2 Site Observations

2.1 Typical Pre-FIRM and Post-FIRM Construction

Typical pre-FIRM structures in the study area are one-story concrete block or wood-frame structures built on slab-on-grade foundations, one- to three-story concrete block structures, and one- to three-story wood-frame structures founded on timber piles. Many of these structures are behind concrete sheetpile seawalls. Many pre-FIRM structures were substantially damaged by the surge accompanying the storm event and were often destroyed because of foundation collapse, wave attack, or both.

Typical post-FIRM structures in the study area are one-, two-, and three-story wood-frame structures elevated on timber or concrete pile foundations. Some of these are new structures that either incorporate older, pre-FIRM structures or were built over them. Post-FIRM elevated structures sustained some wind and flood damage but, overall, performed much better than pre-FIRM structures that were at-grade or that were elevated but not to the BFE or CCCL requirements.

2.2 Observations of Wind Damage

Wind damage observed by the BPAT was generally confined to roofing shingles and tiles, exterior sheathing, unsecured air conditioning compressors, power poles and lines, and signs. However, the wind damage observed did not constitute a large portion of the total damage to structures.

2.3 Observations of Flood Damage

Flood damage was observed along the Gulf of Mexico shoreline at all sites visited by the BPAT (see Figures 2-1 and 2-2). Structures damaged by flood forces generally fell into the following categories:

- pre-FIRM structures founded on slabs or shallow footings and located in mapped V-Zones
- post-FIRM structures in mapped A-Zones, B-Zones, C-Zones, and X-Zones founded on slabs or shallow footings, but exposed to high-velocity flows, high-velocity wave action, flood-induced erosion, floodborne debris, or burial by overwash
- post-FIRM elevated structures not properly constructed or not elevated to or above the elevation reached by storm surge and wave effects
- pre- and post-FIRM structures dependent, in part or completely, on failed seawalls or bulkheads for protection and foundation support.

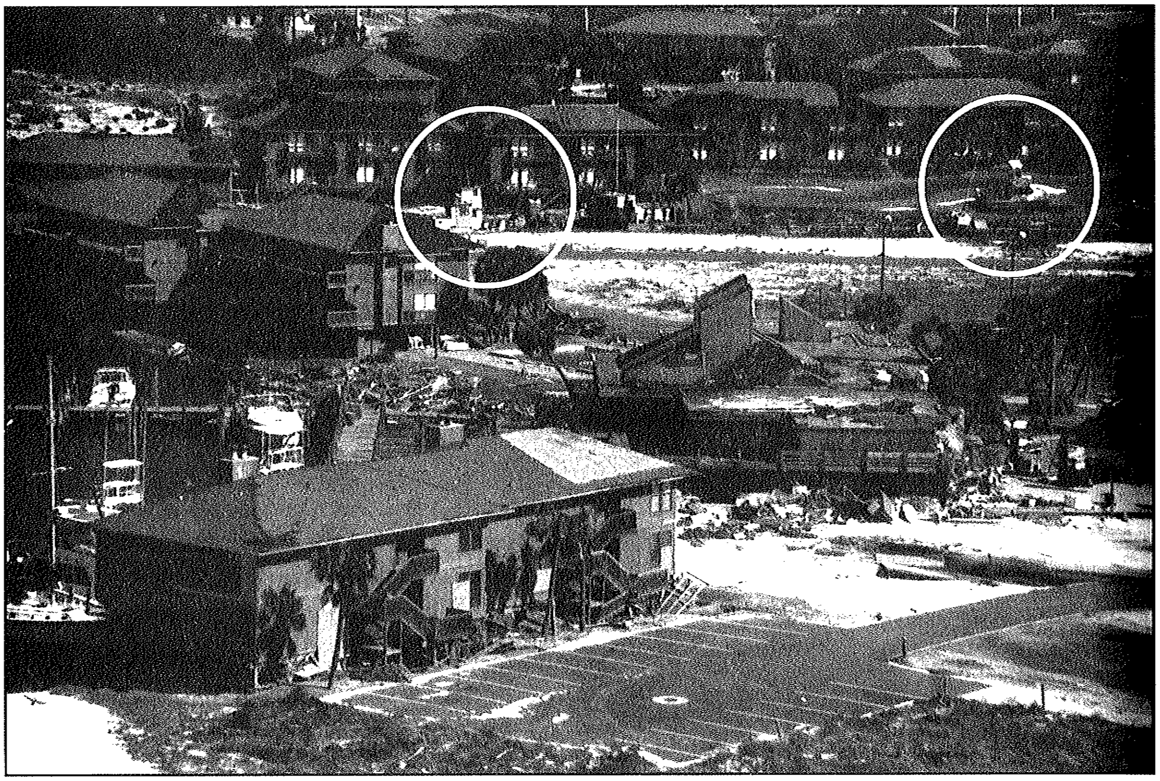

Figure 2-1 *Debris washed inland as a result of surge action from Hurricane Opal (note circled boats).*

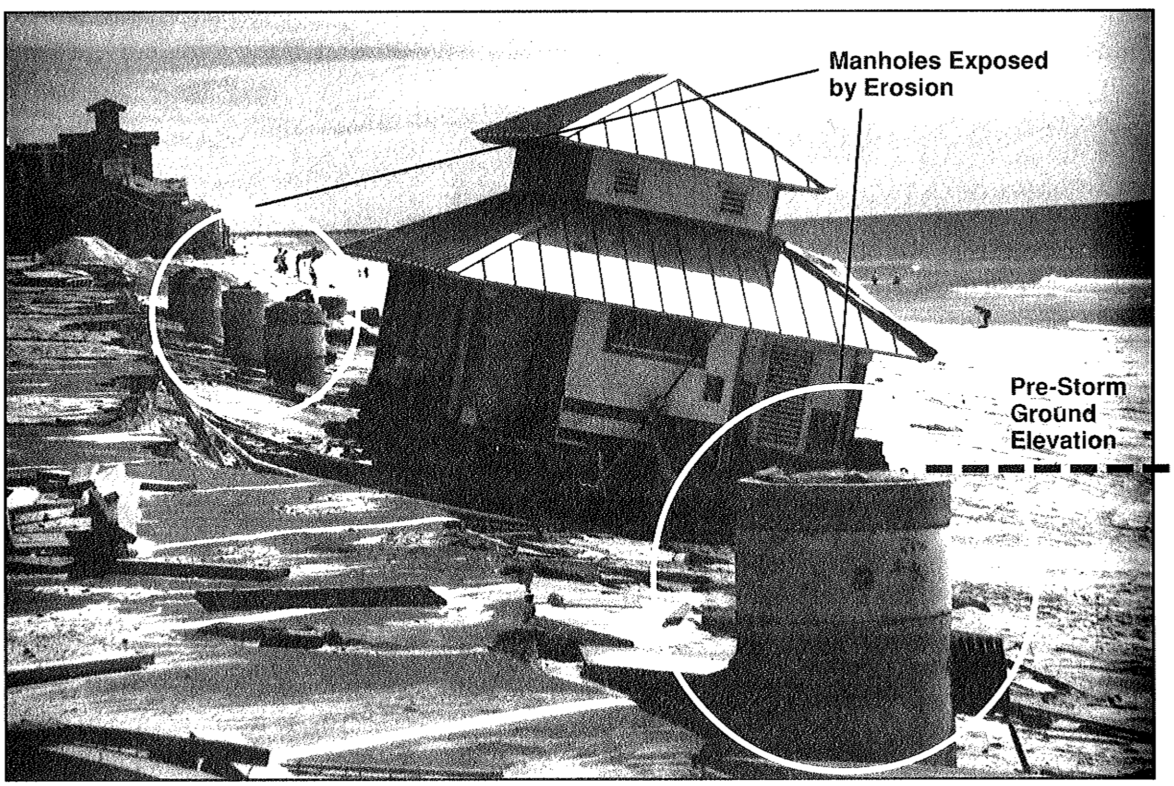

Figure 2-2 *Beach erosion caused major damage to structures, as well as roads and utilities.*

