3 Assessment and Characterization of Damages

The general types of damages the BPAT observed as a result of Hurricane Georges in Puerto Rico are discussed below. More detailed descriptions of the damage observed are included in Sections 4, 5, 6, and 7.

3.1 Wind Effects

The National Weather Service (NWS) reported wind speeds from Hurricane Georges varying from 109 mph to 133 mph (3-second peak gust at a height of 33 feet) as it crossed the island of Puerto Rico. NWS recorded wind speeds at different airports using the Automatic Surface Observing System (ASOS). Since ASCE 7-95 uses 3-second gust wind speeds at 33 feet above ground over flat open terrain conditions, all data recorded under different conditions were transformed to the ASCE 7-95 averaging time and height for comparison purposes. Based on recorded data and BPAT observations, the wind speeds experienced in Puerto Rico during Hurricane Georges did not exceed the basic design wind speed of Planning Regulations 7's 110 mph fastest-mile (133 mph 3-second gust). In addition to this basic design wind speed, an overload factor of 1.3 for light structures and an importance factor of 1.15 for essential facilities are applied, resulting in a higher wind speed for failure.

The siting of structures affected the wind forces that acted upon the building. Lower areas were sometimes shielded from winds by hills or mountains. Buildings on high exposed slopes appeared to receive higher wind speeds because of the speedup of the wind up the slopes of the hills or mountains (due to topographic effects and described in ASCE 7-95) (Figures 3-1 and 3-2). The significance of these topographical effects is not recognized in Planning Regulation 7, but is accounted for in the newly adopted 1997 UBC. The 1997 UBC references ASCE 7-95 for the determination of wind speeds. These wind speeds may be adjusted to incorporate topographic effects on wind speeds.

Doppler weather radar detected three possible tornado events in Vieques, Orocovis, and Jayuya. The output given by Doppler weather radar, which is based on algorithms, is interpreted by meteorologists who decide whether or not a tornado warning should be issued. Sometimes, a circulation detected by Doppler radar that occurs at great elevations may never touch ground. The BPAT members investigated building damage in and around these towns and found no evidence of tornadoes, such as debris spread in a radial manner and/or severely shredded or pulverized debris, indicative of a tornado on the ground.

FIGURE 3-1 The abrupt change in topography in this community outside Loiza caused a speedup in the wind that flows over and around the buildings located on the hill beyond. The wind load provisions of Planning Regulation 7 did not account for wind speedup caused by abrupt changes in topography, and therefore underestimated wind loads on buildings situated on hills, mountains, or escarpments.

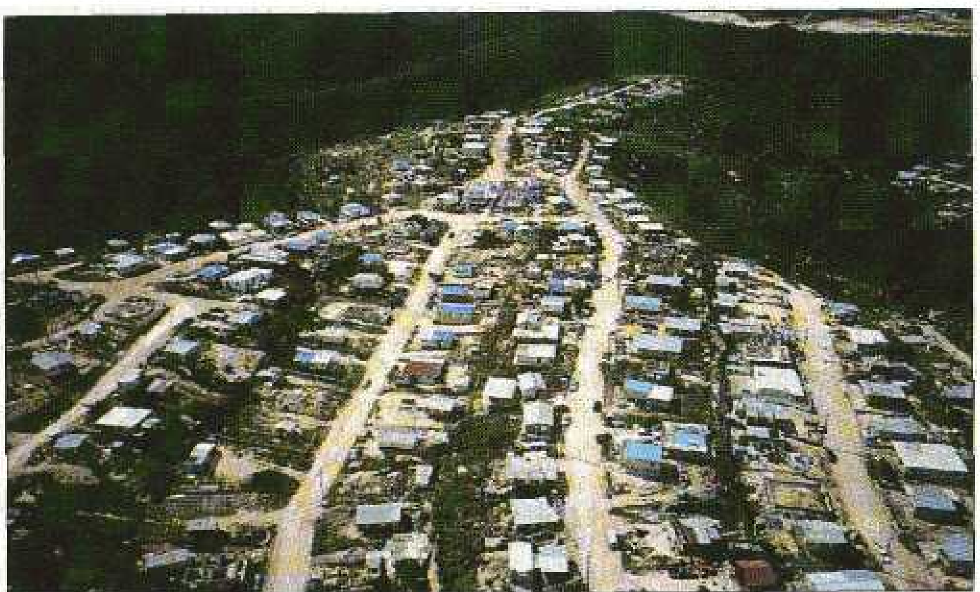

FIGURE 3-2 Wind damage from Hurricane Georges to residential buildings in Puerto Rico. Blue FEMA tarps have been placed on many of the roofs that sustained damage.

