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

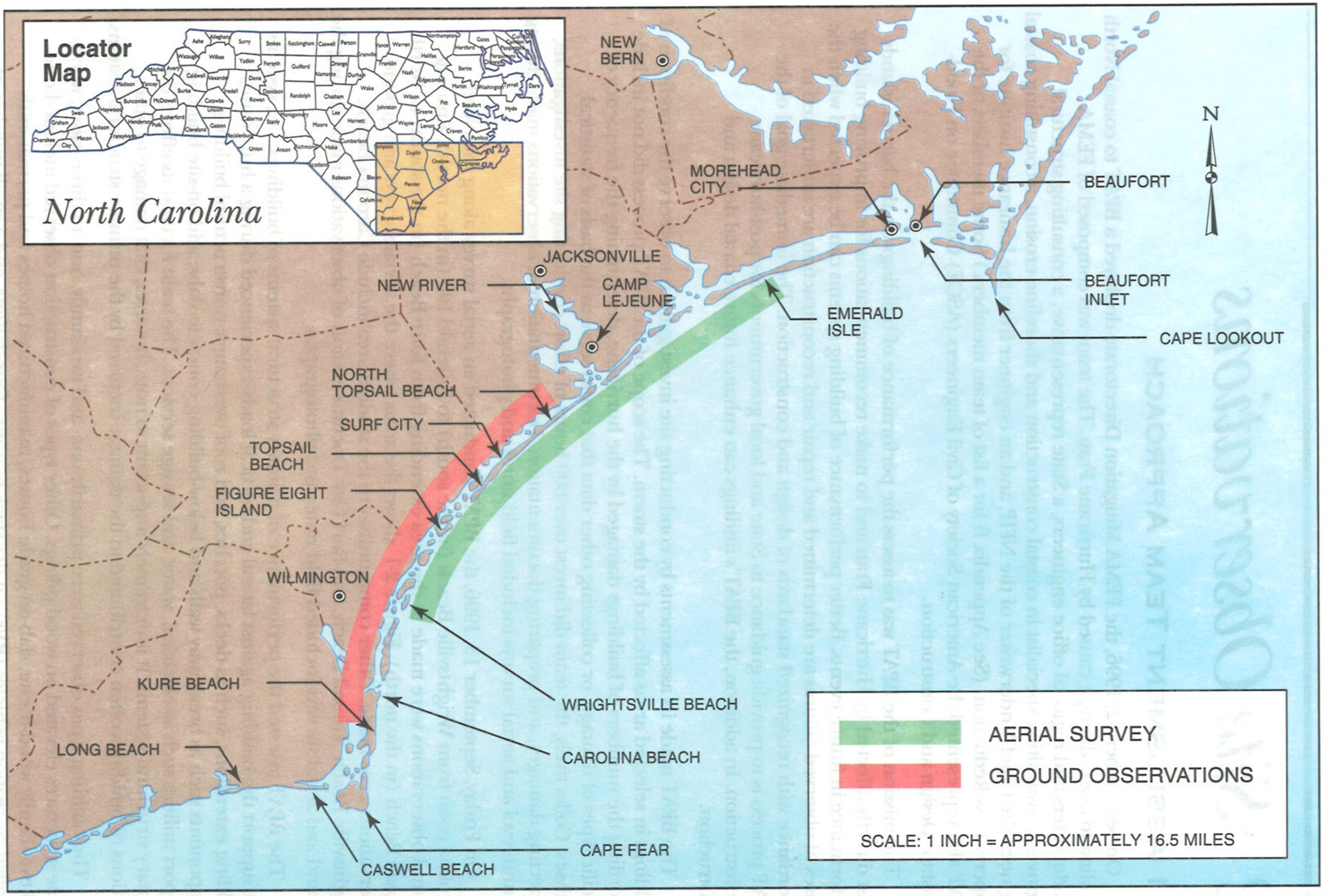

Figure 2-1 Areas of BPAT aerial survey and ground observations.

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.*

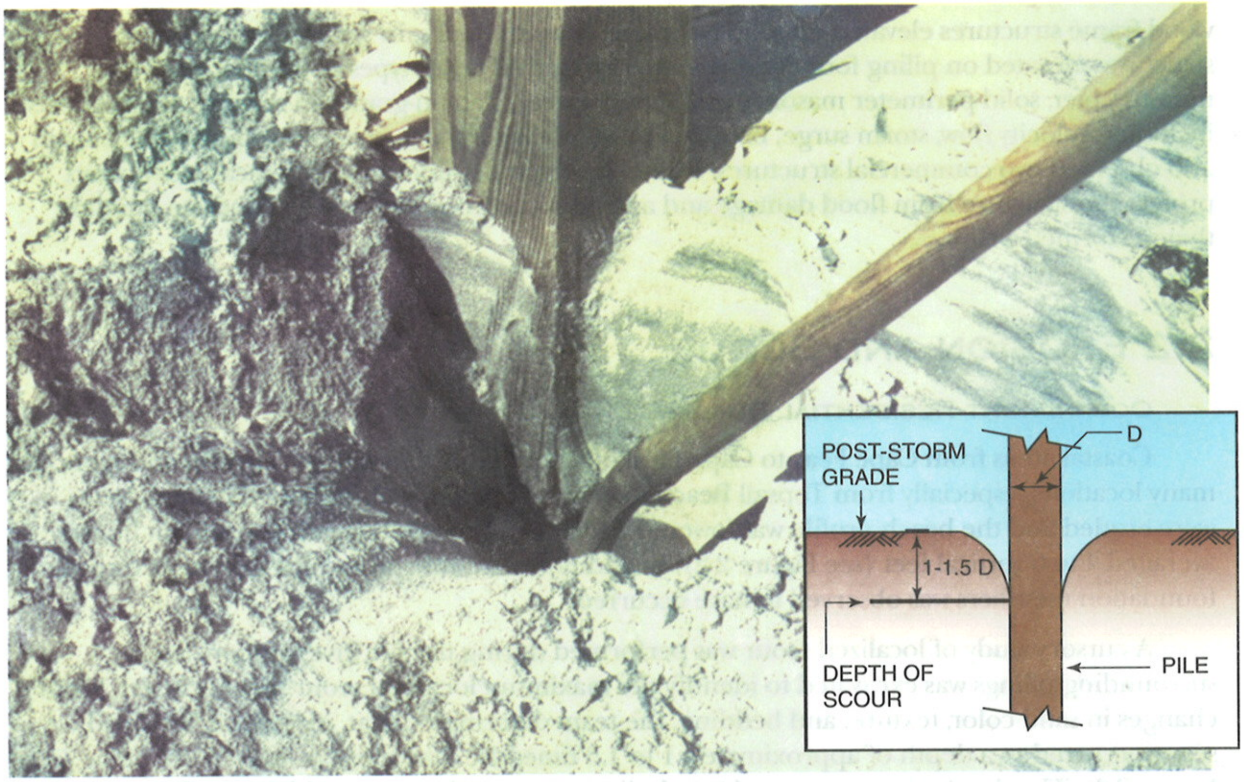

Figure 2-3 *Determination of localized scour from changes in sand color, texture, and bedding.*

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.

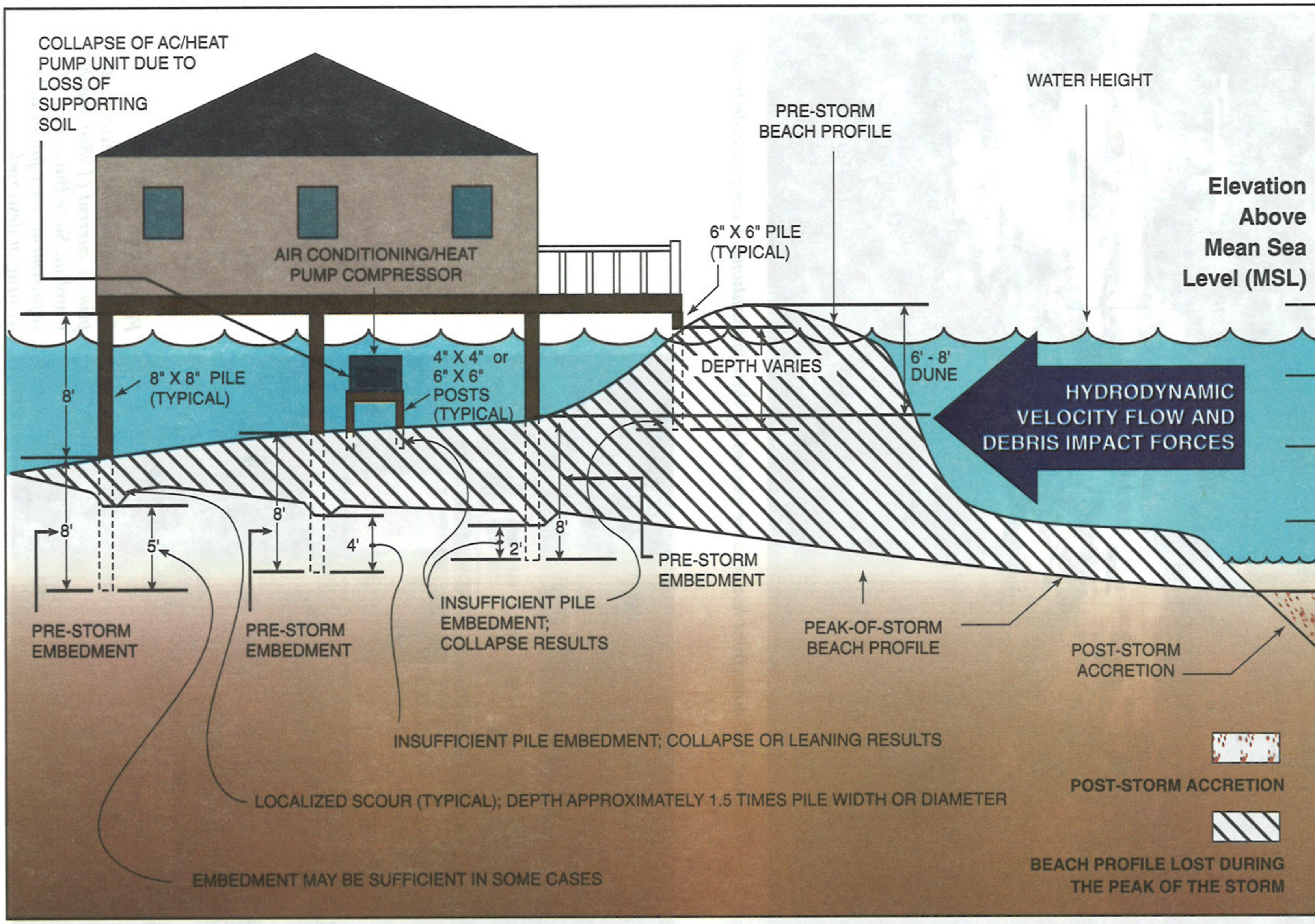

Figure 2-9 *Typical collapse mechanism of post-FIRM building based on pre-1985 embedment requirements in North Carolina coastal areas.*

