FEMA 339 / March 1999

Building Performance Assessment Report

Hurricane Georges In Puerto Rico

Observations, Recommendations, and Technical Guidance

IMAGE COURTESY NASA

Federal Emergency Management Agency
Mitigation Directorate
Washington, DC,
Region II, New York, NY
and the Caribbean Area Office

The Building Performance Assessment Process

In response to hurricanes, floods, earthquakes, and other disasters, the Federal Emergency Management Agency (FEMA) often deploys Building Performance Assessment Teams (BPATs) to conduct field investigations at disaster sites. The members of a BPAT include representatives of public and private sector entities who are experts in specific technical fields such as structural and civil engineering, building design and construction, and building code development and enforcement. BPATs inspect disaster-induced damages incurred by residential and commercial buildings and other manmade structures; evaluate local design practices, construction methods and materials, building codes, and building inspection and code enforcement processes; and make recommendations regarding design, construction, and code issues. With the goal of reducing the damage caused by future disasters, the BPAT process is an important part of FEMA's hazard mitigation activities. For more information about the BPAT program or if you are interested in becoming a member, please visit our website at www.fema.gov/mit/bpat.

Throughout Puerto Rico, the BPAT visited communities where people had lost their life's belongings and literally did not have a roof over their heads. The team was struck by the dignity of those individuals who had suffered great losses and appreciated the courtesy and hospitality that was extended to them. The team also appreciated their patience with the BPAT's questions. This report is dedicated to these individuals, their families, and their friends. Their remarkable spirit is summarized by the saying "*al mal tiempo, buena cara*", which translates as "hard times, strong faces".

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List of Acronyms

A-Zone	Special Flood Hazard Areas, excluding V-Zones
ACI	American Concrete Institute
AISC	American Institute of Steel Construction
ARPE	Administración de Reglamentos y Permisos (Regulations and Permits Administration)
ASCE 7-95	American Society of Civil Engineers Standard 7-95 *Minimum Design Loads for Buildings and Other Structures*
ASD	Allowable Stress Design
ASOS	Automatic Surface Observing System
ASTM	American Society for Testing and Materials
BFE	Base Flood Elevation
BOCA	Building Officials and Code Administrators
BPAT	Building Performance Assessment Team
CAV	Community Assessment Visit
CIAPR	Colegio de Ingenerios y Agrimensores (College of Engineers and Surveyors)
CMU	Concrete Masonry Unit
EIFS	Exterior Insulating Finishing System
EO12699	Executive Order 12699
EO11988	Executive Order 11988
EPS	Expanded Polystyrene System
FEMA	Federal Emergency Management Agency
FIRM	Flood Insurance Rate Map
HVAC	Heating, Ventilation, and Air Conditioning
IBC	International Building Code
ICBO	International Conference of Building Officials
in	inch
LRFD	Load and Resistance Factor Design
mb	millibars
mph	miles per hour
NEHRP	National Earthquake Hazards Reduction Program

NFIP	National Flood Insurance Program
NOAA	National Oceanic and Atmospheric Administration
NWS	National Weather Service
psf	pounds per square foot
SBC	Standard Building Code
SBCCI	Southern Building Code Congress International
SFHA	Special Flood Hazard Area
UBC	Uniform Building Code
V-Zone	An area of special flood hazard extending from offshore to the inland limit of a primary frontal dune along an open coast and any other area subject to high velocity wave action from storms or seismic sources

Executive Summary

On the evening of September 21, 1998, Hurricane Georges made landfall on Puerto Rico's east coast as a strong Category 2 hurricane. It traveled directly over the interior of the island, mainly in an east-west direction, and passed off Puerto Rico's west coast on September 22. Puerto Rico had not experienced a hurricane of this magnitude since Hurricane Hugo, a devastating Category 3 hurricane that passed over the northeast corner of Puerto Rico in a southeast to northwest direction in September 1989.

On September 30, the Federal Emergency Management Agency's (FEMA) Mitigation Directorate deployed a Building Performance Assessment Team (BPAT) to Puerto Rico to assess damages caused by Hurricane Georges. The team included architects, engineers, planners, insurance specialists, and floodplain management specialists. The BPAT's mission was to assess the performance of buildings and other structures throughout Puerto Rico and make recommendations for improving building performance in future events.

After an aerial assessment of the island, the BPAT conducted field investigations in selected areas affected by the storm. The field investigations of significantly damaged areas centered on the performance of single-family residential home construction. Isolated examples of success and failure in commercial buildings (primarily building envelope issues in high-rise buildings) and several essential facilities observed during field investigations were also documented. Commercial buildings were not investigated for compliance with current structural seismic guidelines. One- and two-family residential buildings, however, were investigated for their ability to sustain a seismic event. Seismic resistance of nonstructural elements was also observed.

It is important to note that wind speeds experienced on the island were not of the strength to test the design of Puerto Rico's buildings. A more significant wind event striking Puerto Rico would likely have resulted in even more failures than were observed.

A large number of residential buildings in Puerto Rico experienced structural damage from the high winds of Hurricane Georges. This can be attributed to a lack of a continuous load path from the roof structure to the foundation that the BPAT observed in most of the damaged buildings. In addition, a large number of residential buildings in identified Special Flood Hazard Areas (SFHAs) were damaged from floodwaters.

