FIGURE 5-10 This house is under construction. The surface of the concrete is very rough because the plywood form (which is lying down on the ground) was used repeatedly. The rough texture will be compensated for with a stucco surfacing.

While stucco loss had only minor effects to the buildings where it was applied, the windblown debris could have traveled substantial distances and damaged other buildings. This was a particular problem when stucco debris was blown off of tall buildings. Instead of relying on stucco to provide an attractive wall surfacing, the quality of the cast-in-place concrete and CMU construction should be improved so that the concrete or CMU can be left exposed or painted. This would eliminate the missile problems that resulted when stucco was blown away and became airborne.

The BPAT observed an EIFS covering consisting of synthetic stucco applied over two layers of EPS over concrete. There was a superficial bond between the two EPS layers (Figure 5-11). Ceramic tiles were blown off of concrete spandrel panels on a high-rise building (Figure 5-12) and wind scour caused some exterior paint finish damage (Figure 5-13).

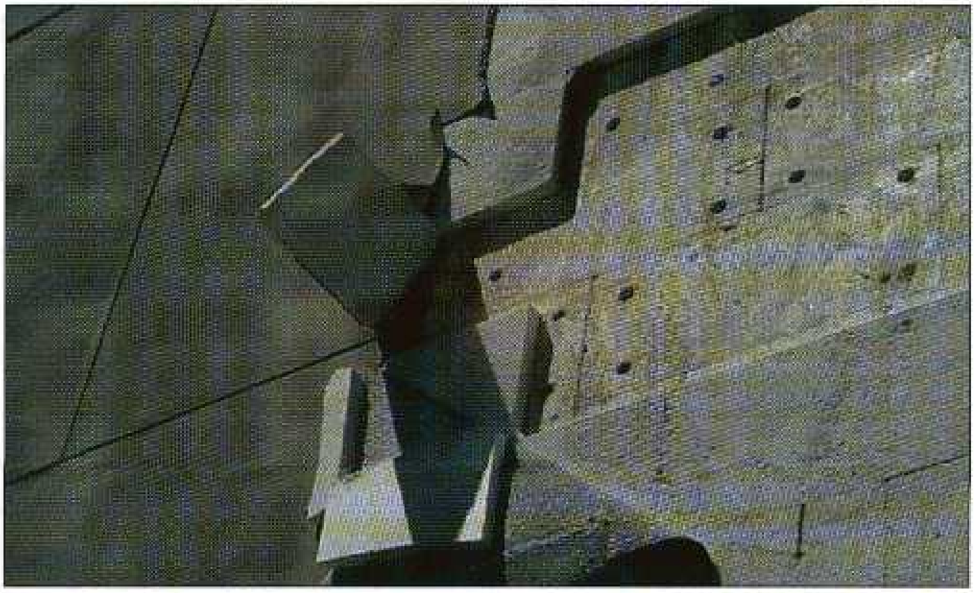

FIGURE 5-11 At this EIFS covering, the synthetic stucco appeared to be well-adhered to the outer EPS layer, but there appeared to be minimal bonding between the two EPS layers. In at least the lower portion of the wall, the first layer was attached with mechanical fasteners deeply recessed into the foam. The delamination occurred near the corner of the building, where the suction pressures were high.

FIGURE 5-12 A mortar skim coat was applied over the concrete, and the ceramic tiles were set in to the mortar. The primary failure plane was between the mortar and concrete.

FIGURE 5-13 This house was located on a mountain top that experienced very high wind conditions. The paint scoured off at some of the soffit areas and along the recessed wall.

5.3 Roof Coverings

Metal panels and concrete (either exposed or covered with a liquid-applied membrane) were the most common types of roof coverings found on residences. Commercial buildings typically were covered with metal panels or built-up membranes. Several other types of roof coverings were also observed.

Historically, damage to roof coverings is the leading cause of building performance problems during hurricanes. In the rains accompanying a hurricane, water entering the building through damaged roofs can cause major damage to the contents and interior. These damages frequently are more costly than the roof damages themselves.

5.3.1 Metal Panels

The BPAT observed a variety of architectural and structural metal panels. Corrugated galvanized steel with exposed fasteners was the most common type found on residences. These panels generally were fastened with smooth- or screw-shank nails (Figure 5-14). With few exceptions, the spacing of fasteners along side laps, eaves, hips, and ridges was insufficient (Figure 5-15).

FIGURE 5-14 The nail attaching this corrugated metal panel partially backed-out. Screws are much more resistant to back-out. Nail back-out is a problem with metal panel systems because of the large number of load cycles and large amount of deformation the panels can experience during a hurricane. Elsewhere on this roof, some of the panels were blown off.