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

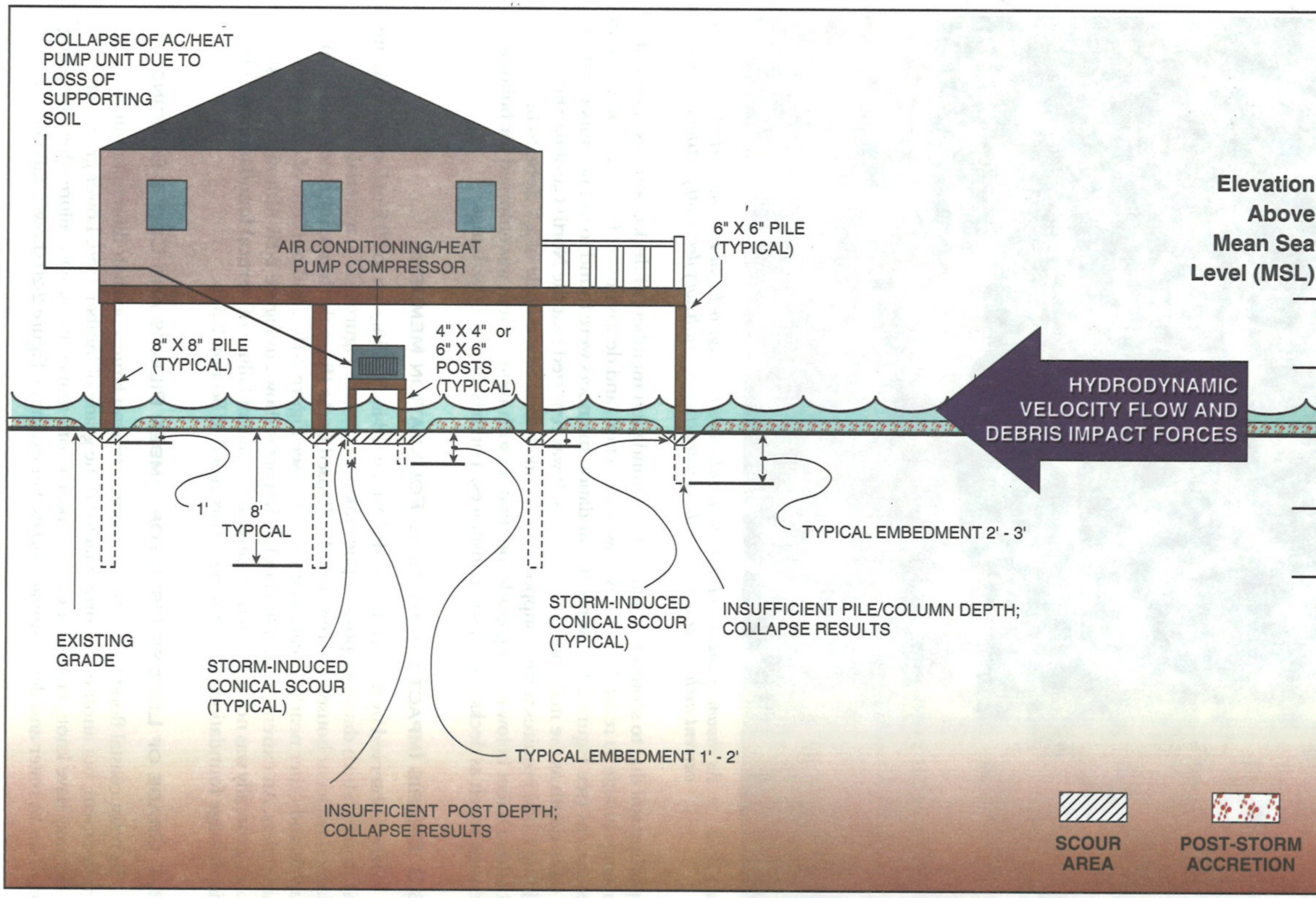

Figure 2-16 *Typical failure of deck / roof overhang and air conditioning / heat pump compressor platform for landward home.*

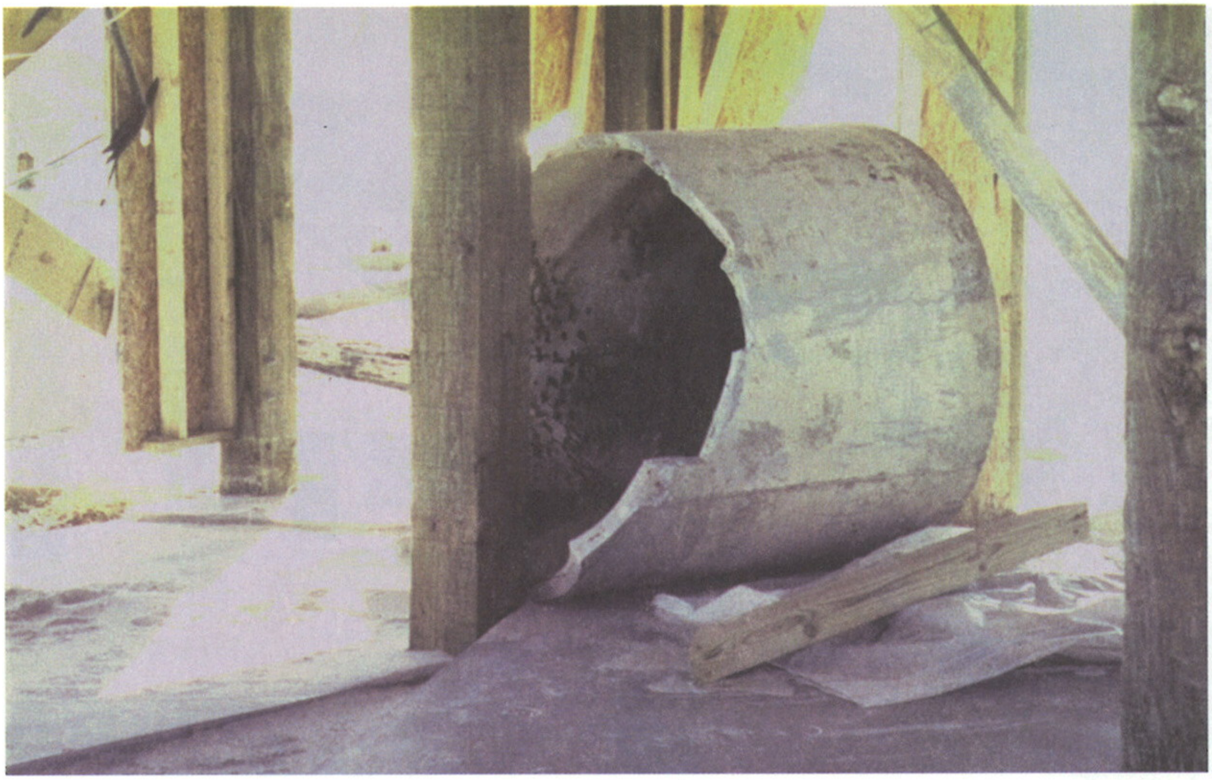

Figure 2-17 *Precast concrete ring section of septic tank became waterborne debris, impacting building foundation members.*

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.

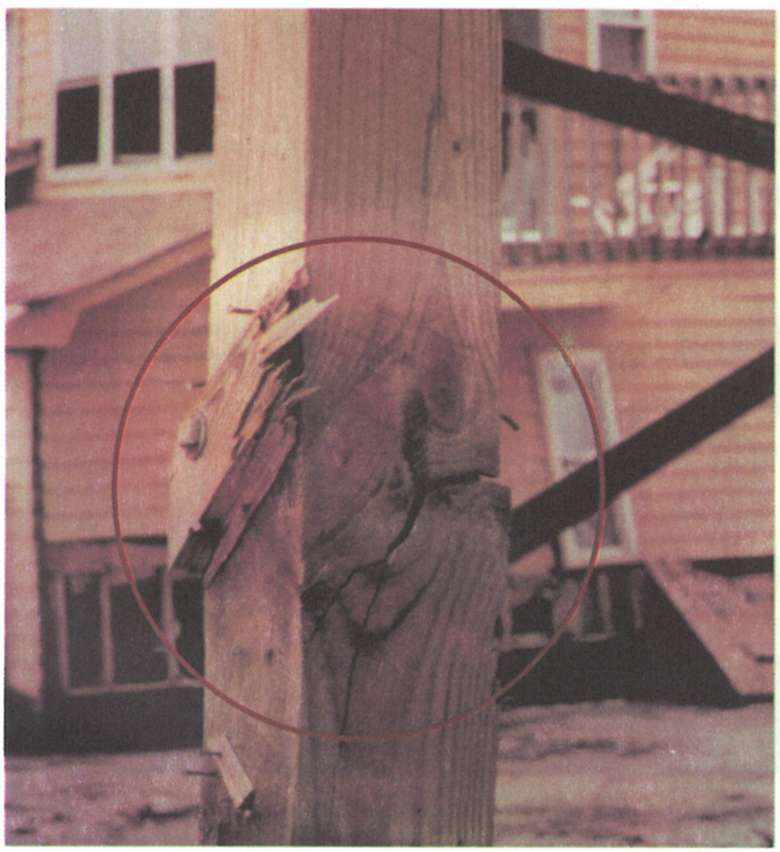

Figure 2-20
Example of broken piling. The piling broke at the location of several knots (circle), where cross-bracing was attached (note remaining bolt and piece of bracing).