A limited number of mid- and high-rise buildings were inspected by the BPAT. Damage observed at these buildings was to nonstructural elements, including damage to glazing, curtain walls, interior walls, and damages to finishes from windborne rain. Building envelope damage resulted from loads on the components and windborne debris that broke glazing.

The BPAT concluded that while not all of the damage caused by Hurricane Georges could have been prevented, a significant amount could have been avoided if more buildings had been constructed to Puerto Rico's existing Planning Regulation 7 (building code).

Furthermore, a lack of compliance with and enforcement of Planning Regulation 13 (floodplain management) contributed to the damages. Additional damage could have been avoided if more buildings had been designed and constructed to current codes and regulations that address flood, wind, and seismic loads. Although the BPAT observed several examples of successful mitigation implementation, many buildings unfortunately received too little attention to mitigation. If effective mitigation efforts had been implemented more extensively in the design and construction of buildings, the widespread devastation of the hurricane would have been substantially reduced.

Puerto Rico's Regulations and Permitting Administration (Administración de Regalmentos y Permisos [ARPE]) has taken several important steps following Hurricane Georges to increase public safety and reduce property damage from natural hazards. These steps include:

- At ARPE's request, the International Conference of Building Officials (ICBO) conducted and completed a peer review of ARPE in January 1999. This peer review evaluated the new needs created by Hurricane Georges as well as the re-engineering effort currently underway.
- The Government of Puerto Rico, including ARPE, passed emergency regulation in December 1998 that repealed Planning Regulation 7 and adopted the 1997 Uniform Building Code (UBC) as the building code for Puerto Rico.
- ARPE is positioned to make recommendations concerning building regulations to the new Certification and Building Board of Puerto Rico that is expected to be created in March 1999 under proposed legislation submitted by the Governor to the Puerto Rico Legislature.
- ARPE and FEMA are implementing a strategic plan to provide the necessary training to make the transition to these new building regulations.

The ICBO's peer review of ARPE assessed how ARPE administers and enforces planning regulations related to building design and construction. The review evaluated ARPE's current needs—and identified unmet needs—to respond effectively to the massive amount of reconstruction necessary following Hurricane Georges as well as future construction. The peer review resulted in recommendations in the areas of policies, procedures, practices, training and education, facilities, salaries, benefits, promotion, and office automation. Since the completion of the peer review, FEMA, ICBO, and ARPE have been working closely together to develop a plan that meets the identified unmet needs.

In addition to the recommendations outlined above, the BPAT recommends the following:

- The Government of Puerto Rico should continue supporting positive mitigation education efforts undertaken by the Puerto Rico Civil Defense, Colegio de Ingenieros y Agrimensores (CIAPR), Colegio de Arquitectos, and the University of Puerto Rico College of Engineering in Mayagüez.
- ARPE and the Puerto Rico Planning Board should use information gathered by the Community Assistance Visit (CAV) in May 1998 and from the damage of Hurricane Georges to continue to educate homeowners on the risks involved in building in floodprone areas. A renewed effort in enforcement of Planning Regulation 13 during the rebuilding stages, specifically in the permitting process, should result in a significant reduction in property loss from future hurricane events.
- The BPAT agrees with the Government of Puerto Rico's decision to adopt the 1997 UBC as an interim step toward adopting the International Building Code

(IBC) when it becomes available. Furthermore, the BPAT recommends several local amendments be adopted.

- Essential facilities should be evaluated for their vulnerability to natural hazard events.
- The Government of Puerto Rico should perform a study on its electrical power distribution system.

2 Introduction

This report presents FEMA's Building Performance Assessment Team's (BPAT) observations on the success and failure of buildings in Puerto Rico to withstand the wind and flood forces generated by Hurricane Georges. In addition, the seismic resistance of some of the buildings observed was assessed. In this report, "buildings" refer to single- and multi-family homes, residential buildings, and commercial and industrial buildings. Recommendations to improve building performance in future natural disasters in Puerto Rico are included. During this building performance assessment, additional consideration was given to mitigation success stories, particularly when mitigation successfully reduced damages. In the context of this document, mitigation is defined as actions taken to prevent building damage and/or minimize the extent and impact of building damage if it occurs.

A separate team has prepared a BPAT report on the effects of Hurricane Georges in the Gulf Coast of the United States. A copy of the Gulf Coast BPAT report is available from FEMA by contacting FEMA's Publication Distribution Center at (800) 480-2520, and requesting FEMA Publication #338, or it may be downloaded from the World Wide Web at www.fema.gov.

2.1 Background of Storm

Historical data indicate that the island of Puerto Rico has been struck or otherwise affected by 10 hurricanes since 1893 [Defensa Civil Estatal de Puerto Rico and FEMA 1996]. Their intense rain and devastating wind speeds have caused extensive damage to the island. Figure 2-1 shows the path of these hurricanes. Hurricane category designators in Figure 2-1 (e.g., CAT 2) are based on the Saffir-Simpson scale.[1] Central pressure of the hurricane (measured in millibars) and wind speed (measured in mph as 1-minute sustained) ranges for hurricane categories of the Saffir-Simpson scale are shown in Table 2-1.