FIGURE 5-15 Only a single row of fasteners were installed along the eave and along each side of the ridge. The side laps are insufficiently attached and are lifting in a few areas. The end lap is too far away from the first row of fasteners—another nailer should have been installed. Clips between the joists and wall were retrofitted prior to the hurricane; however, enhanced attachment of the metal roofing was not performed as part of that work. As a result, several of the metal panels were blown off.

In some instances, a framing member was not provided along rake overhangs. Instead, the nailers were simply cantilevered and the metal panels were just attached at each nailer (Figure 5-16). With a continuous rake framing member, as shown in Figure 5-17, the metal panels can be attached with closely-spaced fasteners. Panel fasteners should be closely spaced along the rake because of the extremely high uplift forces that occur in this area during a hurricane.

FIGURE 5-16 The metal panels along this rake were insufficiently fastened. A framing member was not run up the rake.

FIGURE 5-17 At this house, a framing member was run up the rake, which allowed the metal panels to be fastened between the nailers (purlins). However, the rake member must have sufficient strength to resist design uplift loads, which does not appear to be the case with this member. Rather than installing a metal edge flashing, these metal panels simply were cantilevered beyond the rake framing, providing a loose edge that is susceptible to lifting and peeling during high winds. Other deficiencies that are noted in this photograph include incorrect nailing of roof material to rake member and inadequately sized and spaced nailers.

Corrugated panels as well as other panel system designs frequently blew off the framing. However, in many instances framing failure caused the panel loss.

In addition to the interior water damage that occurs upon blow-off of metal roof panels, the panels themselves can become high-energy missiles that can damage buildings and other property (Figure 5-18). Metal panels contributed significantly to the amount of debris from Hurricane Georges.

FIGURE 5-18 Corrugated metal panel wrapped around a power pole.

Many roofs were corroded because their galvanized coating was not very resistant to corrosion. Many were also not field painted. Use of an aluminum-zinc alloy coating (Galvalume) greatly enhances corrosion protection and is particularly beneficial for roofs located near salt water.

5.3.2 Exposed Concrete and Liquid-Applied Membranes Over Concrete

The BPAT observed several cast-in-place concrete roofs with no roof covering. While these roofs provided excellent wind performance, some leaked during the hurricane due to the heavy rains that accompanied the storm (Figure 5-19). Roofs with liquid-applied membranes over the concrete provided excellent performance.

FIGURE 5-19 This concrete roof deck did not have a roof covering. During the hurricane, water entered the house through the deck. The concrete deck and CMU walls were skimmed with a skim coat of plaster. This house has Miami windows.

5.3.3 Tile

While the BPAT observed clay and concrete tile roofs, they make up only a small percentage of steep-slope roofs in Puerto Rico. The BPAT observed many damaged tile roof coverings (Figure 5-20). In some cases, uplift pressure initiated failure while in others it was caused by missile impact.

FIGURE 5-20 These tiles were heavily damaged, although the wind speed at this location was not very high. As can be seen in the foreground, the roof covering generated a substantial number of missiles. Because of the relatively low wind speed, the tile debris did not travel very far.

Concrete and clay tile roof coverings were vulnerable to missiles. Even when their attachment was well designed and tiles were properly installed, their brittle nature made them especially susceptible to relatively low-energy missiles. Debris from a single damaged tile can impact other roof tiles and lead to a progressive cascading failure. In addition to the roof damage, many high-energy missiles can became airborne.

5.3.4 Liquid-Applied Membranes Over Plywood

The BPAT observed only a few liquid-applied membranes over plywood. As long as the roof structure did not fail they provided excellent wind performance (Figure 5-21).

FIGURE 5-21 This house had a liquid-applied membrane over plywood roof sheathing. This type of roof system typically offered excellent wind performance provided the plywood does not lift. This house was located on the island of Culebra.

5.3.5 Built-Up Membranes

Several built-up roofs experienced membrane lifting and peeling. Since these roofs were not generally exposed to very high winds, damage usually was limited to corner areas, rather than complete loss of the roof covering (Figure 5-22).

In at least one instance, aggregate (gravel) from an aggregate surface built-up roof broke a large number of windows down wind (Figure 5-23). As demonstrated again in this hurricane, aggregate from built-up membranes can travel a substantial distance and break glass. On some buildings, tall parapets have been installed to mitigate this type of damage. However, presently there is insufficient guidance available on required parapet height with respect to design wind speed. The double surfacing technique, wherein essentially all of the aggregate is embedded in bitumen, has proven to be a successful means of preventing aggregate blow-off. However, this is a relatively expensive technique. The most conservative approach to this problem is to eliminate the use of aggregate surfacing, but a mineral surface cap sheet, field-applied coating, or an alternative type of roofing system can also be used.