2.3.1 Erosion and Scour

Where sand dunes existed before Hurricane Opal, significant loss of dune height and width was observed. Many dunes were breached or flattened (see Figure 2-3). Those that remained after the storm were scarped and weakened. Duneface retreat of 75 feet to 100 feet was observed in several locations. Overwash of eroded dune sediments was common, sometimes extending over 500 feet inland and causing burial of roads and at-grade construction by 1 to 4 feet of sand.

In some cases, an estimated 10 to 20 feet of vertical relief was lost at the seaward edge of high dune and bluff areas. Many structures atop high dunes or bluffs collapsed because of a loss of support, either from the undermining of slab foundations or from inadequate pile embedment (see Figure 2-4).

Ground levels at many front-row elevated structures that survived Hurricane Opal were typically reduced 3 to 7 feet, or more. In addition, local scour depressions were observed at the bases of many piles, indicating that 6 to 12 inches of additional soil was lost immediately adjacent to the piles. Scour during the storm probably rendered greater than 6 to 12 inches of soil around the piles unsupporting.

Large scour depressions were observed where large volumes of water flowed during the storm. Depressions measuring 10 to 40 feet in length and width and 2 to 4 feet in depth were observed around some pile-supported structures and near the corners of some at-grade construction. Structures that seemed particularly vulnerable included the following:

- structures at the landward termination of roads and driveways that funneled floodwaters toward the structures
- structures between drainage basins or lakes and larger bodies of water
- structures near locations where floodwaters crossed or breached the barrier islands

2.3.2 Debris

Small debris was widespread, ranging from household items to construction materials. These items did not cause structural damage to buildings, foundations, or other building components. Evidence of much larger debris shifted by floodwaters was also observed, including pier piles and braces, concrete slabs, dumpsters, automobiles, boats, and collapsed houses (see Figure 2-5). Many of these objects washed into buildings, and some caused structural damage.

2.3.3 Slab Foundations

Many slab failures were noted in all types of structures (see Figure 2-6). The major reason for these failures was the loss of support coupled with a lack of reinforcing in the slabs. Welded reinforcing wire fabric was observed in many slabs but did not prevent failure of the slabs once they were undermined.

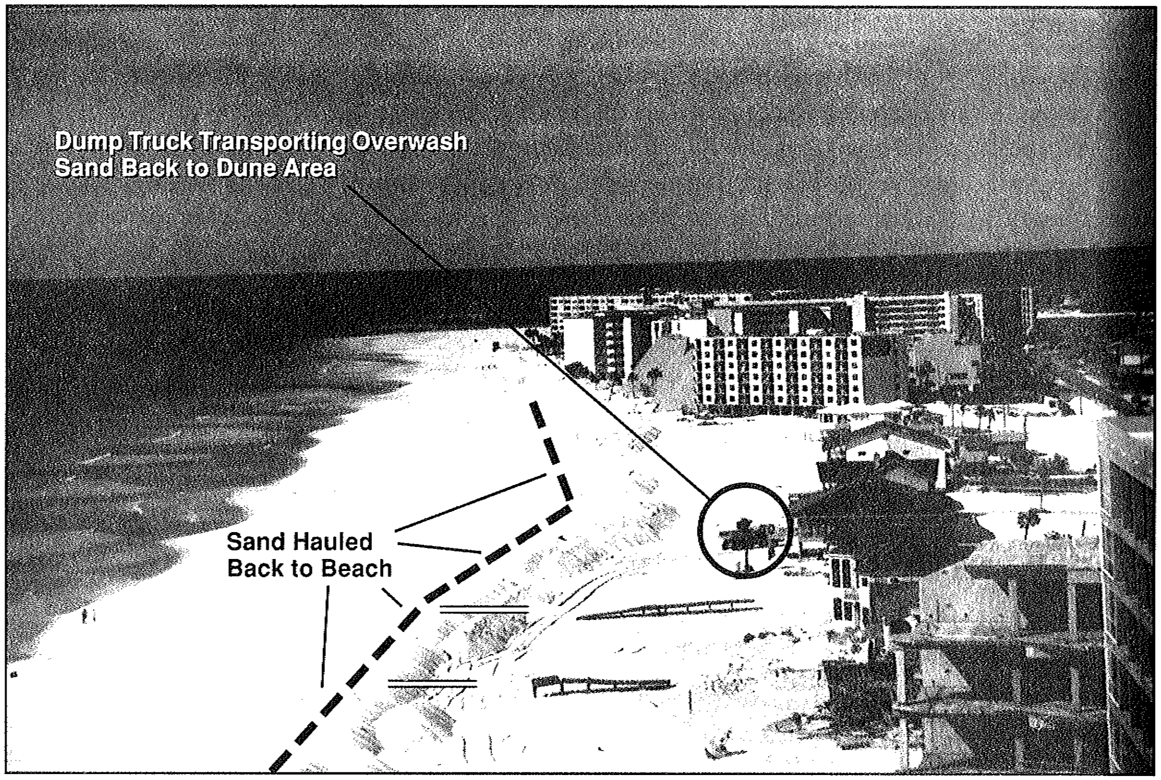

Figure 2-3 *Beach erosion eliminated protection for structures. It is important that the beach and dunes be rebuilt as soon as possible. Arrows point to walkways used to traverse dune that has been washed away.*