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.*

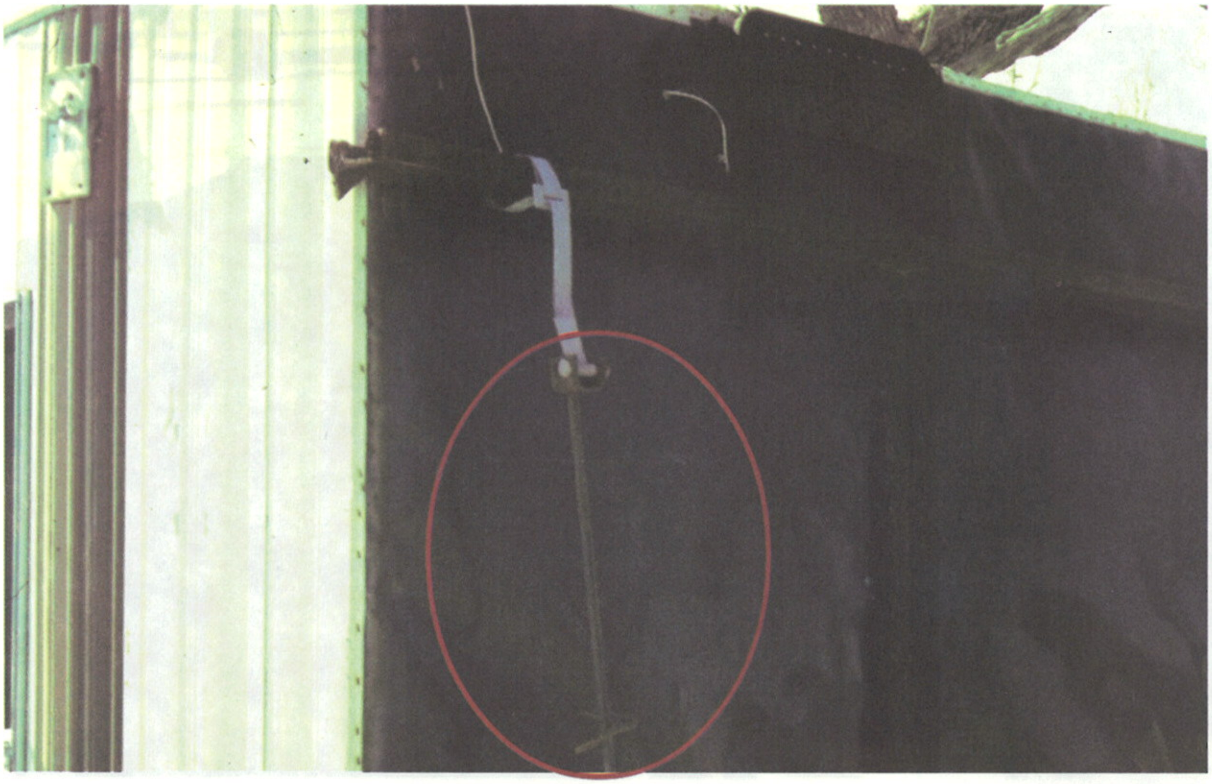

Figure 2-24 *Permanently installed RV overturned as a result of anchor pullout. Anchor (circled) is 2 feet long.*

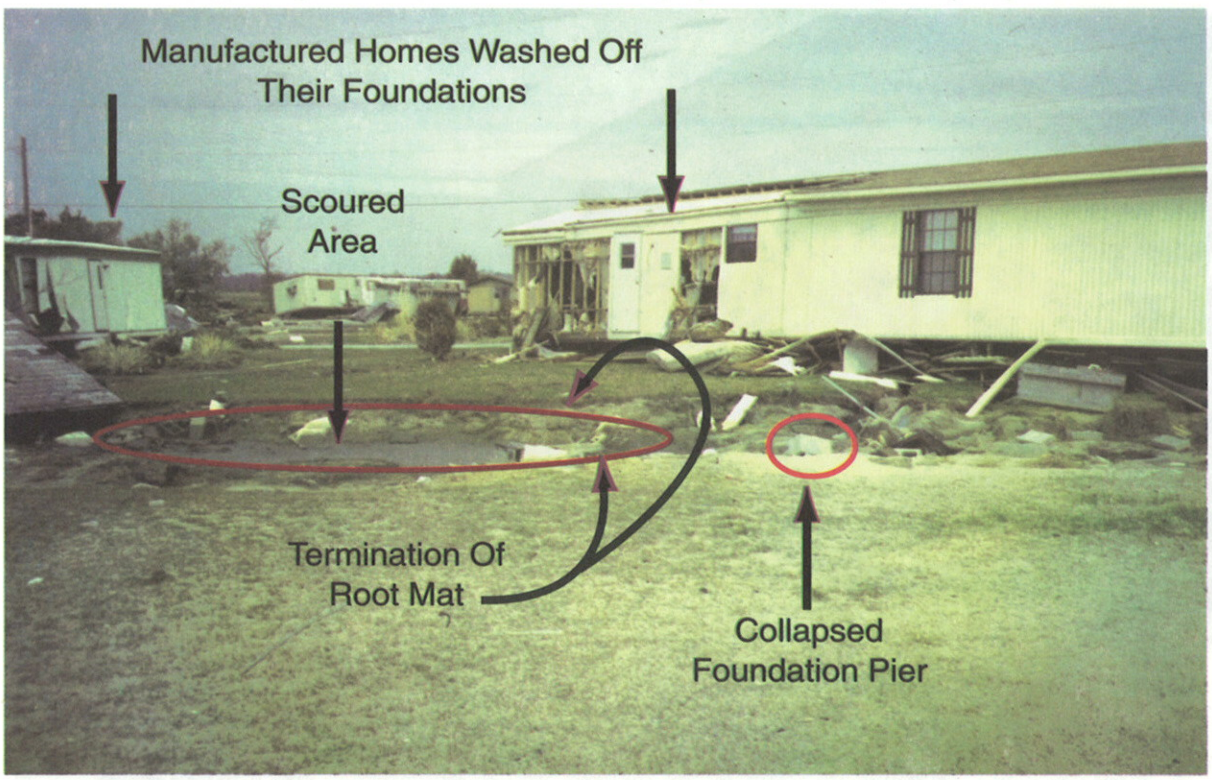

Figure 2-25 *Localized scour beneath pre-storm footprint of manufactured home. Note the collapsed dry-stack block foundation and termination of root mat, which otherwise would have helped stabilize the adjacent ground.*

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).

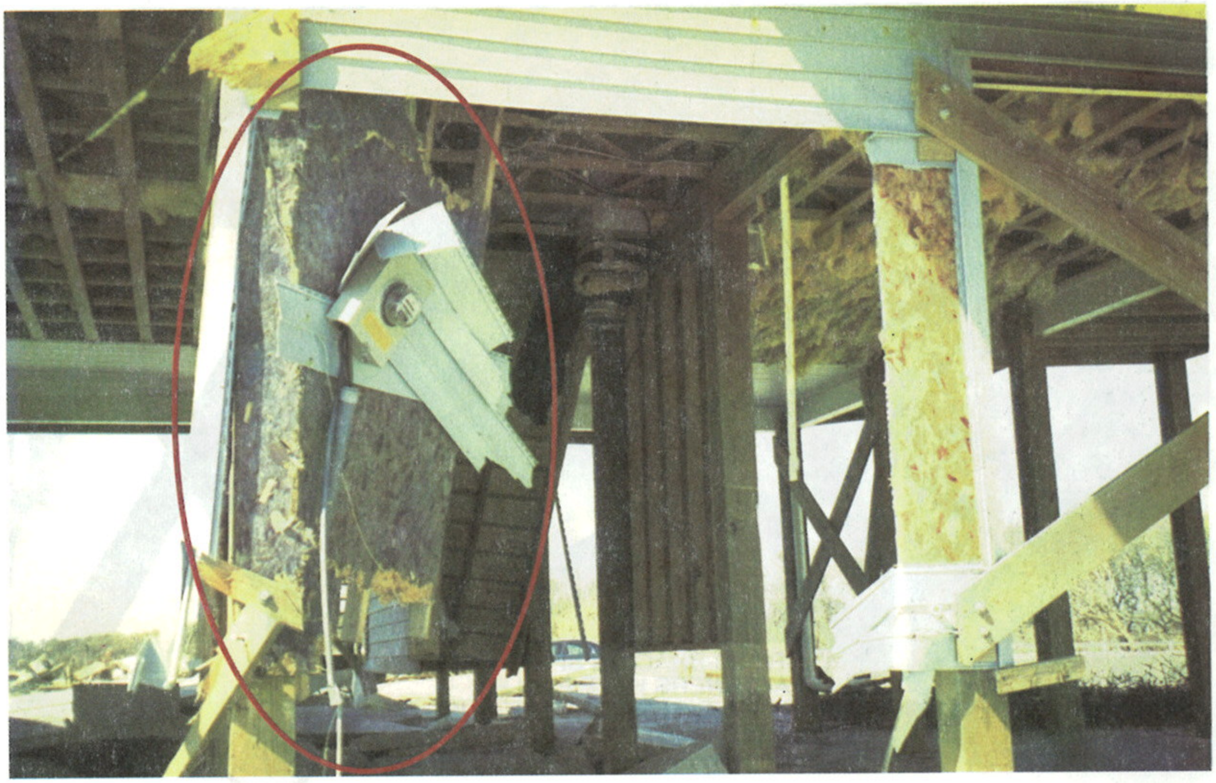

Figure 2-27 *Breakaway wall panel failed to function as designed because continuous sheathing was installed across pilings. No structural damage was observed; however, note damage to utility components installed on breakaway wall panel.*

