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.

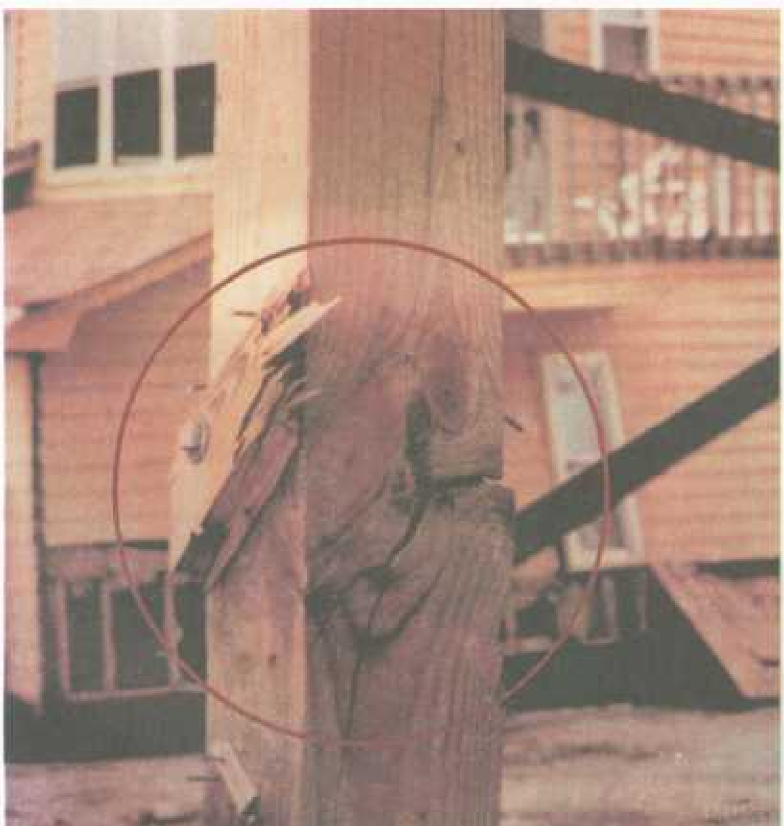

Figure 2-20
Example of broken piling. The piling broke at the location of several knots (circle), where cross-bracing was attached (note remaining bolt and piece of bracing).