Hurricane Georges formed 400 miles south-southwest of the Cape Verde Islands and moved across the Atlantic into the Caribbean on September 16, 1998. It made landfalls in the West Indies; Virgin Islands; Puerto Rico; Hispanola, Cuba; the Florida Keys, the Chandeleur Islands of Louisiana, and coastal Mississippi. Hurricane Georges was upgraded September 17 to a Category 4 hurricane as it moved west through the Caribbean packing 150-mph winds over open water. The storm was downgraded to a Category 2 once it moved through the Leeward, U.S. and British Virgin Islands on September 21. The storm was categorized as a tropical storm late afternoon on September 28. Wind speeds are further discussed in Section 3.1.

[1] The Saffir-Simpson hurricane scale ranks hurricanes by categories (CAT). These categories are based on the central pressure of the hurricane and wind speed (measured as 1-minute sustained).

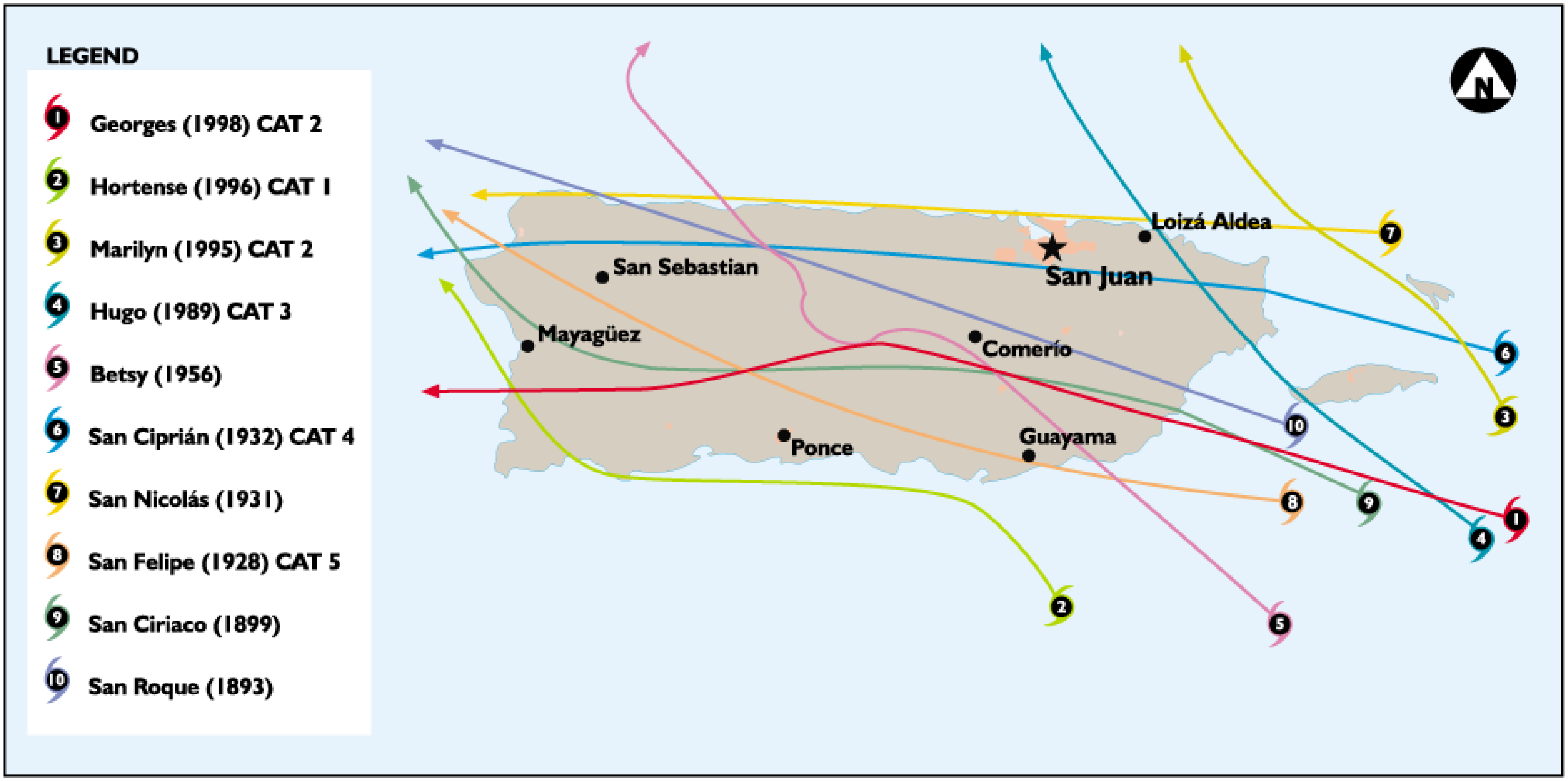

FIGURE 2-1 History of hurricanes in Puerto Rico.
Source: Huracanes en Puerto Rico: Guía de Mitigación de Danõs.

TABLE 2-1 Pressure and wind ranges for hurricane categories of the Saffir-Simpson Scale.