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.*

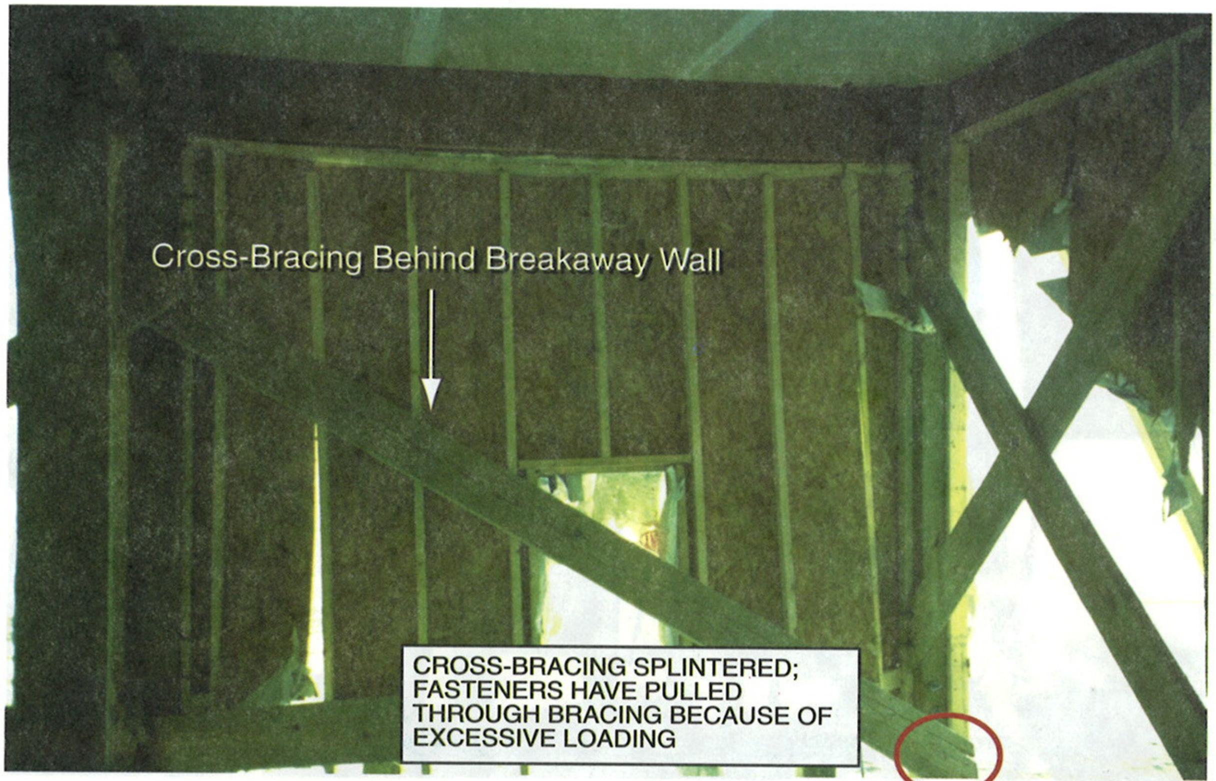

Figure 2-29 *Improper installation of breakaway walls (on the seaward side of cross-bracing) resulted in failure of cross-bracing. Note breakaway wall pushed against cross-bracing.*

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.

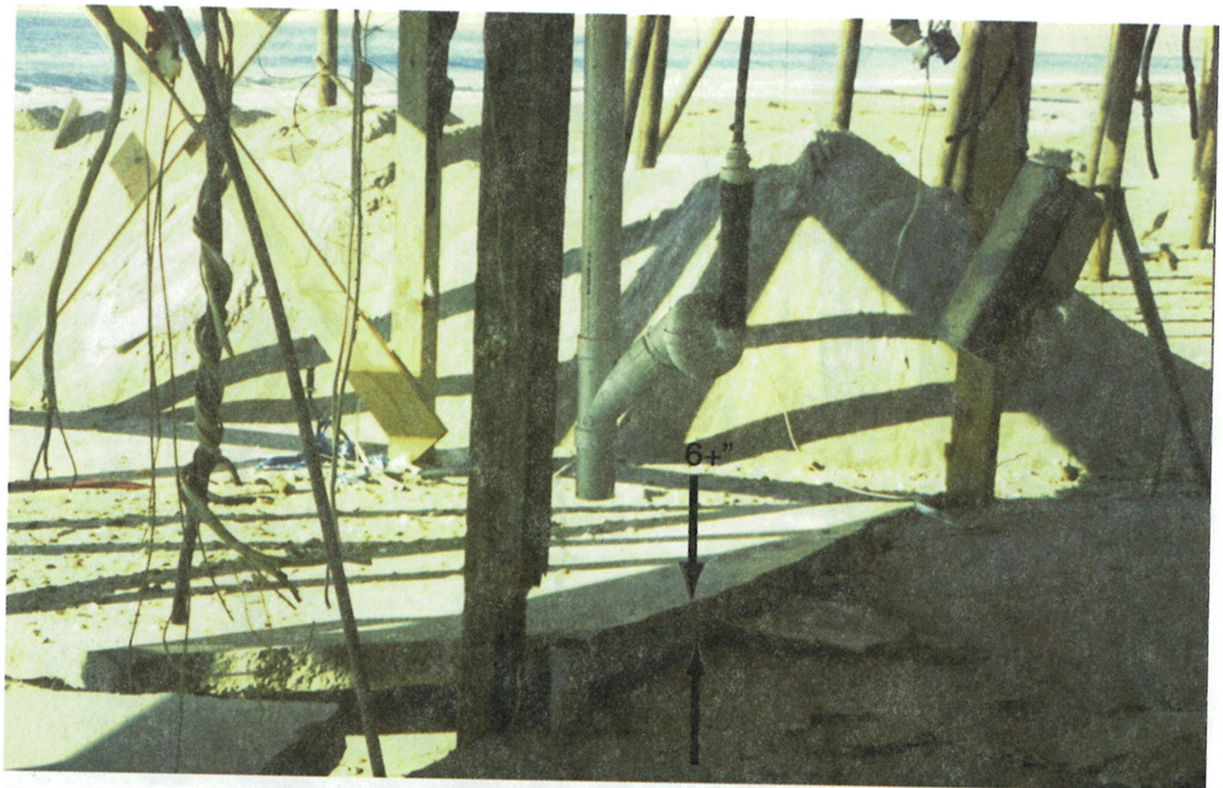

Figure 2-30 *Example of unnecessarily thick slab.*

- 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

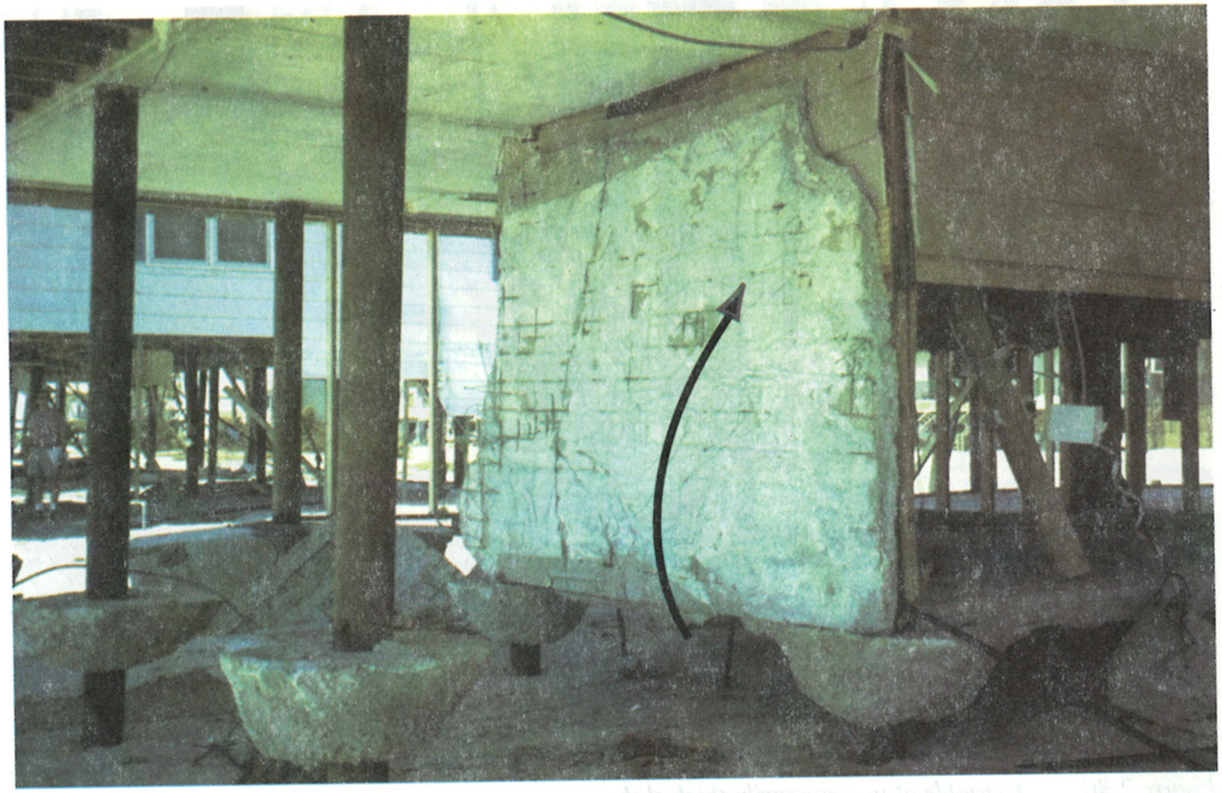

Figure 2-31 *Concrete slab-on-grade flipped up, probably by wave action, came to a rest against two foundation members, generating large, unanticipated loads on the foundation. Note slab is supported on concrete collars around piles and contains wire mesh.*

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.