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.*

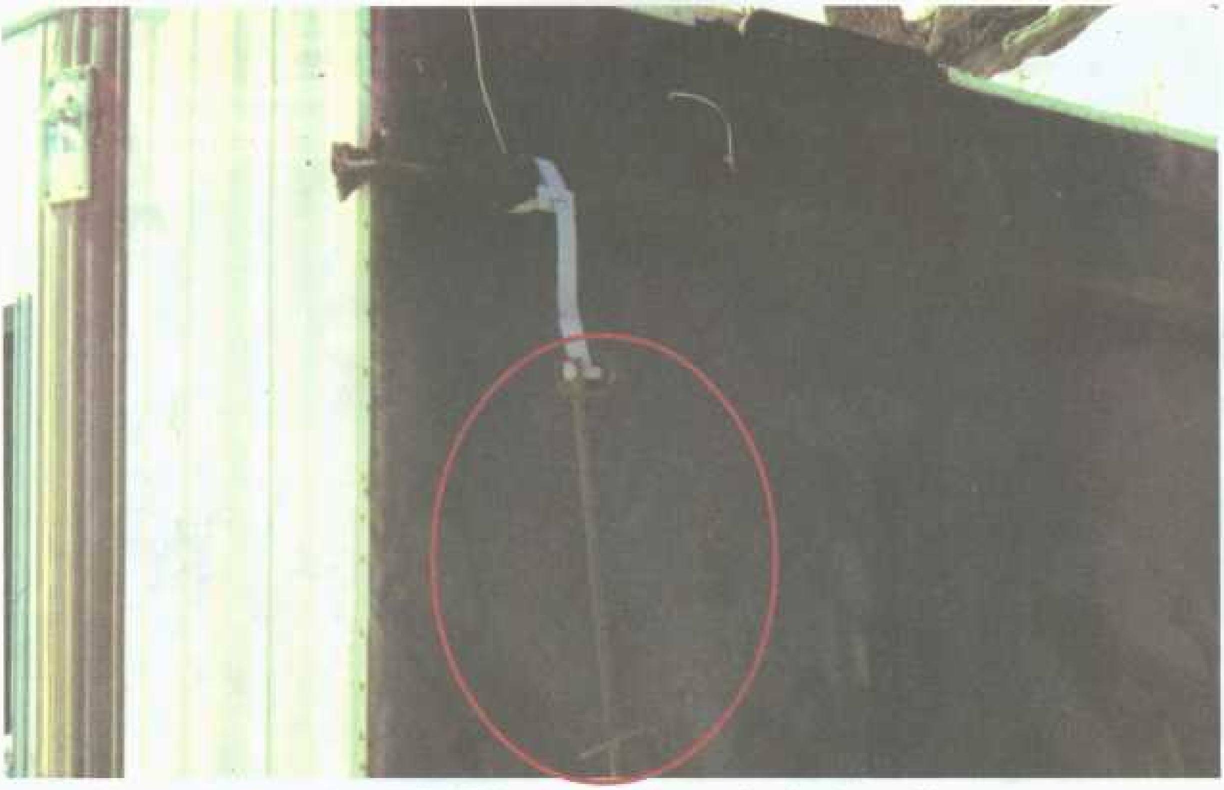

Figure 2-24 *Permanently installed RV overturned as a result of anchor pullout. Anchor (circled) is 2 feet long.*

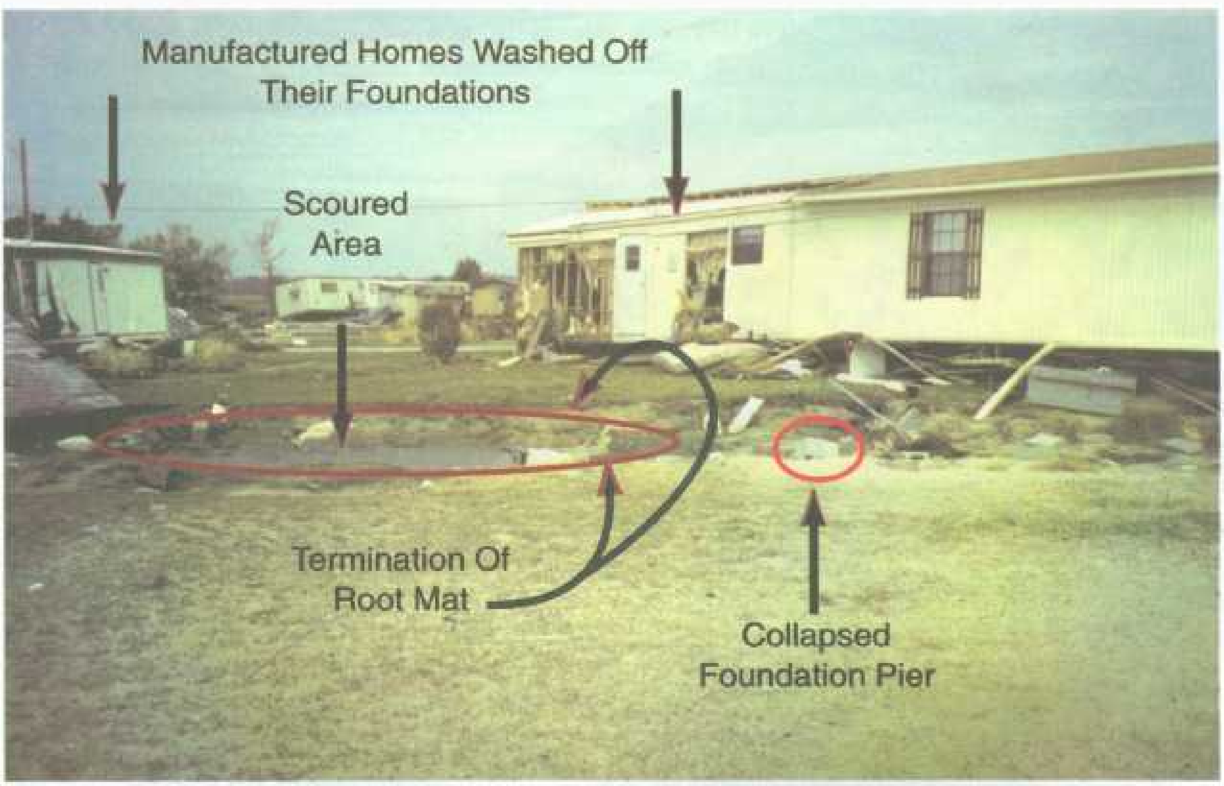

Figure 2-25 *Localized scour beneath pre-storm footprint of manufactured home. Note the collapsed dry-stack block foundation and termination of root mat, which otherwise would have helped stabilize the adjacent ground.*

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).