Category (CAT)	Central Pressure	Wind Speed (1-min. sust.)
1	>980 mb	74 mph - 95 mph
2	965 - 980 mb	96 mph - 110 mph
3	945 - 965 mb	111 mph - 130 mph
4	920 - 945 mb	131 mph - 155 mph
5	<920 mb	>155 mph

On the evening of September 21, 1998 Hurricane Georges made landfall on Puerto Rico's east coast as a strong Category 2 hurricane. The storm passed off the west coast of the island September 22, most probably as a weak Category 2 hurricane. It traveled directly over the island, mainly in an east-west direction. Puerto Rico had not experienced a hurricane of this magnitude since Hurricane Hugo, a devastating Category 3 hurricane that passed over the northeast corner of Puerto Rico in a southeast to northwest direction in September 1989. The only Category 4 and 5 hurricanes to strike the island this century were San Ciprían (Category 4, September 1932) and San Felipe (Category 5, September 1928). Prior to Hurricane Georges, the last hurricane to hit Puerto Rico was Hortense, which was a Category 1 hurricane when it passed over the southwest corner of the island in September 1996.

Rainfall from Hurricane Georges exceeded 18 inches at the center of Puerto Rico at Jayuya. The highest recorded level was east of Jayuya at Comerío, which received almost 26 inches of rain during the two-day period of the storm. Three deaths were directly attributed to Hurricane Georges in Puerto Rico and nine others occurred from medical complications [National Oceanic and Atmospheric Administration (NOAA) 1998].

Hurricane Georges caused extensive damage in Puerto Rico. It was the costliest disaster ever for the American Red Cross, which has spent $104 million for recovery in the Caribbean and United States combined [*New York Times* 1998]. Approximately 80 percent of Puerto Rico's 3.8 million people were without power and water at some point during the storm. Over 30,000 homes were destroyed and 50,000 more experienced major or minor damage. Hurricane Georges destroyed 75 percent of the country's coffee crop, 95 percent of Puerto Rico's plantains, and 65 percent of its chickens [NOAA 1998].

2.2 Team Composition

On September 30, the FEMA Mitigation Directorate deployed the BPAT to Puerto Rico to assess damages caused by Hurricane Georges. The team included architects, engineers, planners, floodplain management specialists, and insurance specialists. See Appendix A.

The BPAT's mission was to assess the performance of buildings throughout Puerto Rico and make recommendations for improving building performance in future events. The BPAT process is intended to provide the government of Puerto Rico, local governments, and other interested parties guidance for post-hurricane reconstruction with the goal of enhancing the performance of buildings exposed to future natural hazards.

Aerial and ground site investigations were conducted to observe building conditions in selected areas affected by the storm. The mission did not include recording the number of buildings damaged by Hurricane Georges, determining the frequency of specific types of damage, or collecting data that could serve as the basis of statistical analysis. Collectively, the team has invested more than 1,000 hours to date conducting site investigations, inspecting damages, and preparing documentation. Documentation included field notes and photographs.

Field investigations of significantly damaged areas mainly focused on one- to two-story buildings (homes). However, some essential facilities and high-rise commercial and industrial buildings were also assessed and are included in this report.

2.3 Methodology

The BPAT conducted two aerial assessments of Puerto Rico. The first passed through Canóvanas, Humacao, Caguas, Jayuya, Adjuntas, Utuado, Aguadilla, Rincón, Mayagüez, Cabo Rojo, Ponce, and Toa Baja. A second flyover of east Puerto Rico included Fajardo and the two islands to the east: Vieques and Culebra (Figure 2-2).

Field investigations began on October 4 and lasted until October 9. Wind and flood damage and success stories were gathered and local residents were interviewed. Power poles, as well as other infrastructure items, were also inspected to determine the effects of the storm.

On October 6, the BPAT split into two groups, a wind investigation team (Wind Team) and flood investigation team (Flood Team). Ground investigations for both groups included visits to Jayuya, Adjuntas, and Utuado (Figure 2-3). On October 7, the Flood Team continued west investigating coastal and riverine flooding in Cabo Rojo, Rincón, Mayagüez, Aguadilla, and Arecibo. The Wind Team remained in the center of the island north of Ponce to observe wind damage and investigate reports of tornadic activity. On October 9, both teams flew to Culebra to inspect this newly designated FEMA Project Impact community.[2] The BPAT team completed its deployment on October 10.

2.4 Planning Regulations

Planning Regulation 7 (building code) was first adopted by the Government of Puerto Rico in 1968 and was later amended in 1987. The "provisions on the minimum loads for calculation of [loads acting on] structures were completely revised, taking into consideration the requirements of the 1982 Uniform Building Code (UBC) and recommendations of the study carried out by the Commission on Earthquakes of the Engineers and Surveyors Association of Puerto Rico," according to the amended regulations. As part of the 1987 Planning Regulation amendment, Puerto Rico was identified as a seismic zone 3, requiring all new construction—single-family houses included—to be seismic-resistant. A design wind speed of 110 mph (fastest-mile) was recommended. Puerto Rico's Regulations and Permitting Administration (Adminstración de Reglamentos y Permisos [ARPE]) regulates these provisions of Planning Regulation 7, which was in effect at the time Hurricane Georges struck

[2] FEMA's Project Impact Program helps communities protect themselves from the devastating effects of natural disasters by taking actions that dramatically reduce the potential for disruption and loss to buildings and property. FEMA provides expertise and technical assistance from the national and regional levels (including other federal and state agencies) to individual communities to mitigate against natural hazard events and provide funding for the administrative support of these initiatives.