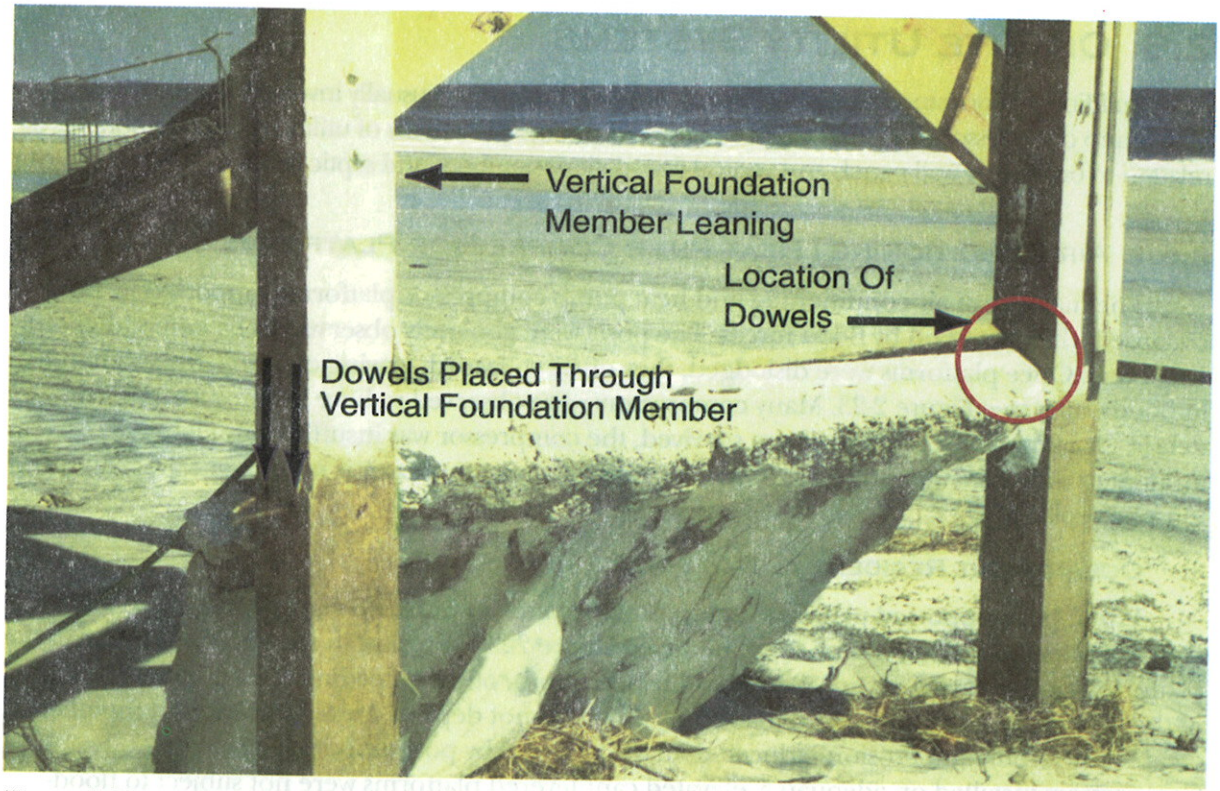

Figure 2-32 *Use of steel dowels to tie slabs to vertical foundation members prevented the proper breakup of slab. A portion of the slab was left attached to the piling, resulting in large, unanticipated loads on foundation members. Note leaning vertical member, on right.*

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).

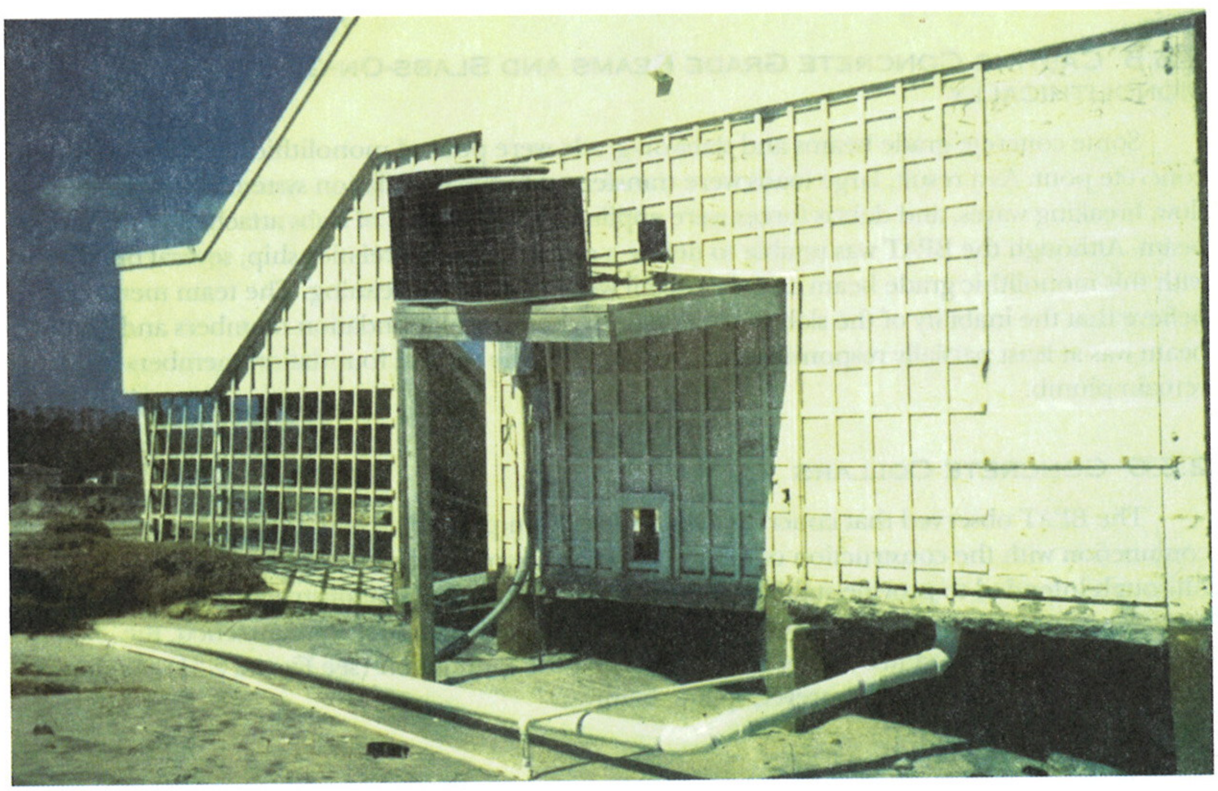

Figure 2-33 *Air conditioning / heat pump compressor platform leaning because erosion and scour caused loss of one supporting column.*

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.*

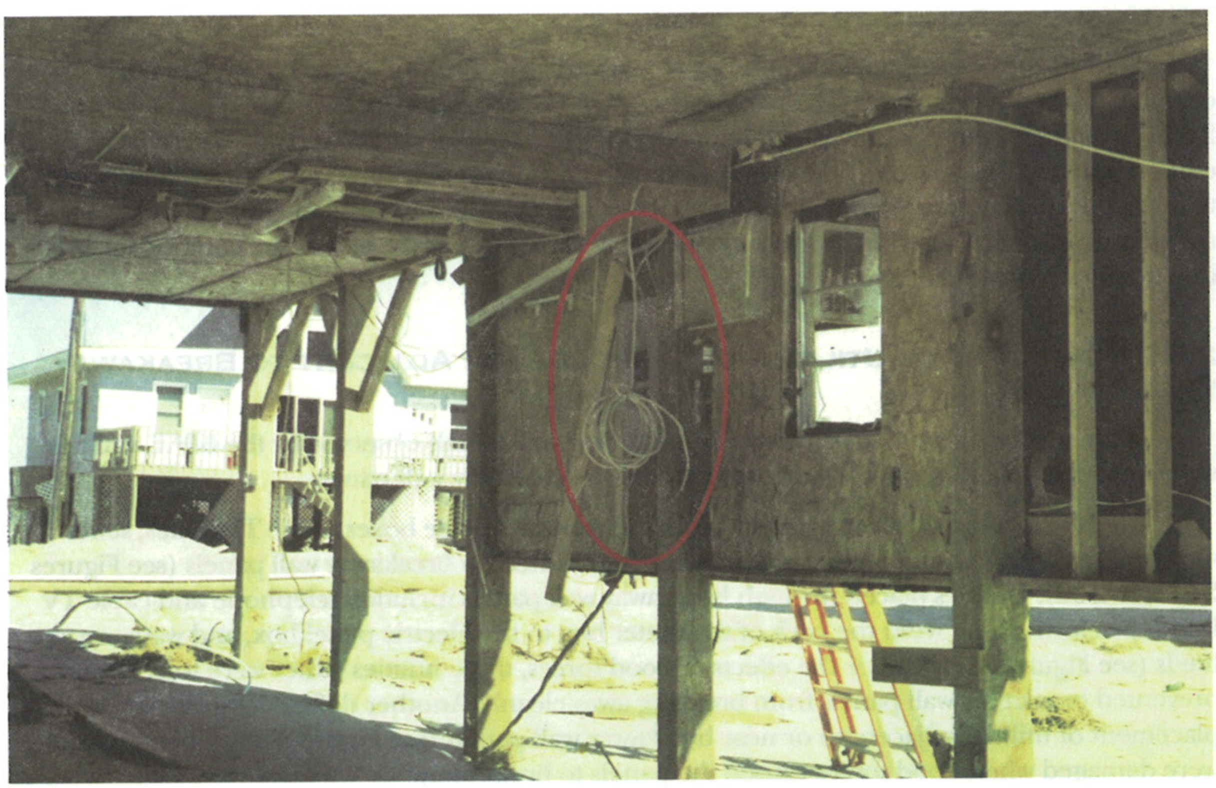

Figure 2-36 *Example of utility component (electric panel box) installed on a breakaway wall panel.*