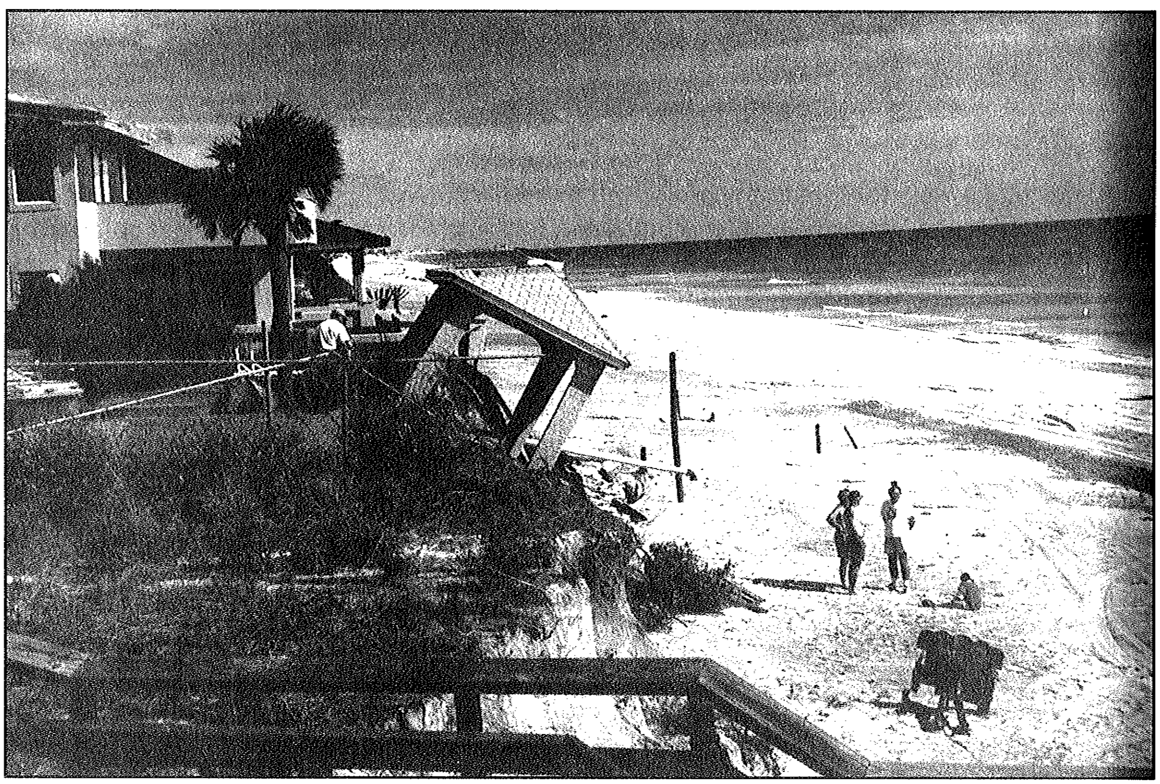

Figure 2-4 *Erosion such as this took place along the gulf coast, causing structures to be undermined and resulting in damage.*

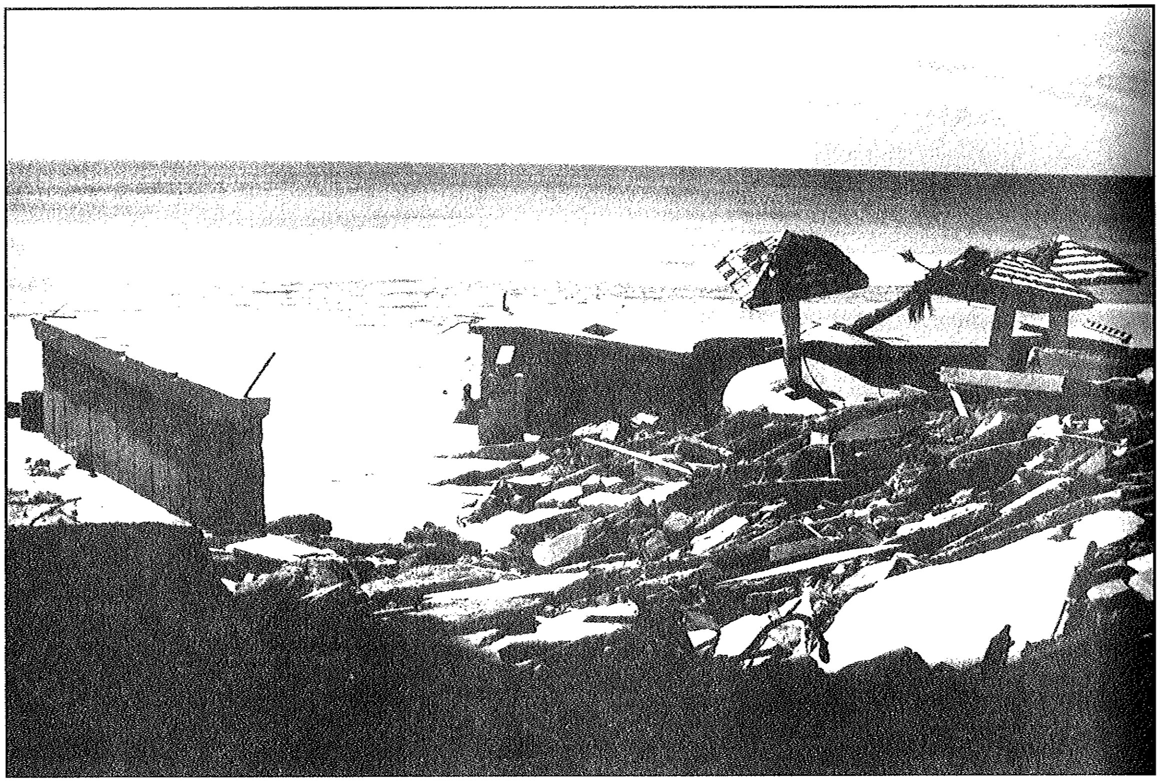

Figure 2-5 *Debris, consisting of broken concrete and wood framing systems, generated by surge action.*

