FIGURE 5-22 This built-up membrane had a mineral surface cap sheet. Because of the roof covering damage, this manufacturing facility on the island of Culebra was shut down for approximately two weeks after the hurricane. This building also experienced roof damage during Hurricane Hugo in 1989.

FIGURE 5-23 The windows in this building were broken by aggregate from the built-up roof of a nearby building (Figures 5-24 and 5-25).

5.3.6 Sprayed Polyurethane Foam

Several sprayed polyurethane foam roofs were observed. They provided excellent wind performance provided the substrate did not lift. Many of them, however, needed to be recoated even before Hurricane Georges occurred. (Recoating is related to long-term roof system performance rather than wind resistance.)

5.3.7 Other Roof Coverings

The BPAT observed several other types of roof coverings, including asphalt roll roofing, corrugated asphaltic panels, and asphalt shingles. Since Puerto Rico has so few of these types of roof coverings, detailed observations were not conducted. The performance of asphalt roll roofing and shingles varied.

5.4 Windows, Shutters, and Skylights

Several types of window, shutter, and skylight problems were observed with residential and commercial buildings. Some problems were caused by missiles and others by over-pressurization.

Most houses had Miami windows, which are metal jalousie louvers, as shown in Figures 5-16 and 5-19. Since there is no glass in the opening, very high or low internal air pressure can be induced, depending upon wind direction and location of other openings in the building. In addition, these units do not offer much protection against wind-driven rain.

Window and door failure effects are discussed in Section 5.1. Windows are more of a problem than non-glazed doors because they are more susceptible to missile damage. While the probability that any one window will be struck by a missile is small, when it does occur, the consequences can be significant. The probability of missile impact depends upon local wind characteristics and the number of natural and man-made windborne missiles in the vicinity.

Windows can be protected from missile damage by special glazing or exterior shutters. Previous research and testing has shown that if special glazing is used, laminated rather than tempered glass should be specified. Although laminated glass is more easily broken than tempered glass, there is a greater probability that broken laminated glass will stay in the frame (provided the frame detailing is suitable); tempered glass will shatter and fall out of the frame as illustrated by Figures 5-24 and 5-32.

Although shutters are intended to protect glazing from missile impact, most shutter designs do not substantially reduce the wind pressure that is applied to the glazing. Accordingly, glazing protected by shutters should be designed to resist the full positive and negative design wind loads.

Glazing is not typically used with Miami window systems. Therefore, wind loading on buildings with Miami windows should be determined by using ASCE 7-95. This typically results in the building being assessed as partially enclosed (i.e., design for high internal air pressure)

5.4.1 Windows

The building in Figure 5-23 had approximately 100 windows broken by aggregate that blew off of a built-up membrane roof across the street. Some panes were tempered glass (Figure 5-24) and others were annealed (Figure 5-25).

FIGURE 5-24 When these tempered panes broke, they did not produce shards of glass, as did the annealed panes.

FIGURE 5-25 Although some annealed panes broke into shards, others just broke at the impact point.

The window frame in Figure 5-26 was blown out by over-pressurization of the building interior when the building envelope was breached elsewhere in the building. Missiles broke the glass shown in Figures 5-27 and 5-28. The three buildings in these photos are all located near one another.

FIGURE 5-26 Half of the window frame blew out. It was attached with two screws in plastic sleeves at the head, three screws at the jamb, and two screws at the sill.

FIGURE 5-27 One pane in this window was broken by a missile, perhaps from the palm in the foreground.

FIGURE 5-28 This large window, which was removed and leaned against the wall after the storm, was broken by a missile, most likely a tree limb.

In Figure 5-29, some window frames in this mid-rise building were blown out while in other cases, just the glass was blown out. This appeared to be caused by negative pressure (suction).