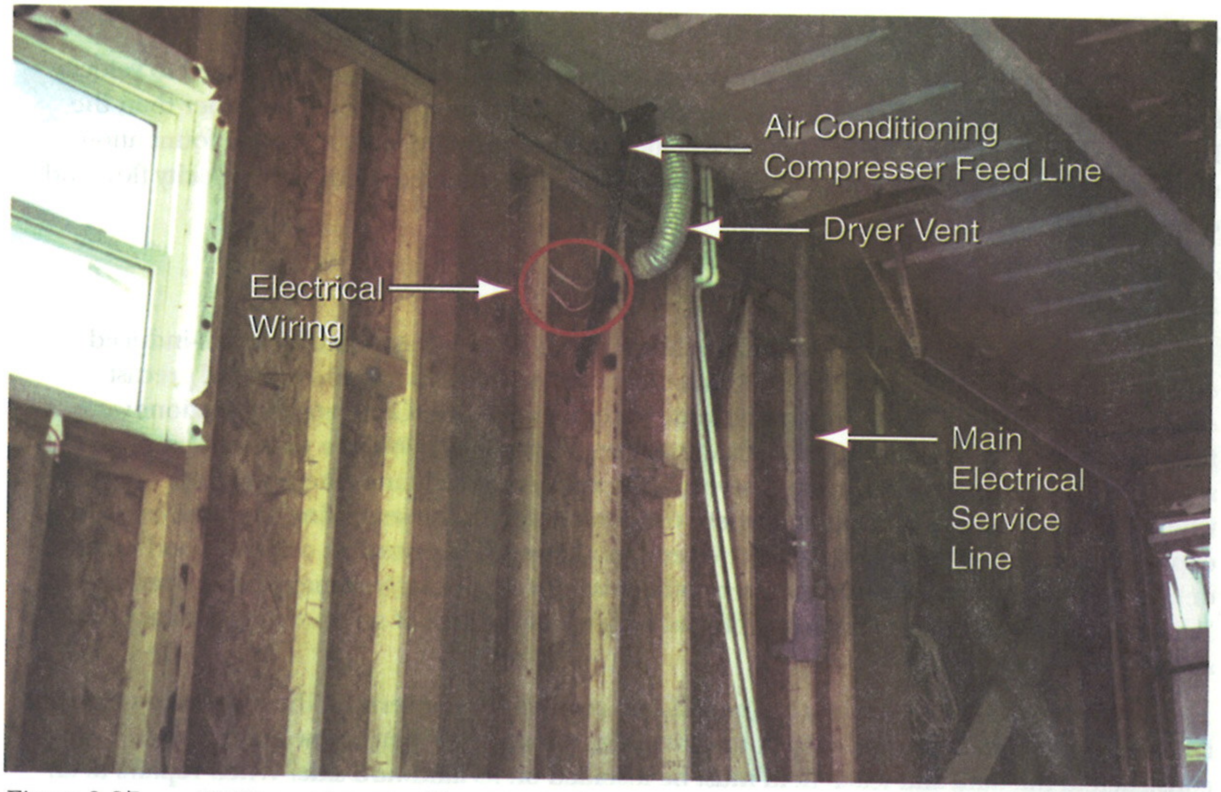

Figure 2-37 *Utility components (dryer vent, air conditioning compressor feed line, main electrical service line out of meter box, and electric wiring) penetrating breakaway wall panel.*

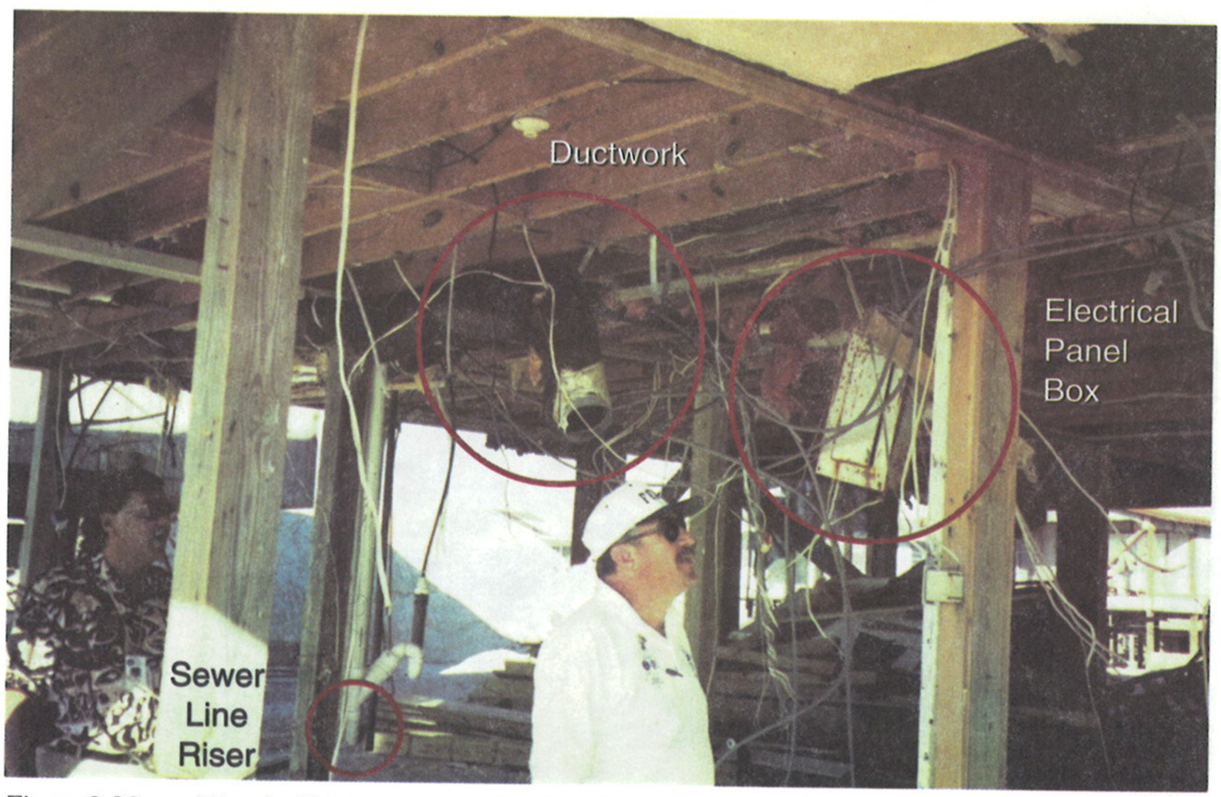

Figure 2-38 *These utility components (wiring, electric panel box, ductwork, and sewer line) were installed adjacent to breakaway wall panel and were damaged when the walls broke away. Note broken sewer line riser pipe on seaward side of piling.*

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.

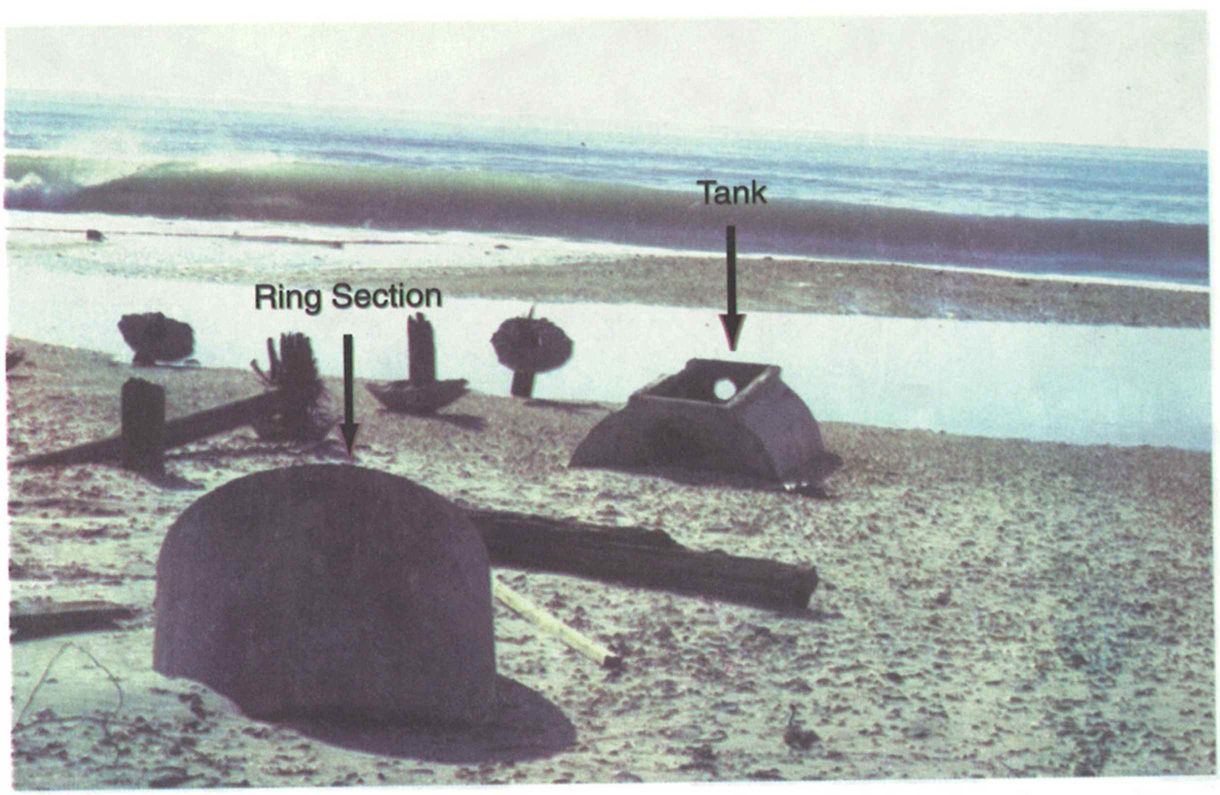

Figure 2-39 *Oceanfront erosion and scour unearthed and damaged septic tanks and systems. Note precast ring section and precast tank.*