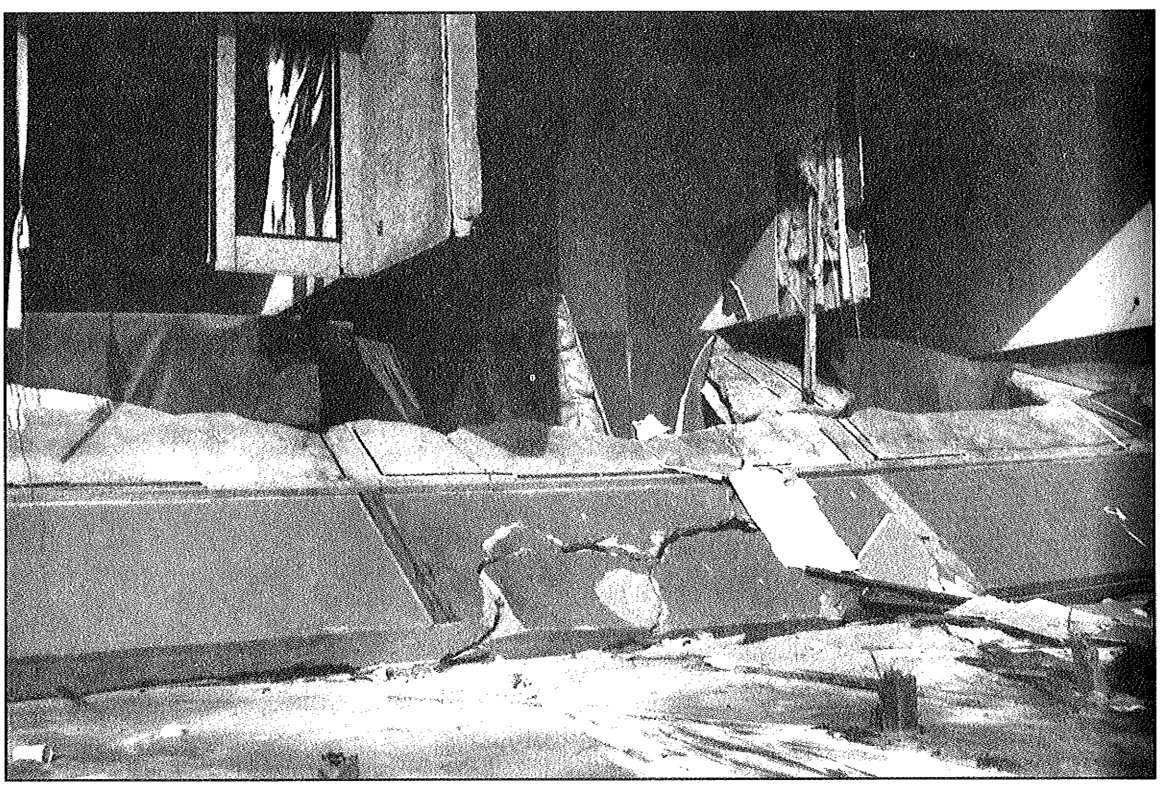

Figure 2-6 *Undermining of concrete decks and floor slabs caused the failure of many unreinforced concrete structures.*

2.3.4 Pile and Pier Foundations

Three to seven feet of vertical erosion at the seaward row of piles was common (see Figure 2-7). This erosion, coupled with insufficient penetration of the piles on many structures, led to structural damage to or collapse of primarily pre-FIRM structures. Undersized piles (6-inch diameter timber in some instances) were not sufficient to resist storm forces; they generally failed and resulted in structural damage or collapse. Piers constructed of concrete blocks on shallow footings frequently collapsed as a result of erosion. Well-designed and well-constructed pile and pier foundations withstood the forces exerted by the storm. Use of splicing techniques was also observed on some eroded piles (see Figure 2-8). Although the splicing of piles placed these structures at increased risk of failure, no failures related to spliced piles were observed.

2.3.5 Framing Systems

The BPAT found many examples of poor framing of timber floor beams and joists in platform-type construction. In particular, poorly fashioned beam-to-beam and joist-to-beam connections were common. Typical problems included the following:

- pile notching greater than 50 percent of pile cross-section
- poor alignment of piles, which resulted in unsupported beams at piles
- use of wooden shims to support beams (i.e., to compensate for notches cut too low)
- overreliance on nails and thin metal straps/hangers

Glue-laminated beams and joists were observed in exterior applications in some recent post-FIRM residential construction. The use of laminated structural members in exterior applications

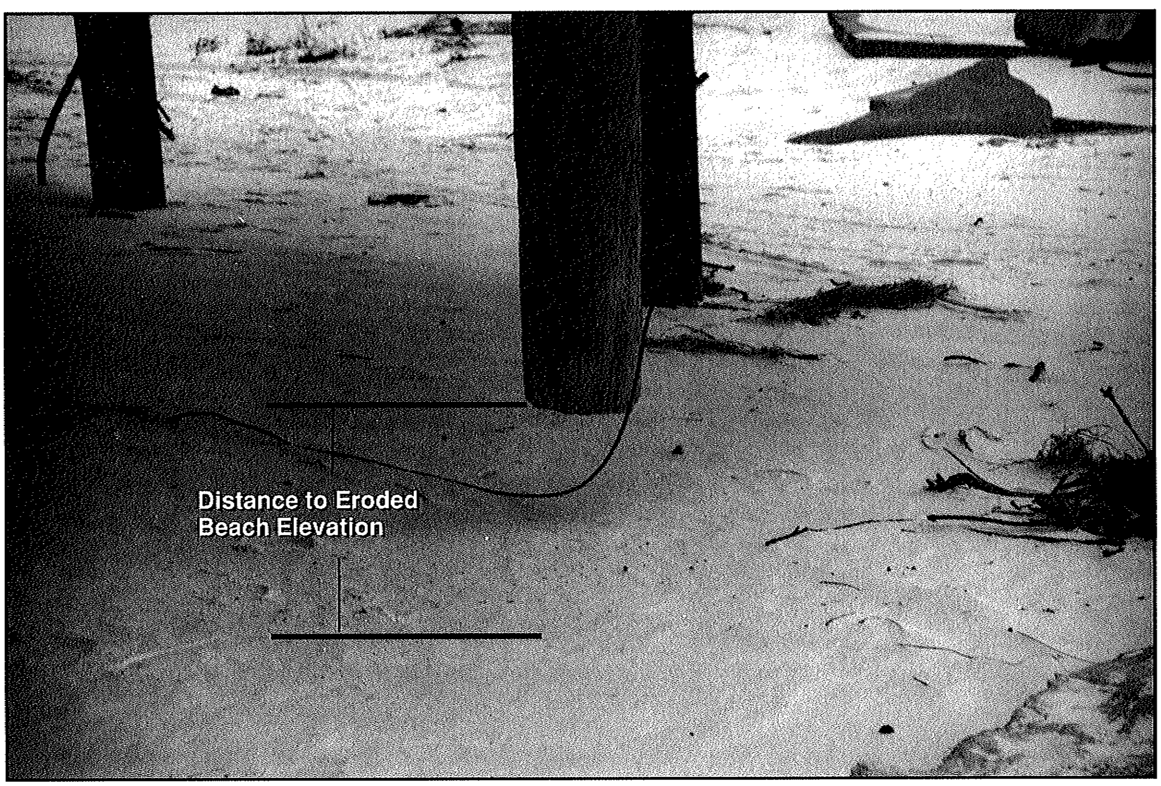

Figure 2-7 *These piles were not embedded deep enough to survive the erosion of the sand. As a result, there is now a large gap between the bottoms of the pilings and the ground surface.*

is of interest because this practice has not been widely observed by previous BPATs. Although laminated structural members rated for exterior use are available, the Hurricane Opal BPAT could not determine the rating of those it saw. No failures of these beams and joists were observed however.

2.3.6 Connections

Many of the connections observed were deficient. The BPAT observed widespread corrosion of galvanized straps, hangers, and joist-to-beam ties beneath elevated buildings. Some of the corroded connectors had failed either before or during the storm.

The BPAT observed some galvanized strap connectors between piles, beams and joists (in otherwise good condition) that failed as a result of insufficient nailing or because storm forces exceeded the design forces (see Figure 2-9). This was not a common mode of failure, however. The BPAT also found evidence that structural components had pulled away from one another when acted on simultaneously by flood and wind forces, despite the presence of the galvanized connectors. In some instances, foundation piles and beams were well-connected and withstood storm forces, while walls or upper structure components were poorly connected and were damaged or destroyed by wind forces, flood forces, or both.