FIGURE 2-2 Flyover routes from October 2 (in red) and October 3 (in blue). Map is not to scale. Source: The Perry Castañeda Library Map Collection.

FIGURE 2-3 Locations of ground investigation by the BPAT. Map is not to scale.

Puerto Rico. In late December 1998, the government of Puerto Rico adopted emergency regulations to repeal Planning Regulation 7 and adopt the 1997 Uniform Building Code (UBC) as the building code of Puerto Rico.

2.5 Floodplain Management Regulations

In August 1978, the Government of Puerto Rico joined the National Flood Insurance Program (NFIP). The NFIP was created by an act of the U.S. Congress to make flood insurance available to property owners in communities that agree to enact and administer floodplain management regulations meeting program requirements. Initial Flood Insurance Rate Maps (FIRMs) of Puerto Rico were issued in August 1978; the most recent updates were published in September 1996.

The Government of Puerto Rico adopted NFIP-compliant floodplain management provisions under Planning Regulation 13 to regulate construction in Special Flood Hazard Areas (SFHAs) identified as flood zones on FIRMs. In coastal areas, this means that buildings must be adequately elevated and protected from the effects of high-velocity flood flow. In V-Zones, buildings must be elevated on piling (or column) foundations and the lowest horizontal structural member of the lowest floor must be at or above the Base Flood Elevation (BFE). In addition, the area below the building must be free of obstructions or enclosed by non-supporting breakaway walls intended to collapse under wind and water loads without causing damage to the foundation or the elevated portion of the building.

In A-Zones, which are less likely to be affected by high-velocity flow, the top of the lowest floor of the building must be at or above the BFE and the areas below the BFE can be enclosed with non-breakaway walls. However, the area below the BFE can only be used for parking, access, and storage. These regulations require new and substantially improved buildings in floodprone areas to be built to reduce flood hazards. The Puerto Rico Planning Board and ARPE regulate Planning Regulation 13.

2.6 Puerto Rico Seismicity

Along with much of the Caribbean, Puerto Rico is subject to significant earthquake and tsunami risk. The written history of earthquake damage in Puerto Rico dates back to 1867 when the first earthquake was recorded, with an estimated magnitude of 7.3 on the Richter Scale occurring off southeast Puerto Rico. In 1918, the island was hit by a magnitude 7.3 earthquake approximately 9 miles off its northwest coast. The ensuing tsunami had wave heights approaching 19 feet and caused major damage. Reportedly, 116 people were killed, 40 as a direct result of the tsunami. A minor earthquake also hit the island in 1922 [Earth Scientific Consultants]. The American Society of Civil Engineers Standard 7-95 (ASCE 7-95), *Minimum Design Loads for Buildings and Other Structures*, as well as the National Earthquake Hazards Reduction Program (NEHRP) 1997 Recommended Provisions, require all structures in Puerto Rico, including single family homes, to be seismic resistant. These documents have stricter requirements for seismic construction in Puerto Rico than Planning Regulation 7 (building code) that was in place when Hurricane Georges struck Puerto Rico. The recently adopted 1997 UBC is compliant with both the 1997 NEHRP and the seismic provisions of ASCE 7-95.

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, Mayagüez, Añasco, and Arecibo. Coastal flooding was noted along the western shore at Rincón and Mayagüez. 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.

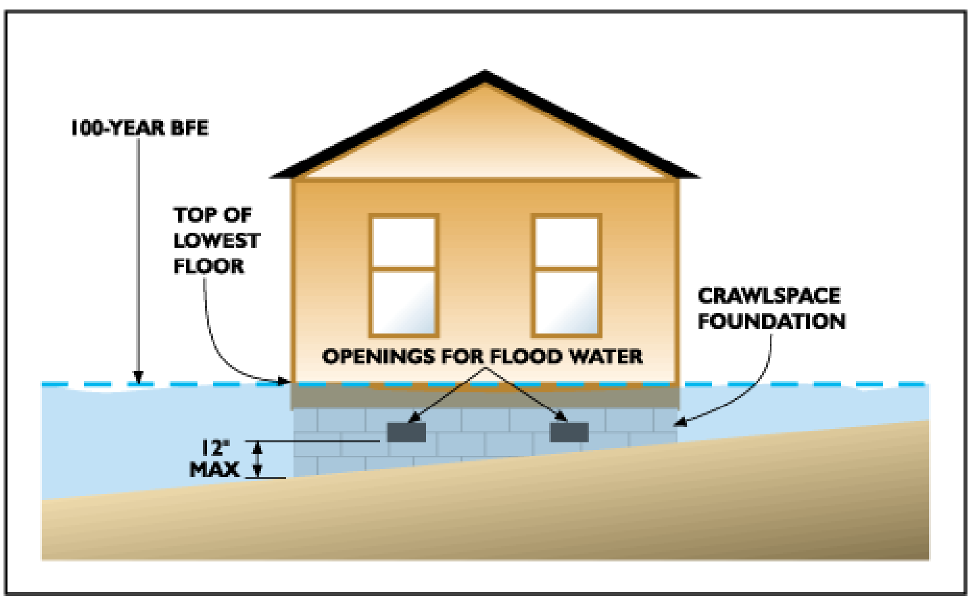

FIGURE 3-10 The top of the lowest floors of buildings in A-Zones must be at or above the BFE. Foundation walls below the BFE must be equipped with openings that allow the entry of flood waters so that interior and exterior hydrostatic pressures can equalize.

