FIGURE 3-15 A landslide inundated this house with up to 5 feet of soil.

FIGURE 3-16 Development adjacent to a representative unprotected cut; the potential for future landslide activity exists.

3.4 Overview of Buildings Evaluated

The BPAT investigated residential and commercial buildings that were affected by wind riverine and coastal flooding, and landslides. These buildings can be categorized into four types of construction:

- Concrete masonry structures with concrete roof decks (residential and commercial)
- Concrete masonry structures with wood-frame roof structures (residential and commercial).
- Combination structure, concrete foundation first floor with wood-frame structure for the additional levels.
- All wood frame structures.

The structural performance of buildings constructed of concrete/masonry with concrete roof decks was excellent. This was true for residential and commercial buildings. Residential buildings and homes constructed of concrete/masonry with wood-frame roof structures experienced widespread roof loss

The all wood-frame structures, almost exclusively residential construction, performed worse than all others and the greatest amount of destruction was observed in them Residential buildings investigated ranged in age from post-WWII to current day construction. Most mid- to high-rise buildings inspected were constructed during and since the 1960's.

3.4.1 Concrete/Masonry Structures with Concrete Roof Decks

Both residential and commercial buildings constructed of concrete/masonry with concrete roof decks were investigated. Figure 3-17 shows commercial buildings of concrete construction with concrete roof structures. These large buildings performed well structurally during Hurricane Georges. Many, however, experienced significant interior damage and property loss due to breach of the building envelope. Loss of exterior windows due to wind and windborne debris was the primary damage observed (Figure 3-18).

FIGURE 3-17 Commercial concrete structures with no structural damage. These structures are located to the east of Old San Juan.

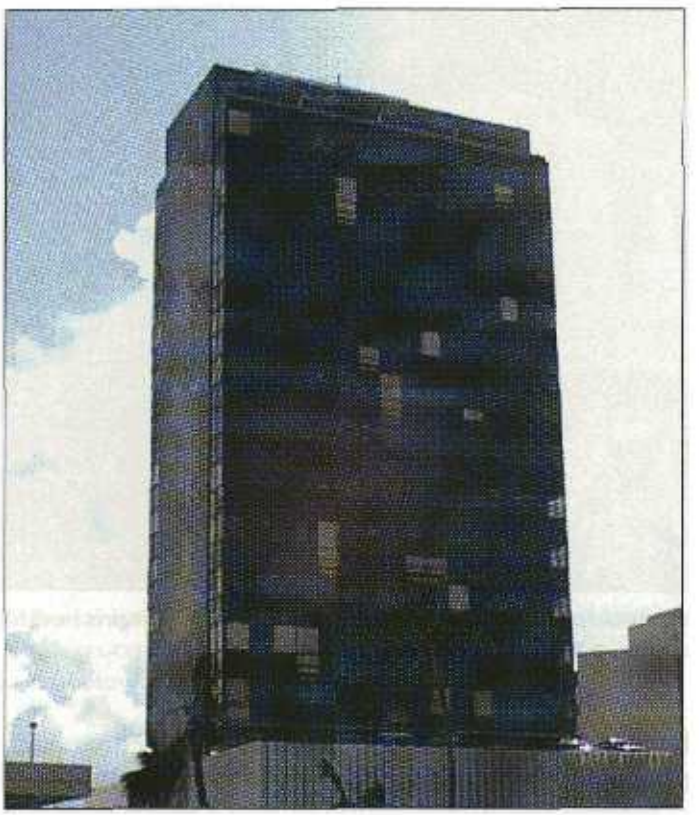

FIGURE 3-18 Commercial concrete structure with interior damage due to breach of building envelope (failed windows). Note: Plywood sheets were installed after the storm to cover broken windows; they were not present prior to the storm.

The BPAT observed that single-family homes constructed of concrete, masonry, (or a combination of both) and with concrete roofs performed well with no structural damage (Figure 3-19). These structures were primarily one- and two-story buildings with reinforced concrete columns/piers and both reinforced and un-reinforced concrete masonry units (CMU) block pier foundations supporting elevated concrete floor slabs.

For the purposes of this report, systems used to protect doors and windows from missiles (windborne debris) are referred to as "shutter systems". Shutter systems observed on the island varied in material and included plywood sheeting, corrugated metal, and pre-engineered metal and plastic panel systems. In Puerto Rico, these temporary shutter systems are commonly referred to as "hurricane panels".

FIGURE 3-19 Residential concrete structure in the mountains north of Adjuntas with no structural damage following Hurricane Georges.