3.2 Riverine and Coastal Flooding

Flood damage was observed mainly along rivers in the west and central areas of Puerto Rico including Utuado, Jayuya, Adjuntas, Mayaguez, Añasco, and Arecibo. Coastal flooding was noted along the western shore at Rincón and Mayaguez. Damage in these areas occurred to buildings constructed without sufficient elevation above the BFE.

Flooding damage fell into two categories: buildings inundated by floodwaters that caused much of the building and contents to be wet, but no structural damage, and buildings with structural damage, where the foundations were undermined by floodwaters. Almost all flood-damaged homes fell into the first category. Figure 3-3 shows a typical non-elevated structure in a community located entirely in an SFHA that was damaged by Hurricane Georges. Figure 3-4 depicts a flood control measure that protected homes on one side of the river. Figure 3-5 is an example of the damage caused to the area along the river opposite the floodwall in Figure 3-4. Although these homes were severely flooded, they experienced minimal to no structural damage. Figures 3-6 and 3-7 illustrate cases where flooding undermined the building foundations.

FIGURE 3-3 Typical non-elevated structures in a community located entirely in an SFHA.

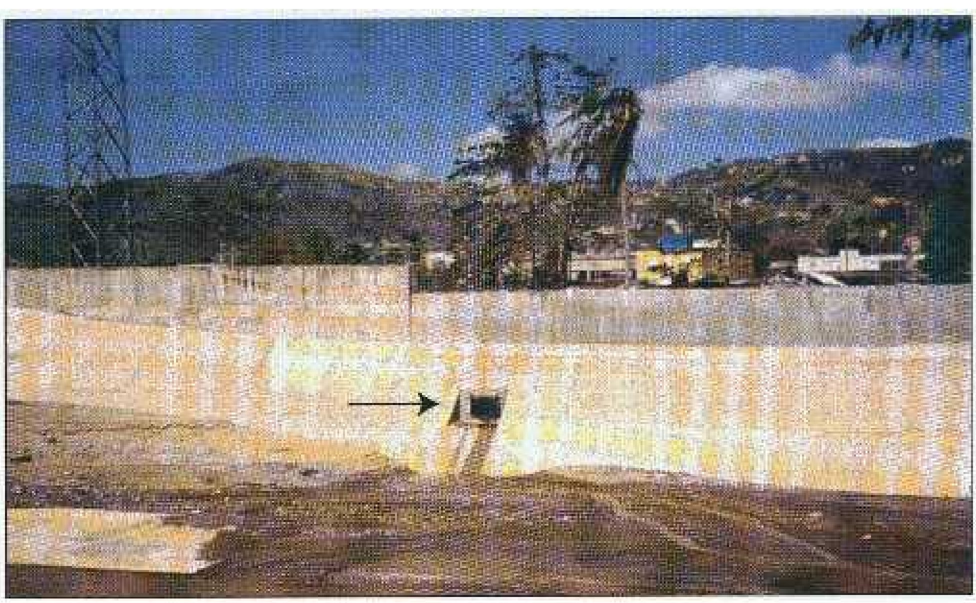

FIGURE 3-4 This flood gate located in Adjuntas prevented backwater from flooding homes located behind it; however, the wall contributed to flooding in the community located on the opposite side of the river, as shown in Figure 3-5.