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.*

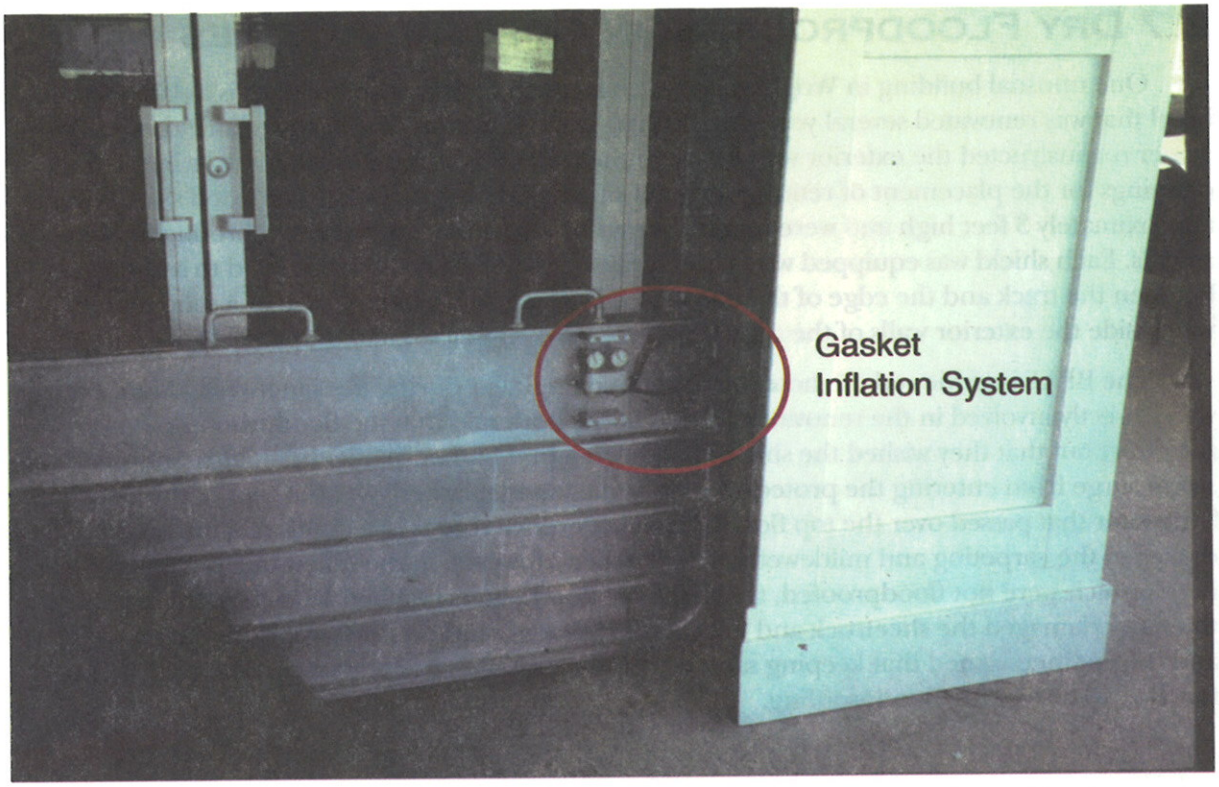

Figure 2-41 *Buildings that are floodproofed require extensive engineering detailing. Note that this flood shield is sealed with a pneumatic gasket.*

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.

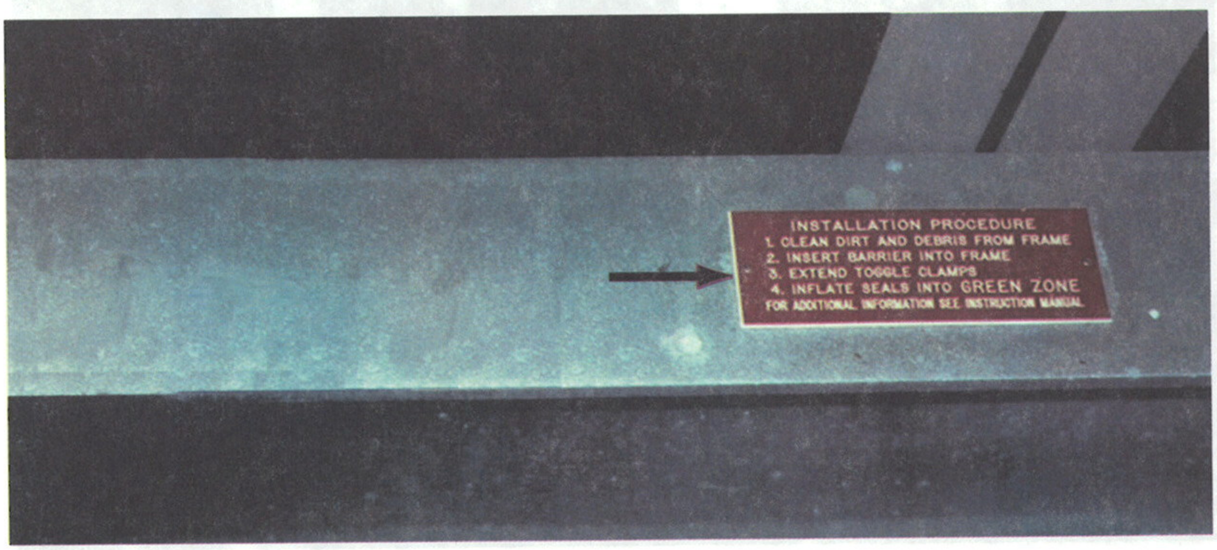

Figure 2-42. *Dry floodproofing often requires extensive human intervention. Note the detailed instructions affixed to this flood shield.*

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.]

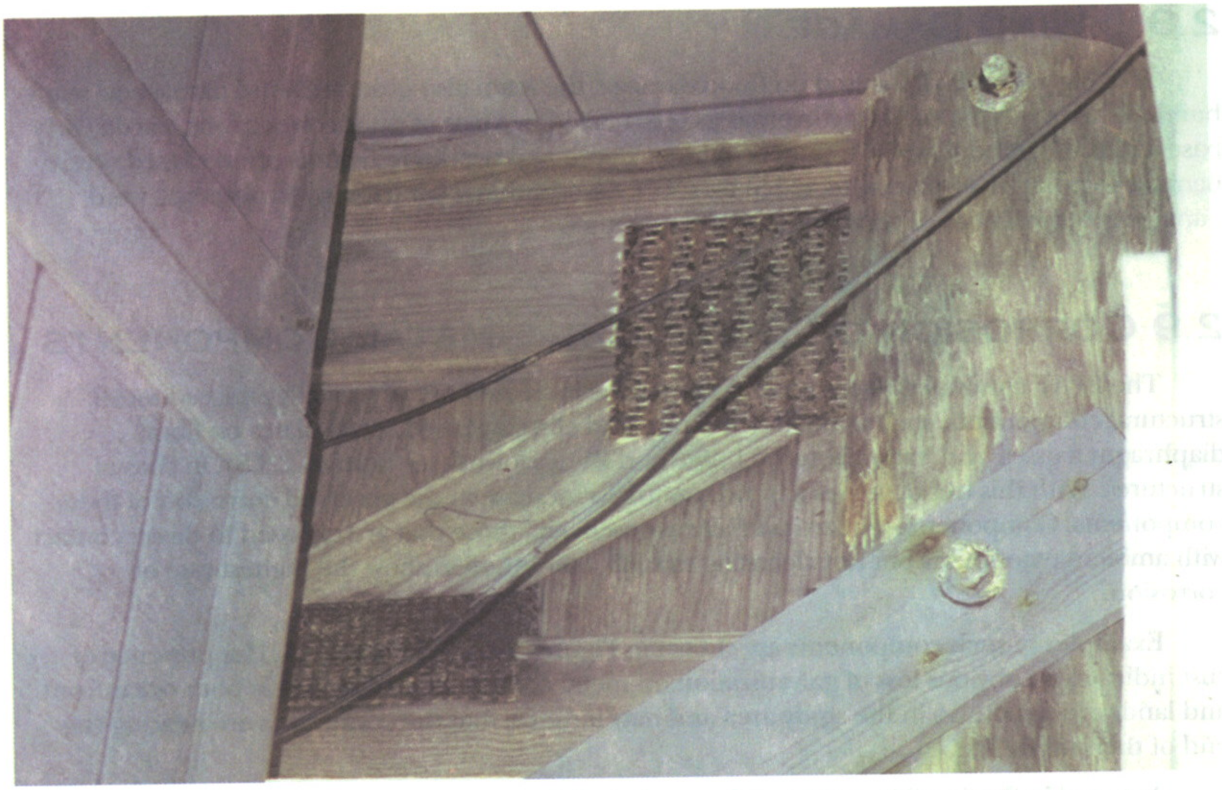

Figure 2-43 *Corrosion of galvanized floor truss plates was observed in many buildings.*