The first floor of concrete/masonry buildings with reinforced concrete roof decks often were elevated a single story or more above the ground on minimally reinforced columns. As a result, they are at significant risk from collapse during a major earthquake. The successful performance of these buildings during Hurricane Georges appears to relate mainly to the dead load from the weight of the concrete roofs and walls that helped resist uplift and lateral wind loads. The size and spacing of reinforcing steel was noted by the BPAT on buildings under construction, and the connections appeared to be based solely on gravity loads and the minimum connections of reinforcing steel for gravity loads. The BPAT observed a general lack of attention to lateral loads in all residential construction. For wood-frame houses, this lack of attention was evident in the amount of hurricane damage they received.

3.4.2 Concrete/Masonry Structures with Wood-Frame Roof Structures

Buildings with walls constructed of concrete/masonry columns with masonry infill and wood-frame roof structures were observed. This construction type is commonly found in Puerto Rico. Buildings of masonry construction with wood roof framing have performed well in other hurricane-prone areas of the United States when a continuous load path is present to transfer wind-induced loads from the roof structure to the foundation. Generally, the BPAT found that there was no attention to a continuous load path (for wind or seismic loads) in the roof structures other than for gravity loads. The sill plate atop the masonry wall was generally attached by extending reinforcing steel through a hole bored in the sill plate and bending the steel to prevent withdrawal, uplift, or displacement of the sill plate.

Most roofs inspected were gable roofs; the remainder were low-slope (flat roofs) and hipped roofs. Figure 3-20 represents a single-family home with a wood-frame gable roof structure that experienced a typical roof failure. Failure of roof structures at gable ends has been well documented following previous hurricanes, especially when insufficient attention has been paid to connection details at the masonry walls or to bracing the gable end wall. This was the case in Puerto Rico.

FIGURE 3-20 Aerial view of a residential concrete/masonry structure with a wood-frame roof structure; only the roof rafters remain. The wood nailers and metal panels were blown off.

3.4.3 Combination Structures, Concrete/Masonry and Wood-Frame Structures

This construction type was observed almost exclusively in single-family home construction. Concrete columns often supported an elevated concrete slab. CMU block, typically 6-in thick, was used to enclose the lower floor or crawl space area. Wood framing completed the walls and roof structure above the first level. Wood framing was generally inadequate. Nominal 2-in by 3-in lumber was sometimes used for studs. Nominal 2-in by 4-in studs, when used, were often spaced up to 4-feet on center. The studs were generally connected to the wall system by nailing to a bottom plate or sometimes directly to the subfloor. Typically, no connection other than nailing was made from the studs to the floor system. When exterior grade plywood was used as sheathing, it generally did not overlap the band joist. Top plates frequently were made of single, rather than double, 2-in by 4-in members. Rafters generally were supported directly over the studs. No connection other than nailing was made from the walls to the rafter or truss system. Figure 3-21 shows this type of single-family home. While wood-frame construction generally performs well in earthquakes, the other building elements commonly found in Puerto Rico—long slender columns supporting the structure—can lead to the collapse of these structures in a significant earthquake.

FIGURE 3-21 A combination residential concrete/masonry structure with an elevated second-floor concrete slab and a wood-framed upper level. Note the lack of damage to the concrete/masonry section of the house and the damage to the wood-frame portion.

In Figure 3-22, the concrete/masonry building is under construction. Details regarding concrete columns, masonry block, and typical reinforcing steel were observed and noted.

FIGURE 3-22 A residential concrete/masonry structure that is under construction. The photograph illustrates this common building practice: concrete columns with unreinforced masonry block infill walls. This is not seismic resistant construction.

3.4.4 All Wood-Frame Structures

All wood-frame structures were almost exclusively limited to single-family homes. These structures were set atop concrete, masonry, or wood piers and foundations. The load path for wind- and seismic-induced loads from the foundations to the floor systems ranged from bolted steel band connectors to no connectors at all. The walls in these houses were constructed of nominal 2-in by 3-in or 2-in by 4-in lumber. Wall frames were weak with studs spaced up to 4-feet on-center. Sill and bottom wall plates were inadequately fastened to slabs or supporting floors. Stud wall construction contained little to no lateral bracing and only single member top plates. Roof support systems typically were nominal 2-in by 4-in members at 4-feet spacing with nominal 1-in by 3-in nailers supporting metal roof panels. Only a very small number of these structure types had a continuous load path from the roof system to the foundation. Figure 3-23 shows a typical wood-frame home that sustained significant damage during the hurricane.

FIGURE 3-23 A residential wood structure located on the hilltops west of Ponce destroyed by wind. The roof system has been removed and the wall system partially collapsed.