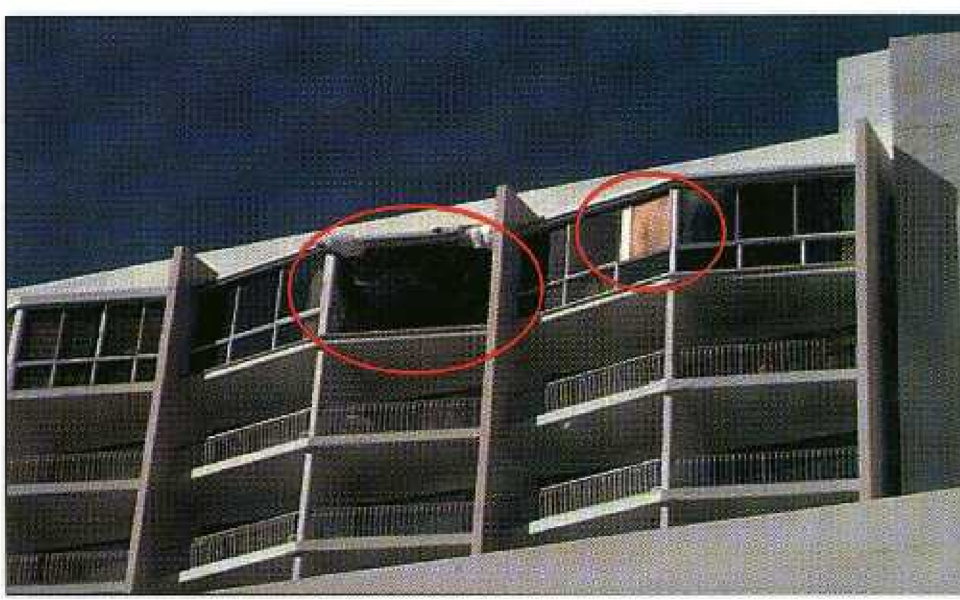

FIGURE 5-29 The glass and frames were blown out at the center room on the top floor. At the room to the right, one of the glass panes was blown out.

The building in Figures 5-30 and 5-31 experienced substantial damage to windows and sliding glass doors. Missiles caused at least part of this damage. The window in Figure 5-32 broke, but since the glass was laminated it did not fragment into separate pieces.

FIGURE 5-30 Several window and glass door openings broke during the hurricane. They were subsequently covered with plywood (Figure 5-31).

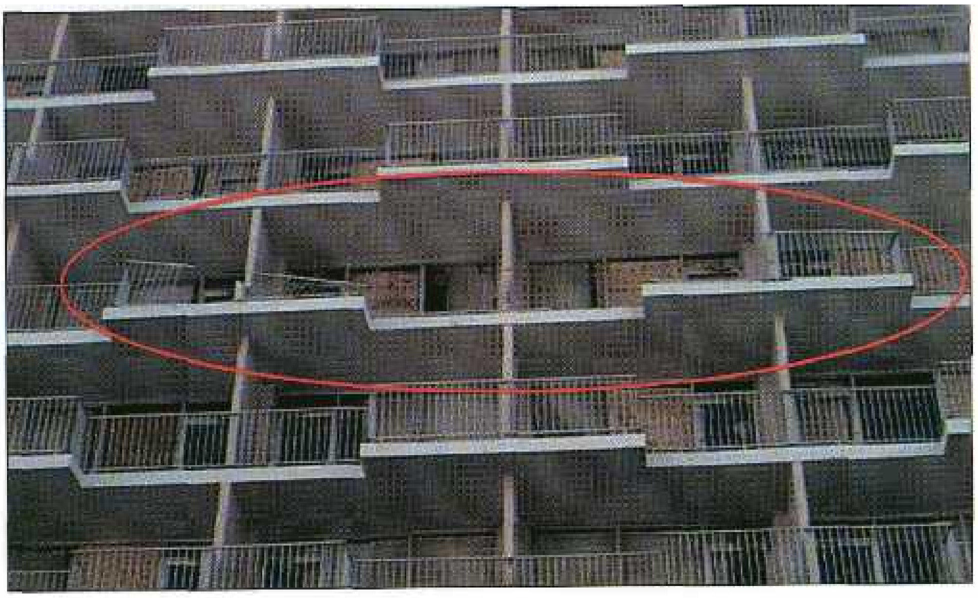

FIGURE 5-31 High-energy missiles from a nearby building damaged several railings of this building.