2.3.7 Bracing

The use of 2 x 8 or similar timber cross-bracing between timber piles was common beneath elevated wood-frame structures. Some bracing failures were observed that were apparently due to horizontal loading from water, debris, or both. The use of threaded galvanized rods and turnbuckles as cross-bracing was less common (see Figure 2-10). No failures of this type of bracing

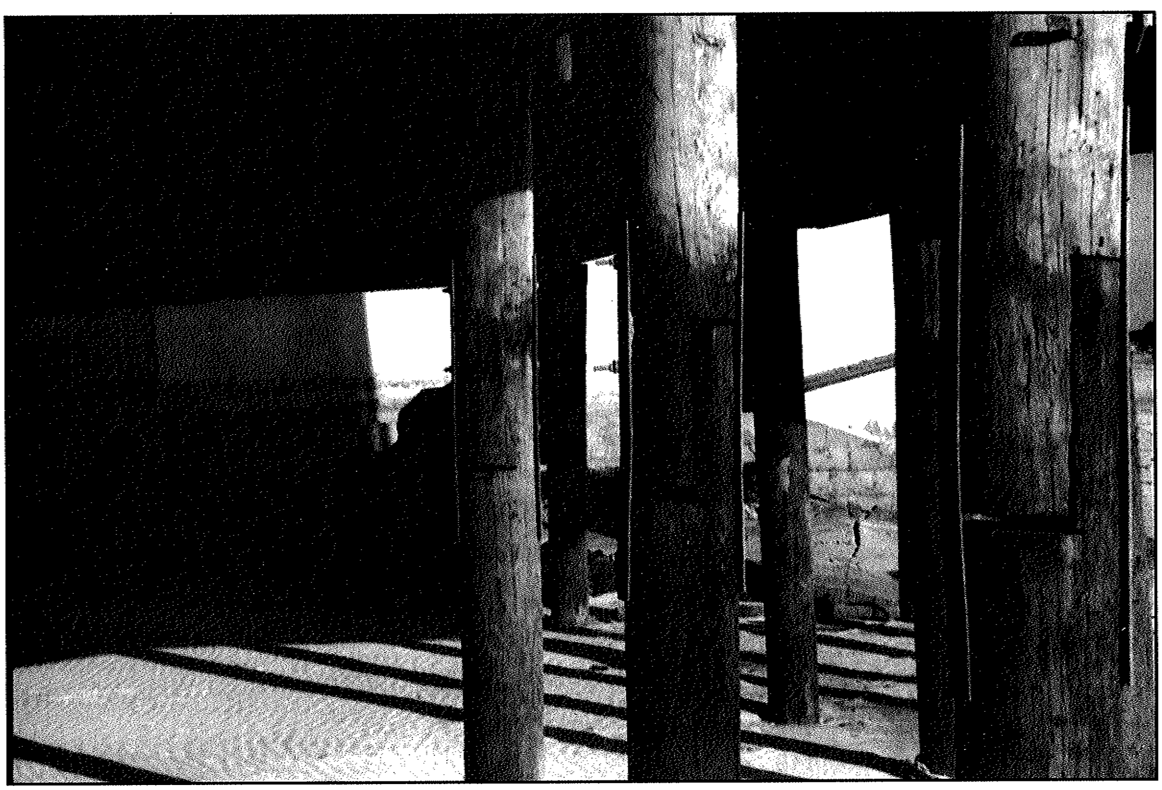

Figure 2-8 *These piles were not long enough and were spliced to add depth. The splicing was exposed by storm-induced erosion.*

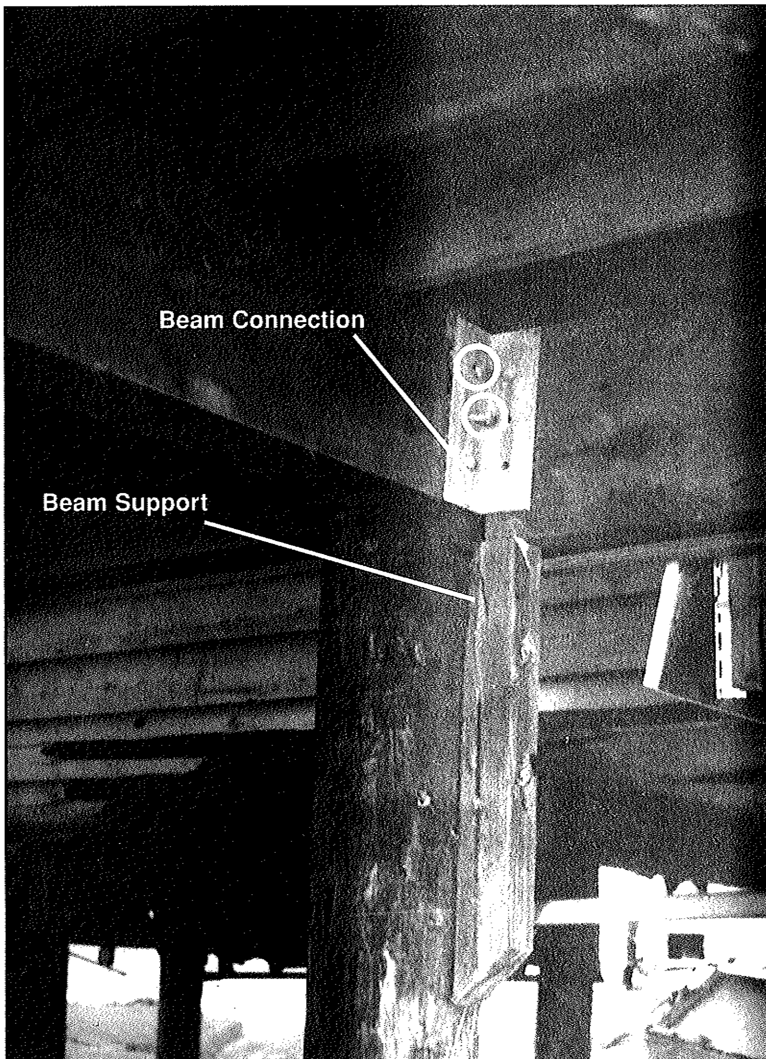

Figure 2-9
The floor beam connection and beam support shown here illustrate the lack of design and proper construction observed on many damaged structures. Note the bolt pullouts (circled). Also, the beam support is attached to the pile with lag bolts rather than bolts that extend through the pile.