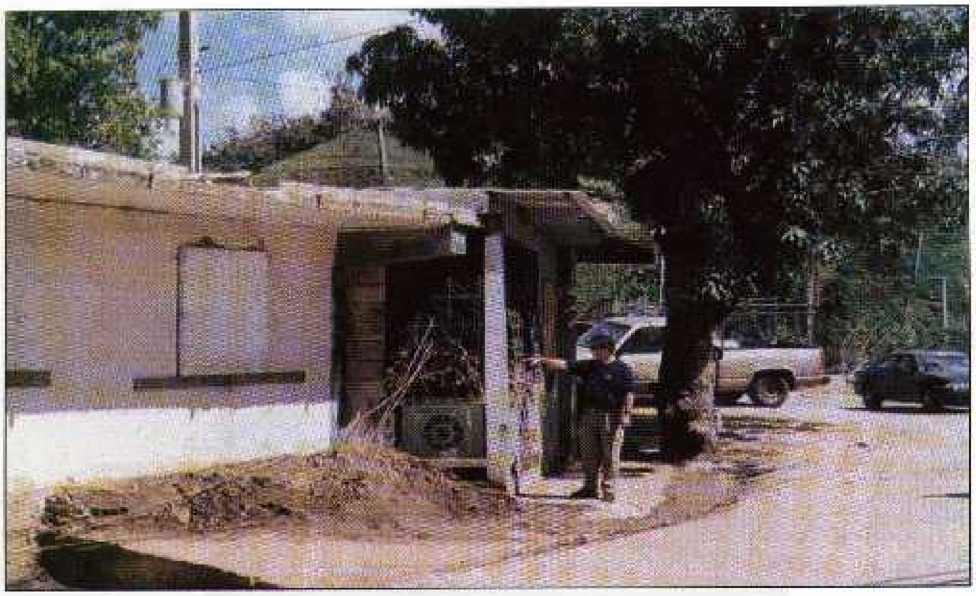

FIGURE 3-5 Residential area on the opposite side of the river from the floodwall in Figure 3-4. The flooding in this area reached a depth of 5 feet.

FIGURE 3-6 Floodwaters eroded soil and undermined the foundation system of this building.

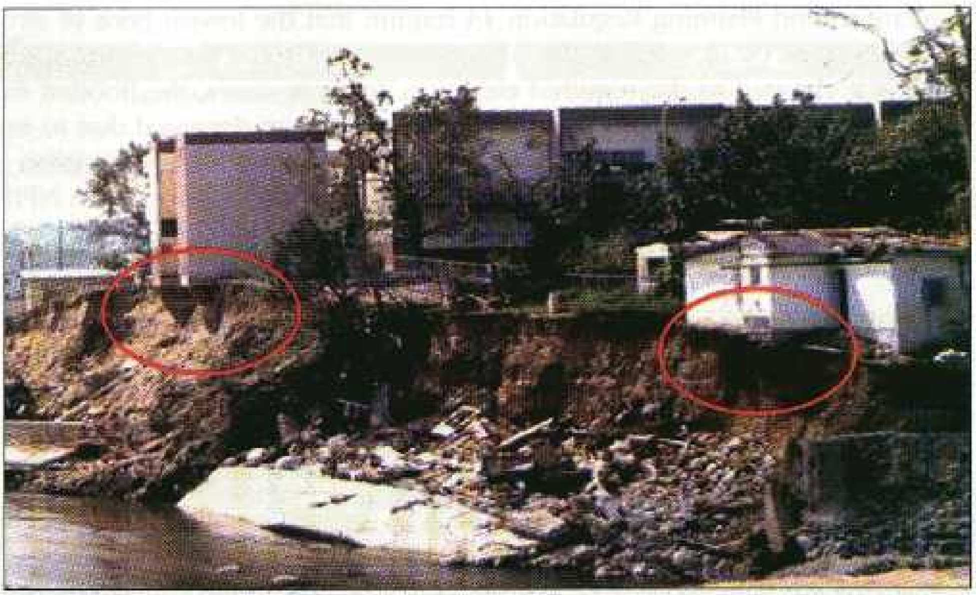

FIGURE 3-7 Riverbank erosion resulted in the undermining of the building foundations of a school (pink building) and house (white building) in Jayuya.

Siting of homes in floodprone areas, such as river and stream beds, was observed throughout Puerto Rico. Figure 3-8 illustrates a home constructed adjacent to and over an existing stream. Structures constructed in this manner are vulnerable to damage from floodwaters.

FIGURE 3-8 Typical construction adjacent to and over the river. Note the debris trapped under the concrete foundation and between the framing.

NFIP regulations and Planning Regulation 13 require that the lowest floor of structures located in A-Zones must be elevated to the BFE. However, in some flooded areas many buildings were not elevated to the required elevation. In many cases, the flooded structures may have been built before the FIRMs were issued. Homes were damaged due to improper elevation in coastal areas (Figure 3-9). Proper elevation techniques for construction in A-Zones are presented in Figure 3-10. A comparison of some of the differences in NFIP requirements for construction in V-Zones and A-Zones is presented in Figure 3-11.

FIGURE 3-9 Structure along the coast damaged by storm surge and wave action.