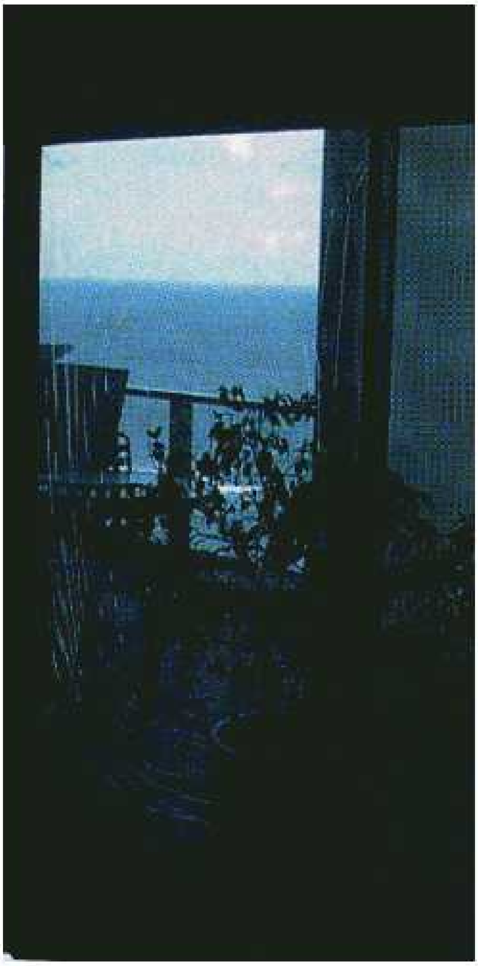

FIGURE 5-32 The broken light in the center is laminated. A sliding glass door located to the left had tempered glass, which was blown out of the frame.

5.4.2 Shutters

Many residential and commercial buildings were equipped with shutters of various designs and materials, as shown in Figures 5-33 through 5-39. Problems observed included shutter panel loss, shutter panel displacement (i.e., the panel deflected and pressed against the window), shutter track loss, and blow-out of the window to which the shutter was attached (Figure 5-40). It should be noted that Miami windows look like a type of storm shutter, but offer very little missile protection.

FIGURE 5-33 A combination of boards and metal panel was used to construct this shutter. Unless shutters are well attached, they can blow off during high winds and become missiles themselves.

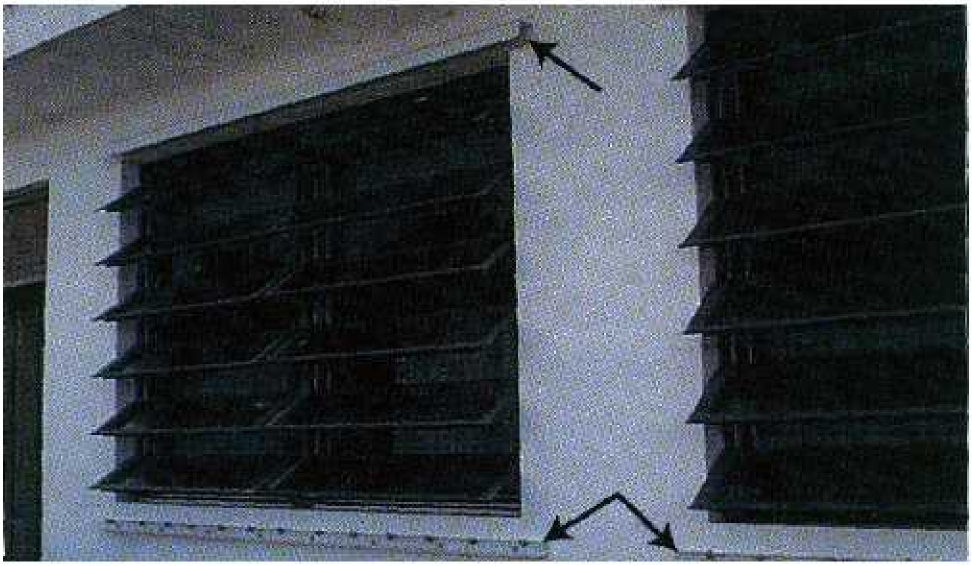

FIGURE 5-34 These windows were equipped with permanent head and sill shutter tracks, which were attached to the wall with closely-spaced fasteners (Figure 5-35).