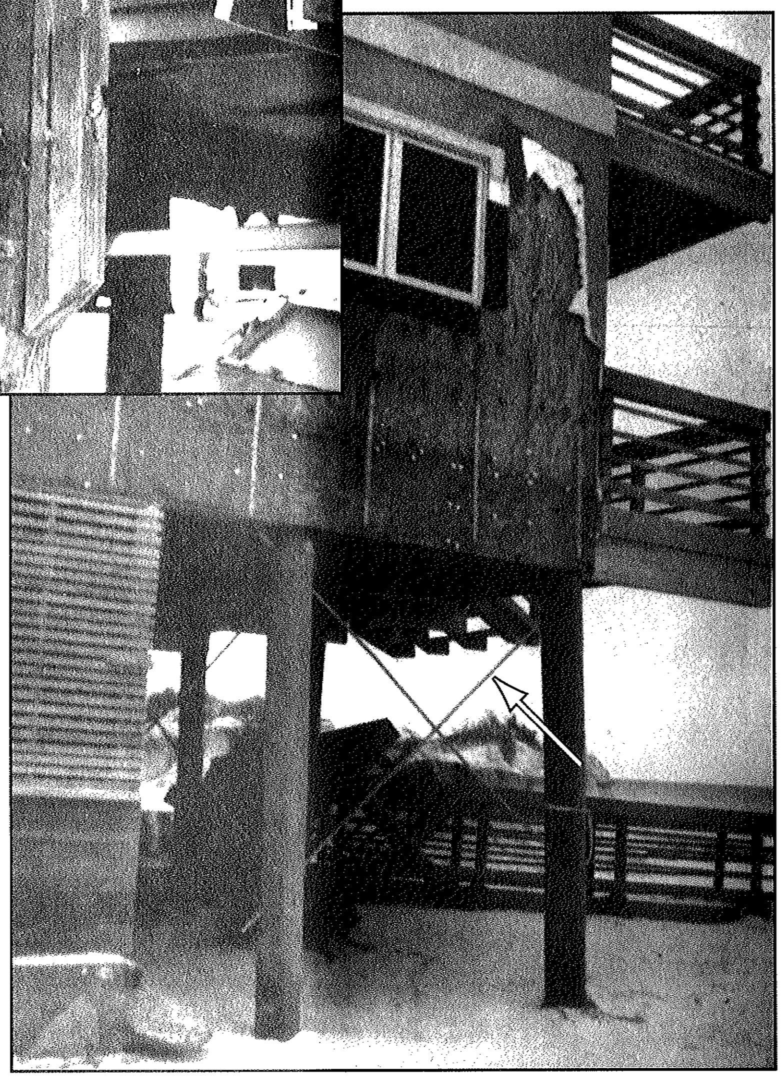

Figure 2-10
This undamaged threaded rod & turnbuckle (arrow) cross-bracing continues to provide additional support as designed.

were noted, but debris was trapped by the bracing, and in some instances, the rods were bent by lateral loads imposed by the force of flood waters acting on the trapped debris.

Use of knee bracing was also prevalent in elevated wood-frame structures. A common problem observed with knee bracing was that timber piles had been notched, some deeply, to accommodate bearing seats for tie-in purposes. Although the BPAT did not observe any structural failures that could be definitively linked to this problem, notching of piles can undermine their structural integrity and should therefore be avoided.

2.3.8 Breakaway Construction and Enclosures

There were a number of damaged or destroyed enclosures below elevated structures (see Figure 2-11), many with electrical wiring attached to breakaway walls. The presence of breakaway walls indicates the designer was aware of potential flood impacts. However, the placement or attachment of utilities to breakaway walls below the elevated portions of the structures demonstrates, at a minimum, lack of awareness of local, CCCL, and NFIP regulations by owners or contractors, or possibly disregard of those regulations.

In some post-FIRM structures with breakaway walls below the lowest habitable floor, the walls broke away as intended but in doing so, damaged exterior sheathing and wall finishes above the lowest floor. The damage above the breakaway wall was usually minor but could have been prevented by better design and construction of this detail (as shown in Figure 2-11). Rolldown garage doors were damaged or destroyed in pre-FIRM and post-FIRM construction alike (see Figure 2-11).

2.3.9 Stairs, Decks, and Porches

Timber stairs and decks were frequent casualties of the storm. Many were supported by short, small-diameter shallow posts or piles. Some decks were supported by knee braces attached to structural piles supporting the main structure. Decks of this design seemed to better resist Opal's forces. Loss of decks sometimes led to roof damage where roof overhangs were supported by posts attached to the decks. In one instance, a deck located seaward of the State's CCCL and permitted by the State survived the storm, while the landward habitable structure (behind the CCCL and not within the State's jurisdiction) was destroyed.

2.3.10 Utilities

The BPAT noted several problems associated with utilities and utility connections at habitable structures:

- Placement of electric meters, panels, boxes, and wiring below a building's lowest habitable floor, rendering that equipment vulnerable to storm surge, wave, debris and overwash damage (see Figure 2-12).
- Attachment of wiring, conduit, and electrical panels to breakaway walls (see Figure 2-13).
- Failure to adequately support and fasten air conditioning compressor units (see Figure 2-14). Many support platforms were destroyed, leading to compressor damage. Some platforms survived, while unfastened compressor units were blown or washed away. Units not properly supported and attached were also observed to have caused damage to exterior walls of some structures.
- Placement of utility lines, septic systems, and mechanical connections and equipment, including air conditioning units, on the sides or seaward of buildings, rather than landward of the building. Loss of air conditioning units and/or utility/mechanical components sometimes led to damage of the main structure.

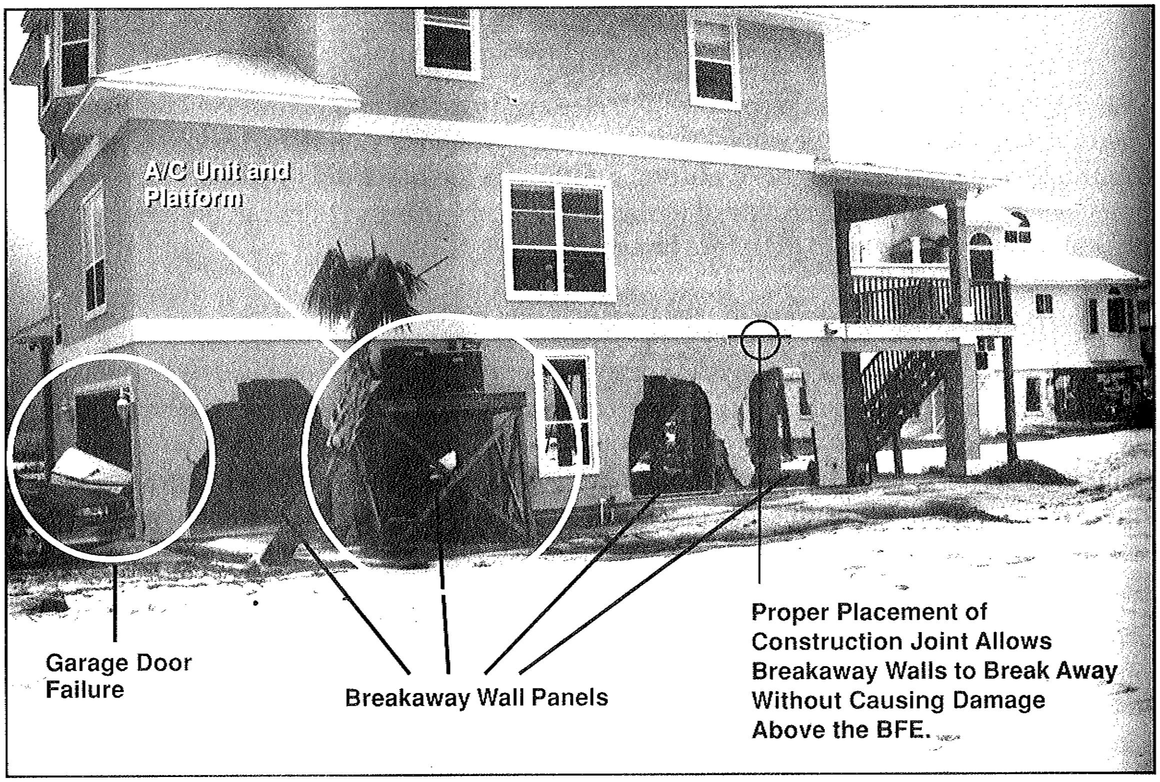

Figure 2-11 *These breakaway walls functioned as designed, lessening the pressures of water, sand, and debris on the structure.*