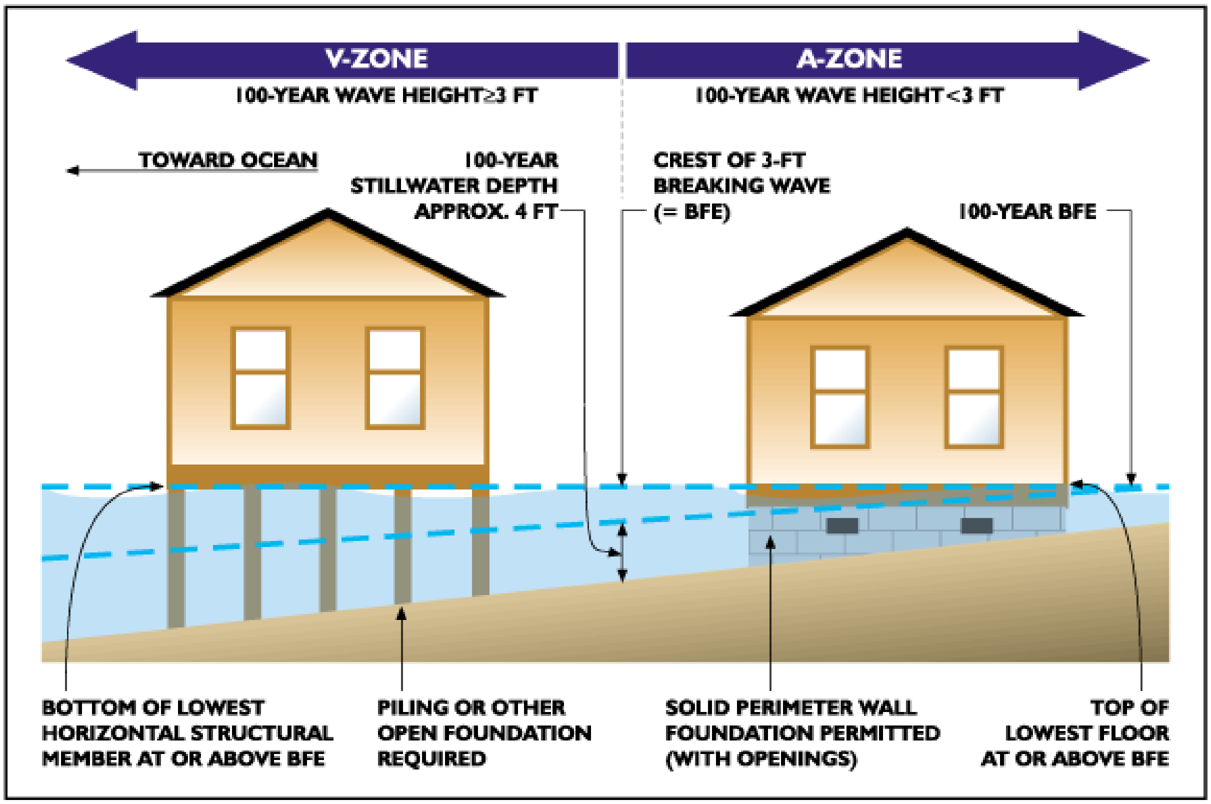

FIGURE 3-11 Comparison of building foundation and elevation requirements in V-Zones and A-Zones.

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.

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.

4 Structural Performance

The BPAT inspected the structural performance of three primary construction types: reinforced concrete, reinforced masonry, and wood-frame. Inspections focused on the performance of single-family buildings. Isolated examples of success and failure in commercial buildings observed during field investigations were also documented.

It is important to state that wind speeds experienced on the island were not of the strength to test the reliability and adequacy of the reinforcing steel used in all of the reinforced and partially reinforced masonry walls. A more significant wind event striking Puerto Rico would likely have resulted in even more failures than were observed.

Planning Regulation 7 of Puerto Rico (building code) required strict practices for different primary construction types. Guidelines that were in place under Planning Regulation 7 for new construction accounted, at least partially, for wind and seismic loads, but these guidelines had not been consistently complied with or enforced effectively. Most of the damage the BPAT observed was directly related to design inadequacies and the lack of enforcement of Planning Regulation 7. Additional damage observed was related to poor quality of workmanship of self-built homes.

The 1987 amendment of Planning Regulation 7, which was in place at the time Hurricane Georges struck Puerto Rico, included wind speed design requirements to 110 mph (fastest-mile) for all buildings and design wind pressures for walls of 30 lbs. per square foot (psf) and for roofs up to 60 psf for residential buildings. Seismic provisions for commercial buildings and one- and two-family homes were also clearly identified. The failure to comply with and enforce this building regulation in all residential building construction resulted in widespread damages from Hurricane Georges. A major seismic event on the island could cause even more damage, since most of the elevated residential structures observed—even those that performed well during the hurricane—are not seismic resistant because they were constructed with inadequate lateral force resisting systems. The adoption and strong enforcement of the 1997 UBC should address many deficiencies observed by the BPAT.

In general, concrete/masonry structures performed well under the wind loading of Hurricane Georges. Structural damage to concrete and masonry structures from floodwater was usually limited to the building foundations as a result of erosion, scouring away of supporting soil, and the impact of waterborne debris.