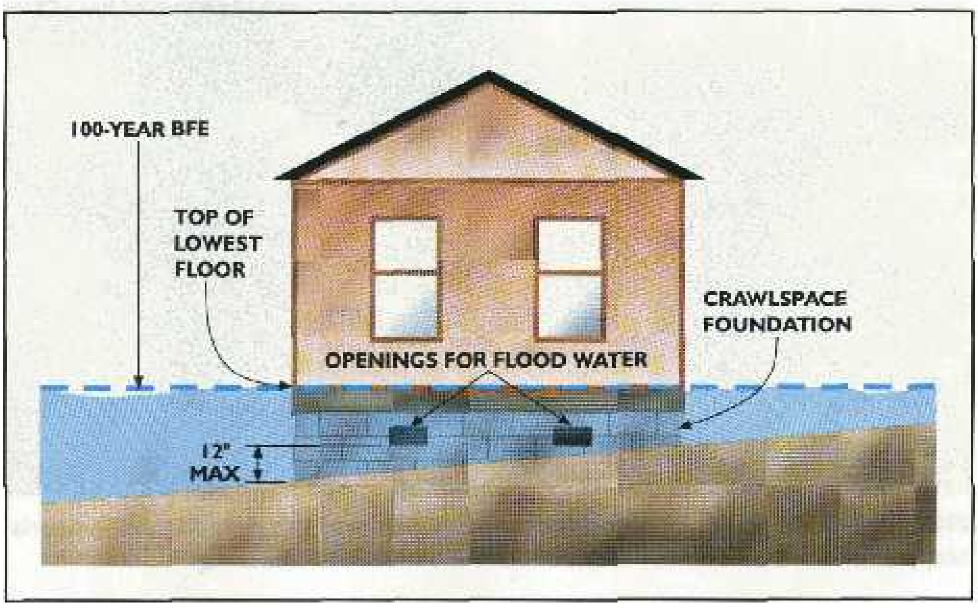

FIGURE 3-10 The top of the lowest floors of buildings in A-Zones must be at or above the BFE. Foundation walls below the BFE must be equipped with openings that allow the entry of flood waters so that interior and exterior hydrostatic pressures can equalize.