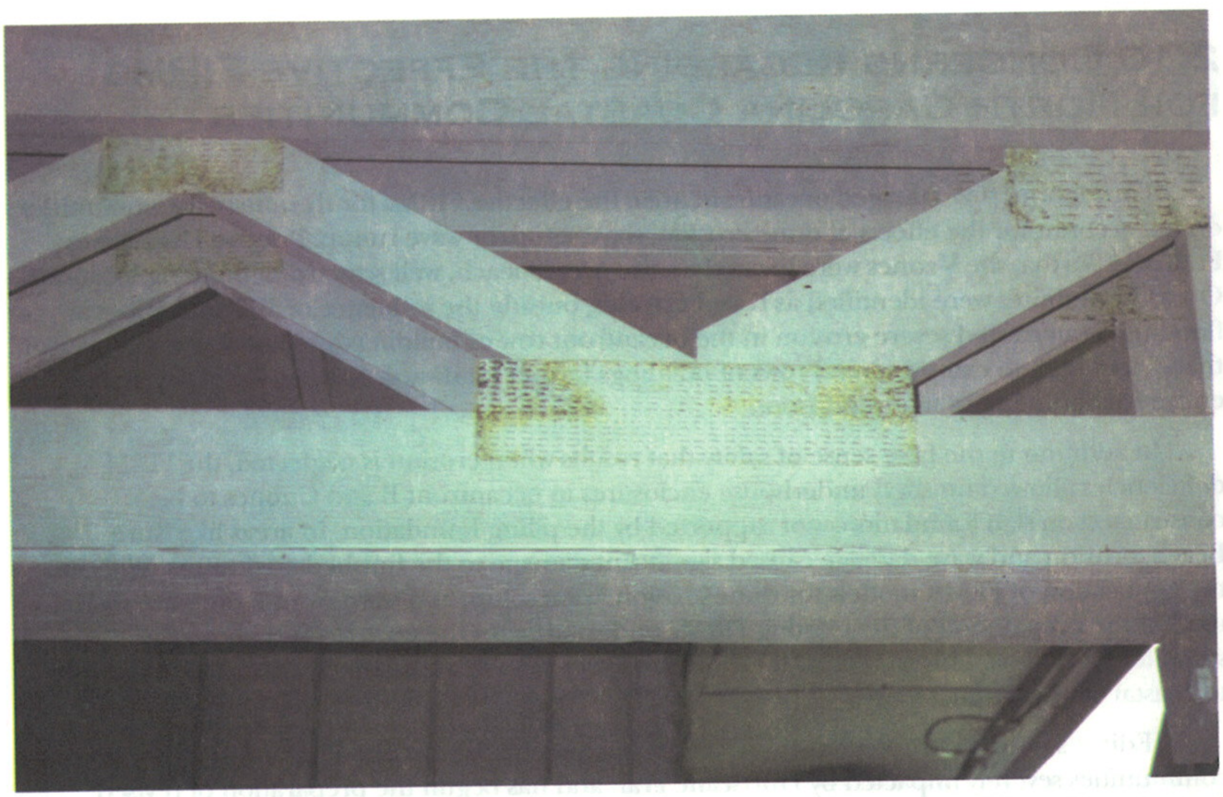

Figure 2-44 *Corrosion of galvanized floor truss plates was observed in many buildings. Note that painting does little to slow the process of corrosion in coastal environments*

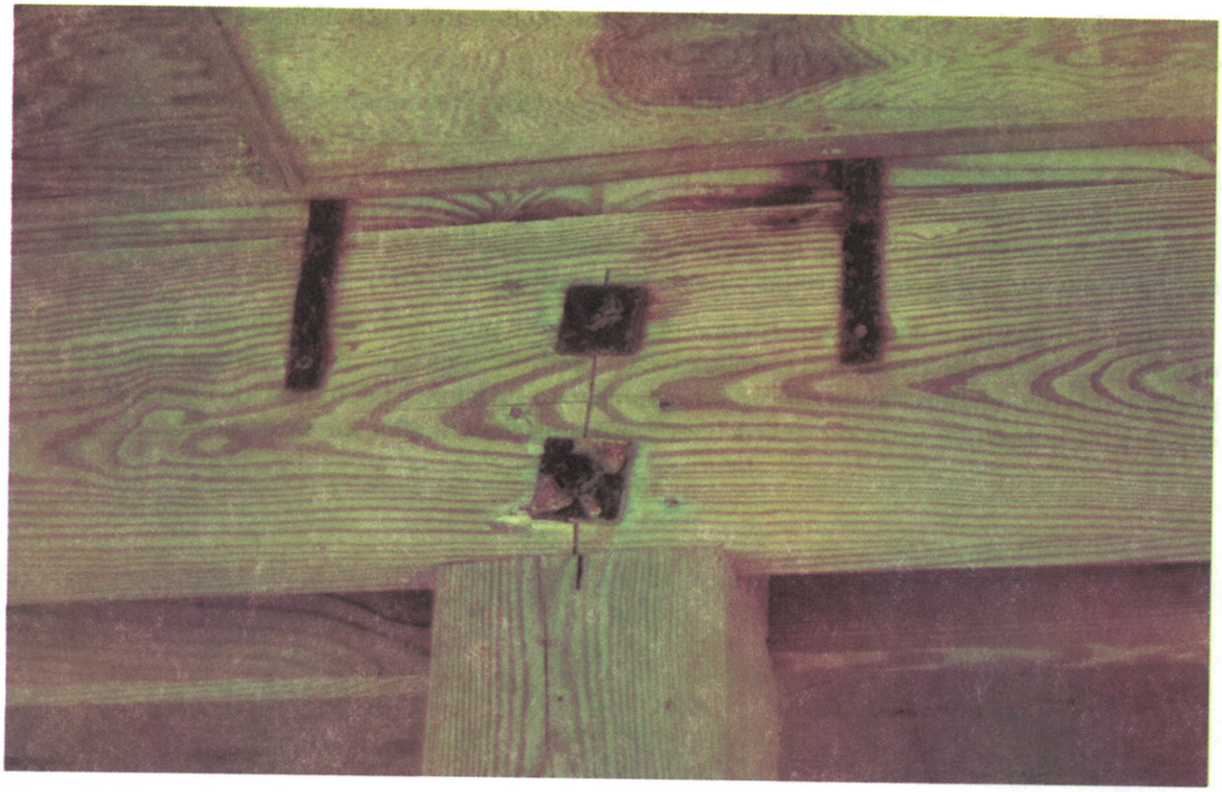

Figure 2-45 Corrosion of hurricane straps and steel plates was also observed in many locations.

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.

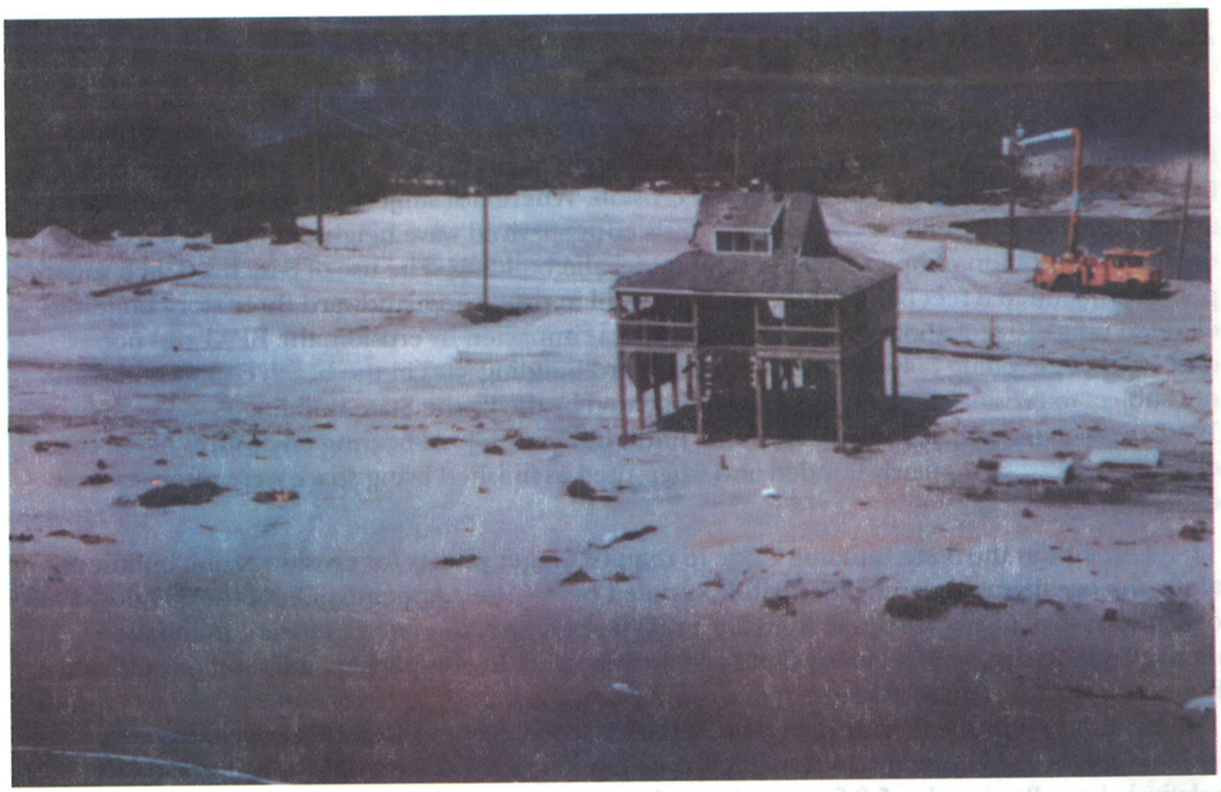

Figure 2-46 ***While this house experienced 6 feet or more of vertical erosion and scour, as well as the loss of breakaway wall panels, the foundation and superstructure performed as designed.***

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.