Wood-frame structures generally performed poorly under wind loads generated by Hurricane Georges and damage was extensive throughout the island. A continuous load path from roof system to foundation was essential for building survival. Figure 4-1 illustrates a continuous load path for a wood-framed structure. The success of concrete and masonry structures illustrated the importance of a continuous load path while the failure in wood-frame structures illustrated the lack of proper wood construction techniques to provide an adequate and continuous load path. Figures 4-2 and 4-3 compare and contrast the success and failure of concrete and wood-frame building systems with similar wind exposure.

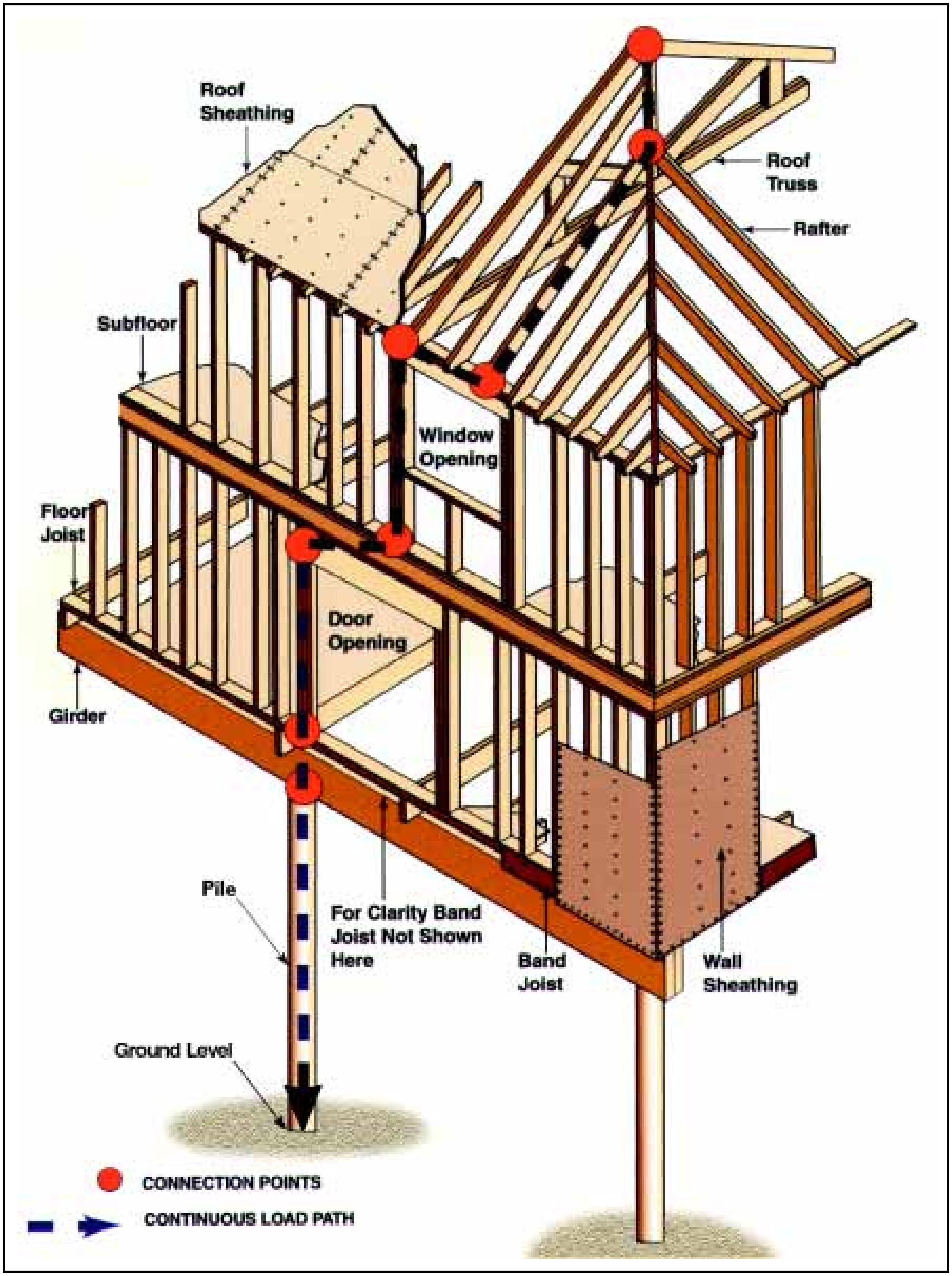

FIGURE 4-1 If a building has a continuous load path, forces and loads acting on any portion of the building will be transferred to the foundation of the building. This transfer occurs through building structural members (i.e., columns and beams) and the connections between these members. In this figure, the load path from the roof structure to the foundation is illustrated for an elevated, two-story wood-frame building.

FIGURE 4-2 A residential community constructed of concrete and masonry buildings with concrete roof structures. This community, located to the west of Luquillo experienced no complete building failures. The eye of the hurricane passed to the south of this community, placing it in the strongest wind quadrant of the hurricane.

FIGURE 4-3 A residential community constructed of wood-frame structures only. This community located to the north of Canóvanas, experienced significant structural damage and failure to almost all of its buildings. The eye of the hurricane also passed to the south of this community, which is located approximately the same distance from the path of the hurricane as the community in Figure 4-2.