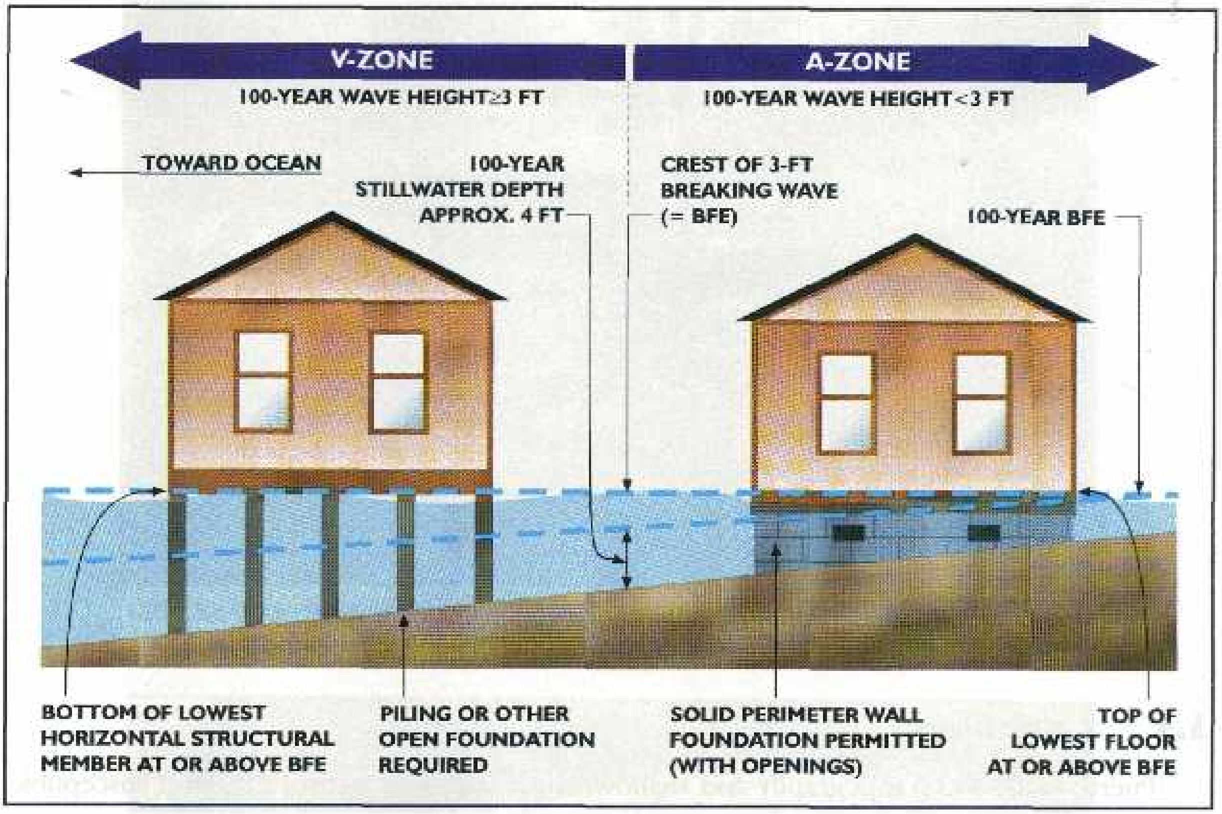

FIGURE 3-11 Comparison of building foundation and elevation requirements in V-Zones and A-Zones.

Buildings were not the only structures affected by the flooding of Hurricane Georges. Infrastructure, such as bridges and roadways, was also damaged Three major bridges and a number of small bridges were washed-out and impassible. A bridge damaged by floodwaters outside Adjuntas is shown in Figure 3-12 and a severely damaged water treatment facility is shown in Figure 3-13

FIGURE 3-12 This bridge outside Adjuntas collapsed due to insufficient design to resist the effects of floodwaters.

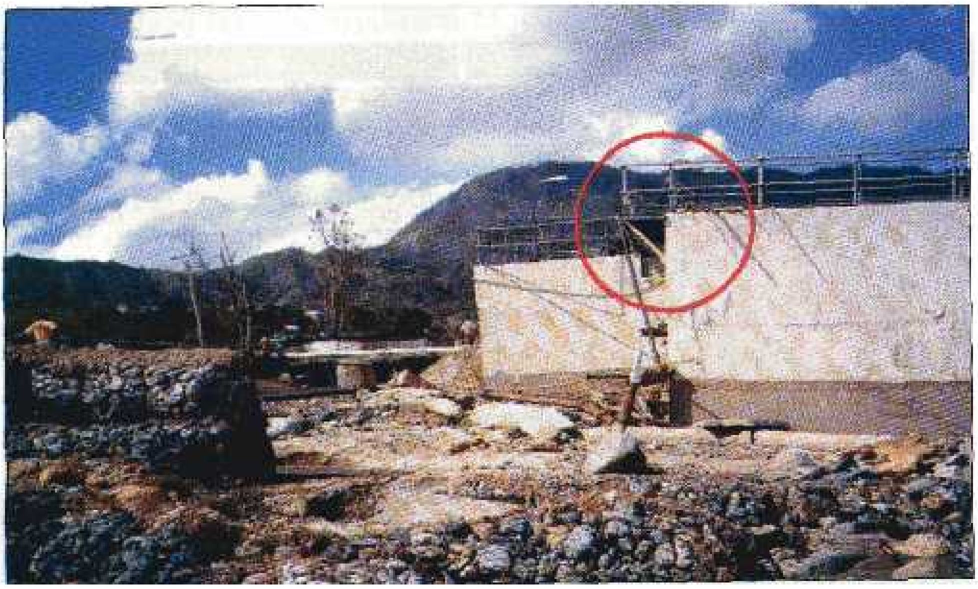

FIGURE 3-13 Severely damaged water treatment facility located in the floodplain in Jayuya; floodwaters overtopped the concrete wall.

3.3 Landslides

Puerto Rico's steep topography and shallow, sandy soils over bedrock make it susceptible to landslides. During Hurricane Georges, widespread rainfall in the more mountainous regions of the island resulted in numerous landslides that blocked and undermined roads, and even destroyed homes (Figures 3-14 and 3-15). This will become a greater problem in the future as more developments and houses are constructed in regions prone to such risks. A more detailed review and analysis of this problem needs to be undertaken. Figure 3-16 illustrates problems with unrestricted development. Many single-family homes are located beneath a cut that is void of vegetation, making the slope susceptible to landslides.

FIGURE 3-14 Aerial view of a now uninhabitable house caught in a landslide.