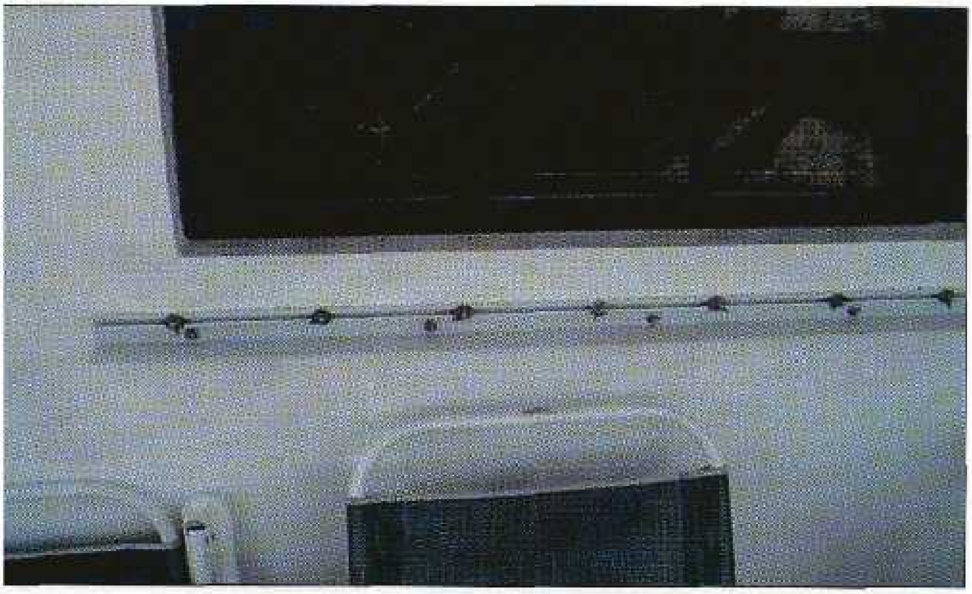

FIGURE 5-35 Close-up of Figure 5-34. The steel shutter panels were designed to be locked into the track with wing nuts spaced 6-in on center, a more reliable attachment than that shown in Figure 5-36.

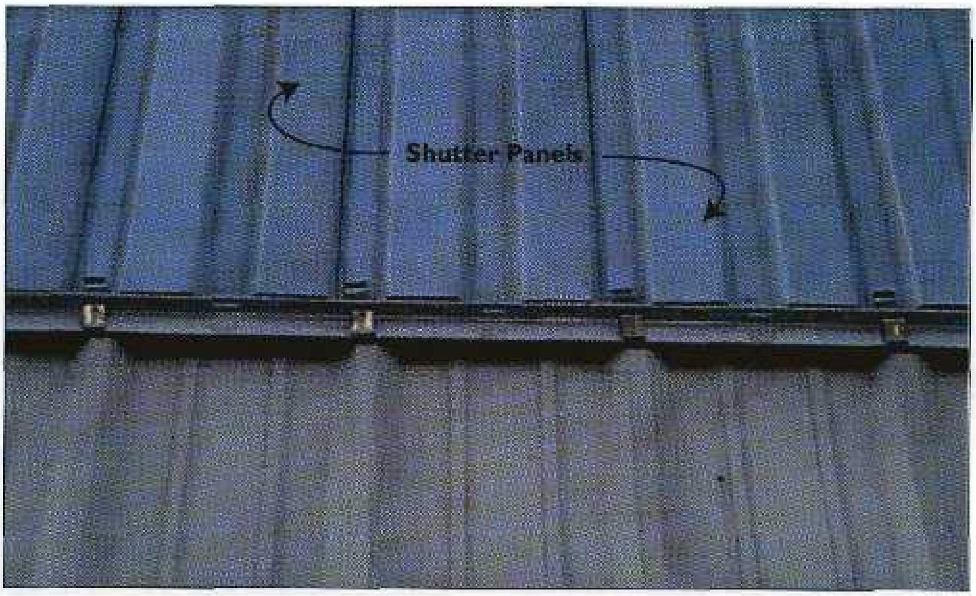

FIGURE 5-36 Looking up at a shutter panel held in place by clips (a metal wall panel occurs below the shutter track). These clips were spaced 12-in on center. Clips are not as reliable as the bolted attachment shown in Figure 5-35.