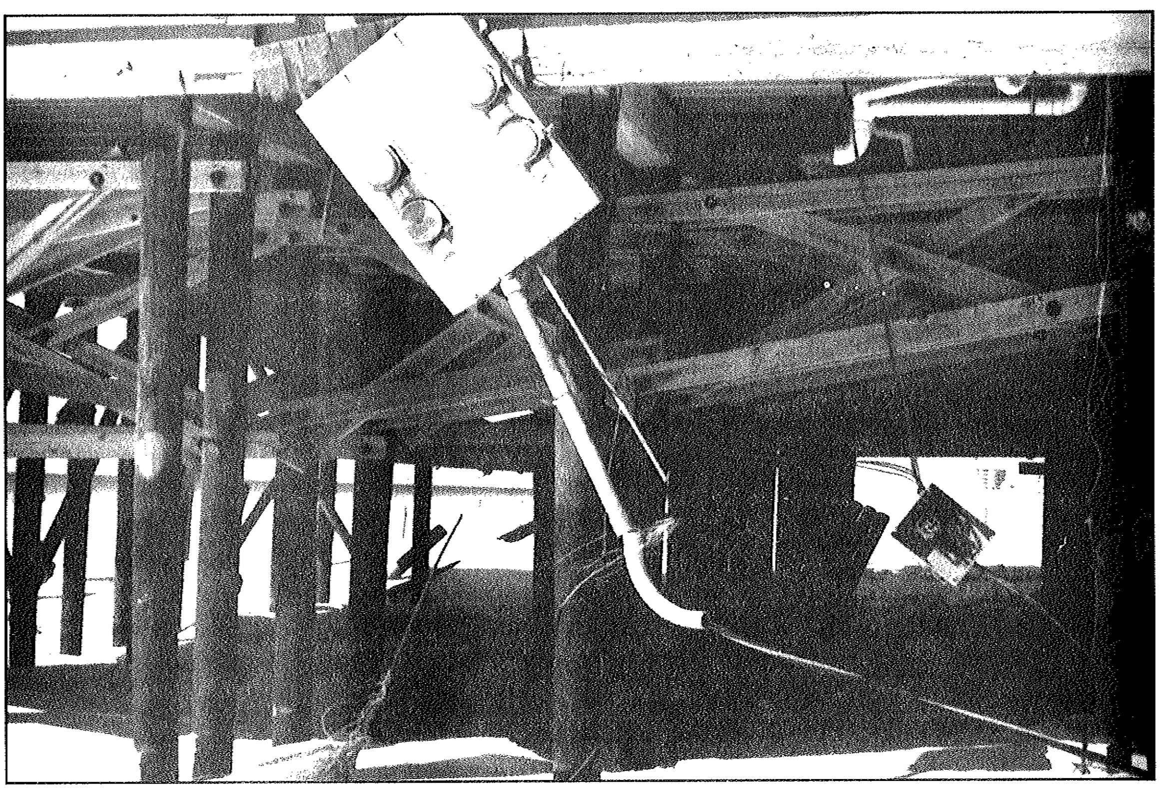

Figure 2-12 *Utility lines and boxes dislocated by hurricane forces. Note that the cross-bracing and pile support system remain in good condition after the storm.*

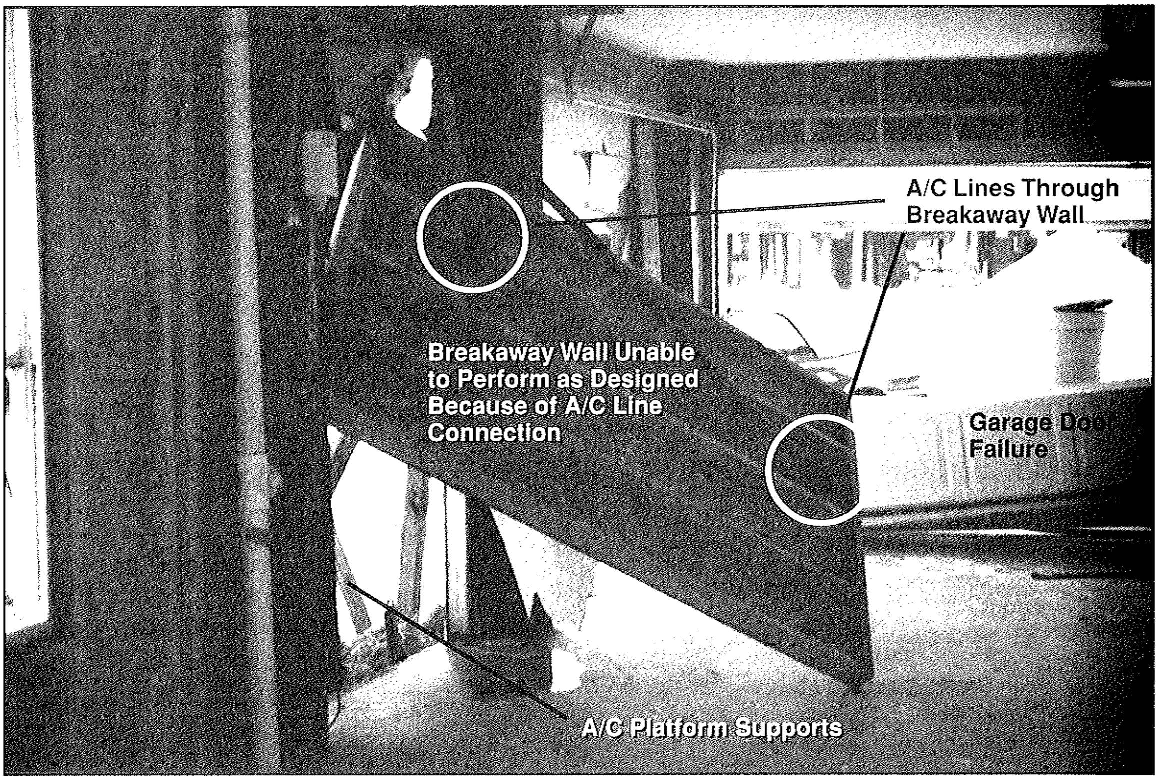

Figure 2-13 Interior view of breakaway wall blocked by air conditioning unit and support platform (see Figure 2-11). Electric and cooling lines were extended through the breakaway panel.

