. FEMA recently issued NFIP Technical Bulletin No. 8, *Corrosion Protection for Metal Connectors in Coastal Areas,* which provides guidance concerning the selection, installation, and maintenance of metal connectors such as truss plates and hurricane straps.

Appendix A

Building Performance Assessment, Damage Assessment, and Hazard Mitigation Reports Prepared by the Federal Emergency Management Agency

The Oklahoma City Bombing: Improving Building Performance Through Multi-Hazard Mitigation, in conjunction with the American Society of Civil Engineers, August 1996

Hurricane Opal in Florida, A Building Performance Assessment, August 1996

FEMA DR-TX-1041, Flooding in Southeast Texas from the Storm of October 15 - 21, 1994, August 1995

FEMA DR-GA-1033, Flooding in Georgia from Tropical Storm Alberto, January 1995

Preliminary Field Assessment — Hurricane Emily on the North Carolina Outer Banks, January 1994

Building Performance: Hurricane Iniki in Hawaii — Observations, Recommendations, and Technical Guidance, January 1993

Building Performance: Hurricane Andrew in Florida — Observations, Recommendations, and Technical Guidance, December 1992

Building Performance Assessment Team Report: Noreaster, Delaware and Maryland, January 1992

Flood Damage Assessment Report: Hurricane Bob, August 1991

Damage Assessment of Flooded Buildings 1985 - 1990, June 1991

Flood Damage Assessment Report: Tropical Storm Allison, June 1990

Flood Damage Assessment Report: Noreaster of April 1990, June 1990

Flood Damage Assessment Report: Riverine Flooding in Central Kentucky, February 1990

Flood Damage Assessment Report: Hurricane Hugo, October 1989

Flood Damage Assessment Report: Texas, June 1989

Flood Damage Assessment Report: Noreaster, Mid-Atlantic Coast, March 1989

Flood Damage Assessment Report: Riverine Flooding in Maine, June 1988

Flood Damage Assessment Report: Noreaster, Mid-Atlantic Coast, April 1988

Flood Damage Assessment Report: Riverine Flooding in Central Michigan, May 1987

Flood Damage Assessment Report: Riverine Flooding in Allegheny County, Pennsylvania, January 1987

Flood Damage Assessment Report: Riverine Flooding in Clive, Iowa, September 1986

Flood Damage Assessment Report: Hurricane Gloria, February 1986

Improving Resistance of Buildings to Wind Damage: Hurricane Elena, September 1985

Hazard Mitigation Team: Hurricane Diana, 1984

Proposed Changes to Building Codes in Response to Hurricane Alicia, August 1983

Hazard Mitigation Report: Noreaster, Outer Banks, North Carolina, October 1982

Hazard Mitigation Report: Hurricane Frederic, September 1979

Appendix B

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Appendix C

Executive Summary from Piling Embedment Study Performed by Woodward-Clyde Federal Services on Topsail Island, North Carolina

Executive Summary

Purpose

As a result of Hurricane Bertha (July 12, 1996) and Hurricane Fran (September 5, 1996), a large number of structures were damaged on Topsail Island, North Carolina. Topsail Island includes the communities of Topsail Beach, Surf City, and North Topsail Beach. An initial review of the structures indicated that shallow embedment depth of their foundation pilings could have been the primary cause of structural failure due to the storms. FEMA contracted with Woodward-Clyde Federal Services (Woodward-Clyde) to perform testing and evaluation of the piling lengths and embedment depths. The purpose of the testing was to determine whether the pilings meet the embedment depth requirements of the current North Carolina State Building Code. The current version of the Code was implemented on January 1, 1986.

Project Execution

To identify oceanfront structures built after the implementation of the current Code (January 1, 1986), Woodward-Clyde obtained aerial photographs for Topsail Island from the North Carolina Department of Transportation. The photographs represent the periods immediately after January 1, 1986, prior to Hurricane Bertha, after Hurricane Bertha, and after Hurricane Fran. From these photographs, a total of 205 post-1985 oceanfront structures were identified. Duplex or multiplex units (two- to four-family structures) were considered single structures for purposes of this study.

Of the 205 structures, a total of 16 (7.8 percent) were identified as having leaning pilings (11 structures) or were identified as total losses (5 structures). Structures identified as total losses were either completely washed away by the storm or were so severely damaged that the structures were totally destroyed. Many of the 205 structures identified received other damage such as roof, wall, deck, and concrete damage caused by both flooding and high winds. However, the focus of this study was on damage to piling foundations that supported elevated residential one- to four-family structures.

Field inspections of the 205 oceanfront structures were conducted to identify piling damage and general building parameters. A total of 20 damaged and undamaged structures were initially identified for piling testing. However, after homeowner approvals were requested and received, it was determined that only 11 structures would be tested. These 11 structures include 7 structures with leaning pilings and 4 structures with no leaning pilings.