FIGURE 5-37 These windows were equipped with roll-up shutters.

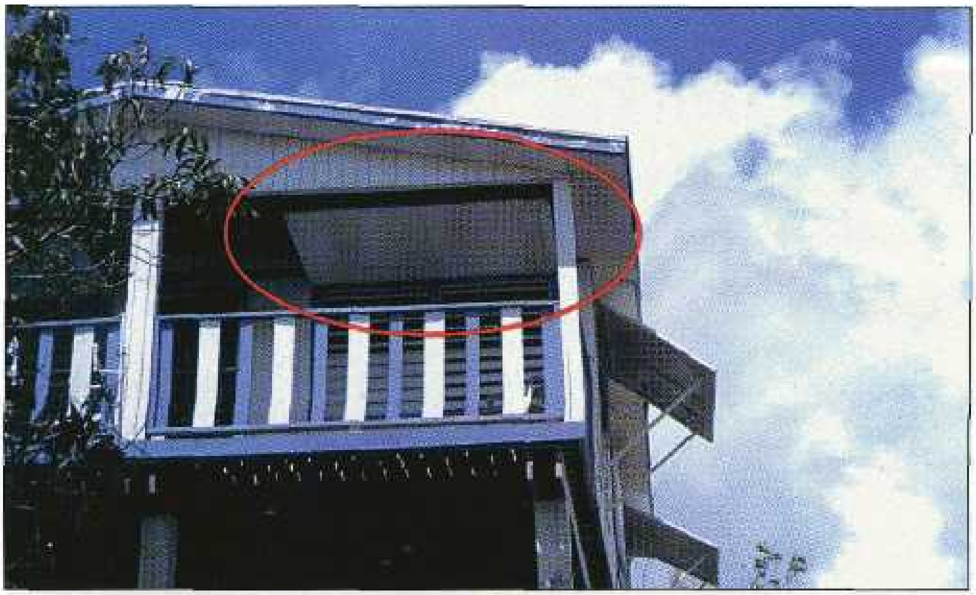

FIGURE 5-38 This house had hinged plywood shutters. The front shutter protects a Miami window.