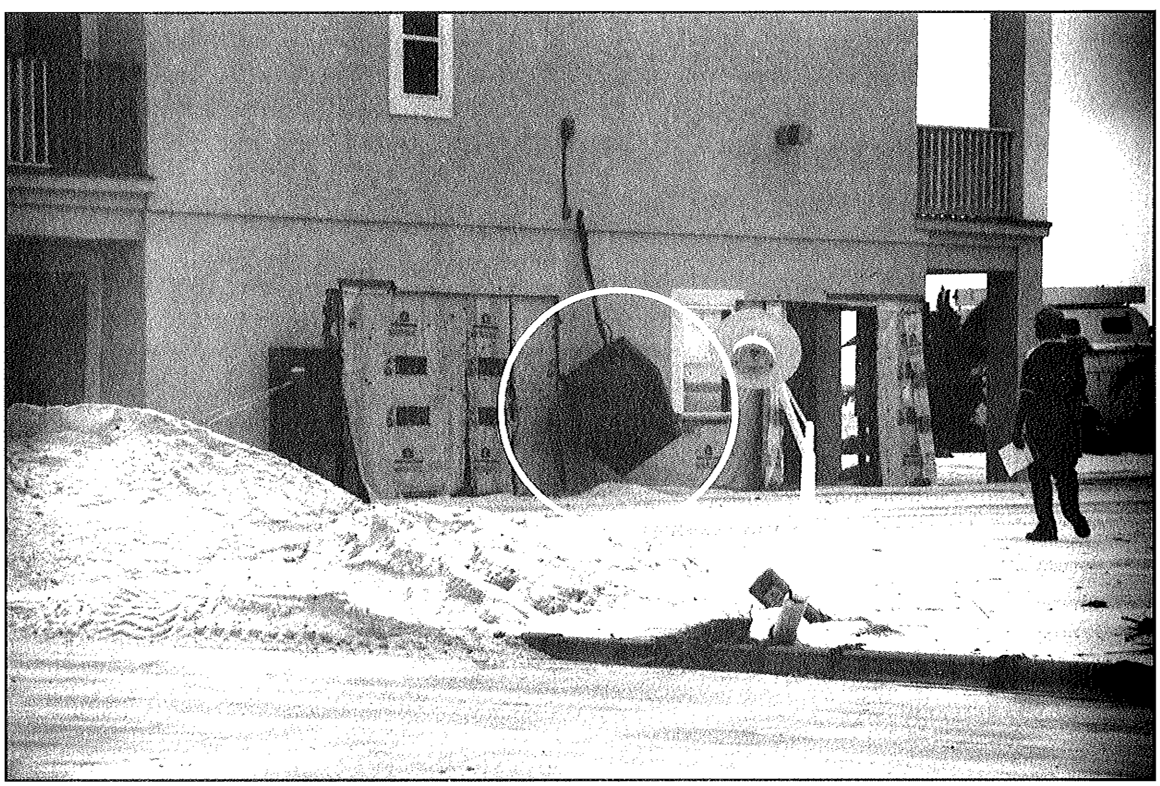

Figure 2-14 These breakaway panels functioned as designed. Note the loss of the air conditioning unit platform.

2.3.11 SEAWALLS

The BPAT observed widespread failure of seawalls and bulkheads along the Gulf of Mexico shoreline (see Figure 2-15). Damage figures from the State of Florida revealed that over 3 miles of seawalls and bulkheads were destroyed by Hurricane Opal, including 1.3 miles of concrete walls, 1.0 mile of concrete block walls, and 0.8 mile of timber walls (FDEP 1995). Failed walls contributed to damage of buildings, pools, and other structures, due to loss of backfill and generation of debris.

Many walls appeared to have failed because wing walls or return walls were flanked by erosion and scour. Many seawall returns flanked by erosion and scour were no more than 20 to 30 feet long, although some longer returns (50 feet to 75 feet) were also flanked.

Seawalls were usually destroyed when backfill was washed from behind the walls because of overtopping, insufficient wall embedment, or return wall flanking. Habitable structures founded on slabs or shallow foundations, swimming pools, and other structures that relied on seawalls to retain supporting soil, were frequently undermined and destroyed when seawalls failed.

The BPAT noted that retaining walls constructed of concrete blocks were particularly vulnerable to damage by Hurricane Opal. Walls most likely to have survived were observed to have:

- reinforced concrete slab or sheetpile construction
- sufficient wall height or backfill protection to prevent significant overtopping and loss of backfill

Figure 2-15 Fractured seawall, damaged by storm forces. Note the erosion of the bank behind the wall.

- sufficient anchorage and embedment to prevent collapse from seaward rotation of the cap or toe
- return walls extending landward of the seaward face of the building or structure being protected and landward of the effects of erosion and scour

2.3.12 Drainage and Drainage Structures

The BPAT observed the remains of several new stormwater discharge structures adjacent to or between multifamily buildings. These structures consisted of large-diameter corrugated plastic pipes, probably intended to carry stormwater runoff from parking areas and other impervious areas to the beach. Unfortunately, the seaward portions of these pipes were destroyed during the storm and their pre-storm configurations are not known with certainty.

It did appear, however, that erosion beneath habitable structures near these damaged discharge pipes was more severe than at areas away from the pipes, possibly a result of direct discharge of upland stormwater runoff adjacent to or beneath the habitable structures. It is likely that the pipes failed because of erosion and scour caused by the storm or because of the loss of protective seawalls and bulkheads. It is possible, but not known for certain, that the pipe failures and discharge adjacent to the multifamily buildings contributed to foundation damage at those buildings.

2.4 Incorporation of Pre-FIRM Construction into New Construction

Many single-family structures appeared to have been constructed above or adjacent to portions of older pre-FIRM structures and probably resulted from efforts to expand and/or reconstruct older, smaller structures. This type of construction is vulnerable to storm damage because the foundations of the pre-FIRM and post-FIRM sections can respond differently to storm forces and erosion. For example, the BPAT found a damaged house in Mexico Beach that was supported by two types of foundations. One part of the house was supported on concrete block piers placed on the old pre-FIRM slab-on-grade. The remainder of the house, which extended beyond the original pre-FIRM footprint, was supported on timber piles set in concrete encasements. Although the piles and slab survived the storm, the concrete block piers did not. With the loss of the piers, the house listed to the unsupported side and the floor beams separated from the newer, pile foundation. Had the entire house been supported on timber piles, it may have survived with little or no damage.

2.5 Design, Construction, and Workmanship

After observing hundreds of damaged or destroyed structures, the BPAT has concluded that many structures seem either to have been built without the aid of detailed design plans (prepared by a design professional) or not to have been built in accordance with plans that were available. Failure of non-engineered or poorly designed foundations, structural systems, and critical connections often led to major damage or complete loss of structures. Such losses are preventable.

Numerous instances of poor workmanship were also noted by the BPAT during its inspections. In particular, the BPAT found several examples of misalignment of timber foundation piles and poor framing practices in platform-type construction. The BPAT also noted recurring problems with concrete construction. For example, reinforcing steel was missing from or misplaced in slabs, footers, and wall grade beams, and welded wire fabric reinforcement was frequently at the bottom of, not centered in, the slabs. Although no damage was observed that could be definitively linked to these examples of poor workmanship, such practices should be avoided in any construction, especially in areas subject to coastal storm forces.