Testing Procedures

Using a nondestructive test methodology to determine total piling length, Woodward-Clyde tested 5 pilings at each structure, a sampling of approximately 25 percent. For the test, accelerometers were mounted directly to each piling. The piling then was struck on its side with a hammer. The hammer blow created dispersive stress waves that traveled the length of the piling. Data recorded by the accelerometers were then digitally processed and analyzed. Analysis of the data yielded a computation for the total length of the piling. Ground level and top-of-piling elevations were surveyed and used to determine piling embedment depth.

Typical accuracy using this type of testing is ± 10 percent. In three piling test cases, the return signals recorded were not accurate enough to allow for a piling length determination. Therefore, for 3 of the eleven 11 structures, only 4 instead of 5 pilings were tested, yielding a total of 52 tested pilings.

Piling Test Results

The current North Carolina State Building Code requires that piling tips be at -5 feet m.s.l. or 16 feet below grade, whichever is shallower. The findings of the tests are based on the evaluation of the piling embedment depths in relation to the -5 feet m.s.l. criterion, since this, rather than the 16 feet below grade criterion, is the controlling factor for piling embedment in the test area. This is because pre-storm grade elevations for most oceanfront houses on Topsail Beach were less than 11 feet m.s.l.

Of the 11 structures tested, 4 were one-story above the pilings and 7 were two or more stories above the pilings. The following table summarizes the findings.

No.	Stories Above Top of Piling	Pilings Leaning	Cross Bracing	Total Pilings per Structure	Piling Not Meeting Code	Average Differential to Meet Code[1] (Feet)
1	1	yes	yes	21	4 of 5	0.9
2	1	yes	yes	21	4 of 5	2.0
3	2	yes	no	20	4 of 4	4.7
4	2	yes	no	20	4 of 4	5.6
5	2	yes	no	15	5 of 5	3.3
6	2	yes	yes	15	4 of 4	4.2
7	2	yes	yes	12	5 of 5	6.1
8	3	no	no	30	2 of 5	3.4
9	2	no	no	15	1 of 5	0.7
10	1	no	yes	50	5 of 5	2.6
11	1	no	no	25	5 of 5	4.7

[1]Average differential is the average distance from the tip of piling to -5 feet m.s.l.

Note: Information on the effects of erosion and scour is provided in the sections of the report preceding this appendix.

ONE-STORY STRUCTURES (TOTAL OF FOUR)

- Two had leaning pilings.
- Three had some bracing, although none is required by the current Code. The structure that had no cross-bracing was not damaged.
- Ninety percent of the pilings tested for these four one-story structures (both with and without leaning pilings) did not meet the current Code requirement for piling embedment depth.

TWO- AND THREE-STORY STRUCTURES (TOTAL OF SEVEN)

- Five had leaning pilings.
- Two of the five structures with leaning pilings had cross-bracing at the time of the storm, but none of the structures had cross-bracing in accordance with the current Code. The two structures that did not have leaning pilings had no cross-bracing. It should be noted that the current Code allows for alternative bracing systems if they are designed and sealed by a Licensed Professional Engineer or Architect.
- Including the pilings within the 10-percent accuracy range, 78 percent of the pilings tested for the seven two-story structures (both with and without leaning pilings) did not meet the current Code requirement for piling embedment depth.

The following table provides a breakdown of the number of pilings by the amount of additional embedment depth necessary for the piling to meet the Code requirement. Of the 52 pilings tested (including those pilings within the 10-percent accuracy range), over 80 percent did not meet the Code requirement.

ADDITIONAL DEPTH (FEET) REQUIRED TO MEET CODE	NUMBER OF PILINGS
0	9
0-1	3
1-2	6
2-3	8
3-4	4
> 4	22

It was observed that all on the identified post-1985 structures that had leaning pilings, the pilings leaned inland in a westerly direction (the direction of the storm surge).

Conclusions

From the field observations and test results, Woodward-Clyde concludes the following:

- Approximately 92 percent of oceanfront structures built after the implementation of January 1986 Code changes did not sustain significant piling damage.
- All tested post-1985 structures that had leaning pilings did not meet the requirements of the current Code. Of all the pilings tested, both leaning and not leaning, over 80 percent did not meet the Code requirement.
- It appears that the Code requirement for piling embedment depth may be more effective in preventing piling damage than the requirement for cross-bracing. This includes those pilings within the 10-percent accuracy range.

From the test results and the field observations, it appears that a structure should sustain minimal piling damage if it is constructed according to the current Code requirements. However, several factors exist that prevent a complete evaluation of the piling requirements in the Code:

- The study involved testing only 11 of 205 post-1985 oceanfront structures.
- The findings for the piles not meeting Code are limited to structures whose piling embedment depth is controlled by the -5 foot m.s.l. criterion.
- The majority of the structures tested did not meet the embedment depth requirement of the Code, including those that did not have leaning pilings.

Recommendations

For the reasons cited above, the relative effectiveness of the two embedment criteria, "tip penetration of at least 5.0 below mean sea level or 16 feet below average original grade which ever is least," cannot be made. Therefore, Woodward-Clyde can not recommend a change to the piling embedment depth requirement of the North Carolina State Building Code at this time. Woodward-Clyde does, however, recommend that better construction and inspection practices be implemented to ensure proper installation of the pilings so that they at least meet the current Code requirements.