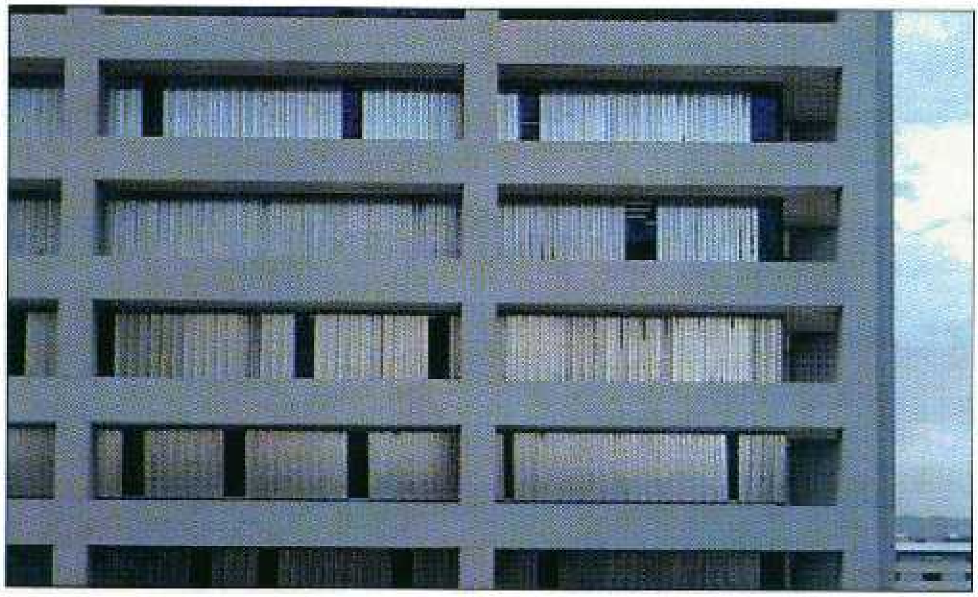

FIGURE 5-39 Steel shutters were used on this mid-rise building, which had a narrow balcony in front of the windows. Since wind speed increases with building height, the shutters on the upper floors can receive very high wind loads. The length of the shutters on this building requires the shutter panels and their connection to the tracks to be strong enough to resist being blown out of the track. The shutter panels also must be stiff enough to prevent deformation against the glass, or they must be set far enough away from the glass so they do not press against it.

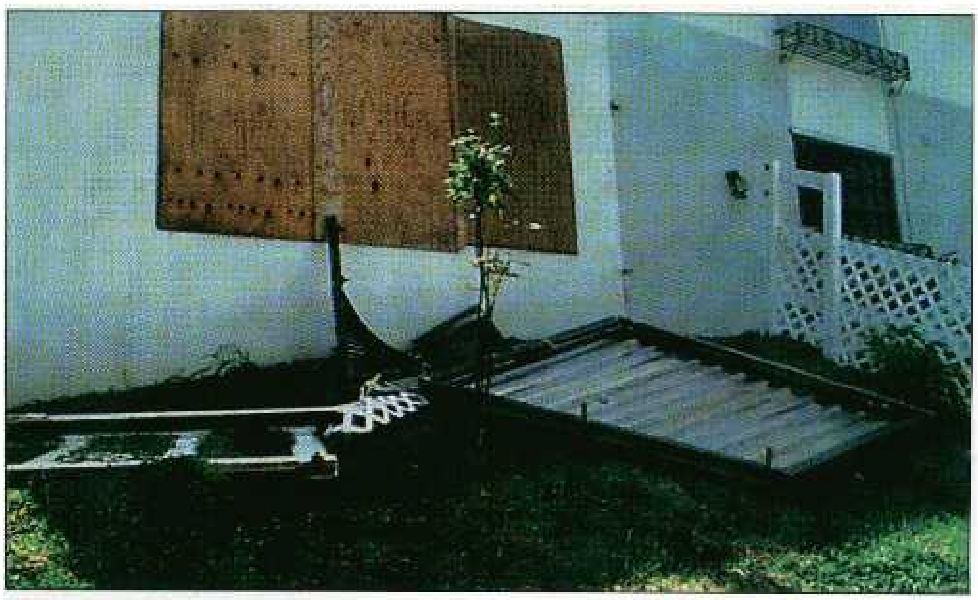

FIGURE 5-40 The window lying on the ground was protected by a shutter. However, the shutter was attached to the window frame. The window frame fasteners were over-stressed and the entire assembly failed. Attachment of the shutter directly to the wall framing is a more reliable method of attachment.

5.4.3 Skylights

The BPAT observed a few broken skylights during its investigation. Most were glazed with acrylic sheet. Missiles caused some of the damage. In a large atrium covered with prefabricated translucent panels, many of the skylight panels were blown off.

5.5 Seismic Resistance of Nonstructural Elements

The BPAT noted the lack of compression struts, diagonal ties, and perimeter suspension wires in several buildings with acoustical ceilings (Figure 5-41). A lack of bracing was observed on some interior gypsum board/stud partitions as well as inadequate reinforcement and bracing of interior non-load bearing CMU walls (Figure 5-42).

FIGURE 5-41 Part of the exterior envelope of this building blew away, resulting in damage to the acoustical ceiling. This revealed a lack of seismic resistance of the ceiling system, light fixtures, and ductwork.

FIGURE 5-42 An interior view of a house under construction (the steel joists a supporting formwork for the concrete slab). The CMU partition is inadequately reinforced and is not supported or laterally braced at the top of the wall.