Residential reinforced concrete/masonry structures with concrete roof decks performed well regardless of wind direction or velocity. Concrete/masonry structures with wood wall and roof framing generally performed poorly, regardless of siting. High velocity flood waters caused structural damage in SFHAs. Lower velocity floodwaters (also in SFHAs) inundated houses, causing considerable damage inside the buildings. Several concrete and masonry structures were left unstable from riverine and coastal erosion and mountain landslides (Figure 4-4).

FIGURE 4-4 Concrete residential structure with foundation damage caused by a landslide. Note unstable footings (circled).

4.1 Reinforced Concrete

The BPAT observed no structural damage to reinforced concrete residential or mid- and high-rise buildings. It was obvious that mid- and high-rise buildings received considerable attention from design professionals. Where concrete frames were observed, infill walls ranged from fully glazed to CMU (typically 6-in standard block) to metal and wood stud walls. Exterior cladding was stucco (trowel-applied cement plaster typically ½-in thick), Exterior Insulating Finishing Systems (EIFS), and block, brick, or stone veneer. These wall and cladding systems exhibited varying degrees of success or failure, as discussed in Section 5.2.

4.1.1 Reinforced Concrete Mid- and High-Rise Buildings

The lack of structural damage to reinforced concrete mid- and high-rise buildings was probably related to the role of the design professional in their construction as well as the fact that Hurricane Georges was not a design event. However, several buildings received considerable damage to the building envelope and are discussed in Section 5. The BPAT did not determine the seismic resistance of the mid- and high-rise buildings it observed.

4.1.2 Reinforced Concrete Essential Facilities

The BPAT inspected two fire stations, one in Adjuntas and the other on the island of Culebra, located approximately 20 miles east of the main island. Both fire stations had concrete roof decks. The stucco finish on both buildings prevented a direct observation of the wall systems that reportedly consisted of concrete columns with CMU infill. These structures also had open security grilles in the truck bays rather than large rolling doors. Neither station sustained structural damage during the hurricane. The Adjuntas fire station, which completed construction in 1998, featured a small percentage of exterior windows and an emergency electrical generator that was protected and enclosed within the building envelope (Figure 4-5). The BPAT was unable to determine the seismic resistance of either fire station.

FIGURE 4-5 Fire station in Adjuntas.

4.1.3 Concrete/Masonry Structures with Concrete Roof Decks

Reinforced concrete buildings (single-family homes) with reinforced concrete roof decks generally did not sustain structural damage (Figure 4-6). First floor walls in reinforced concrete residential buildings were usually 6-in to 8-in thick and constructed of reinforced concrete columns with masonry infill, or were solid concrete walls. CMU walls had varying amounts of reinforcement within the cells. Roof decks typically were flat and constructed of reinforced concrete. Many were exposed concrete with no roof covering. This structure type performed extremely well. Even buildings with unprotected wall openings did not experience structural damage.

The most significant damage observed for this type of construction centered around building envelope issues. Buildings (specifically single-family homes) typically had 4-in aluminum jalousie louvers (Miami windows) that were vulnerable to water infiltration during high wind events and allowed development of high internal pressure. Shutter systems are discussed in more detail in Section 5.4.

Residences constructed of reinforced concrete and a wood roof structure generally did not perform well during Hurricane Georges. Buildings without shutter systems were often breached, resulting in pressurization of the building and blown-off roofs. When shutters were observed to have been properly designed and installed, the roof framing and roofing typically were inadequate for lateral and uplift pressures, even without the added pressure from internal pressurization of the building.

FIGURE 4-6 Residential home constructed of reinforced concrete and masonry with a reinforced concrete roof deck in the mountains outside Adjuntas.

4.2 Masonry

The BPAT investigated a limited number of residential and nonresidential masonry buildings. Most of the buildings observed had wood-frame roof structures that were damaged during the hurricane (Figure 4-7).

FIGURE 4-7 Typical roof system failure between wooden roof system and concrete or masonry wall system.

4.2.1 Masonry Commercial Buildings

The BPAT observed several commercial buildings located on the island. Although many of them weathered the storm with minimal to no damage, this was mainly due to the siting of the buildings in areas of little wind and the buildings' relatively short un-reinforced masonry walls. The BPAT concluded that the commercial masonry buildings observed did not experience design level winds. Nonresidential buildings were observed with masonry wall systems and wood-framed roofs. Some roof failures in these buildings were the result of a poor connection between the wood-roof framing and the masonry walls. Termite damage was also observed in some residential wood-frame buildings, but the problem did not appear to be widespread. Figure 4-8 shows a termite-infested roof member that failed during the hurricane. The wood purlin and metal roof covering was separated from a building constructed with masonry walls and a wood-frame roof structure (Figure 4-9). Termite-weakened wood members were likely the starting point of this roof failure. Figure 4-10 is a close-up of the typical nailed connection between the purlins and the supporting rafters.

FIGURE 4-8 Termite-damaged wood purlin attached to metal roof panel. The entire roof system of this building failed and is shown in Figure 4-9.

FIGURE 4-9 Masonry wall church that lost roof purlins and its corrugated metal roof. Nails were the only connections used to resist wind loads. The gable ends of this church were unsupported except for purlins resting in the masonry.

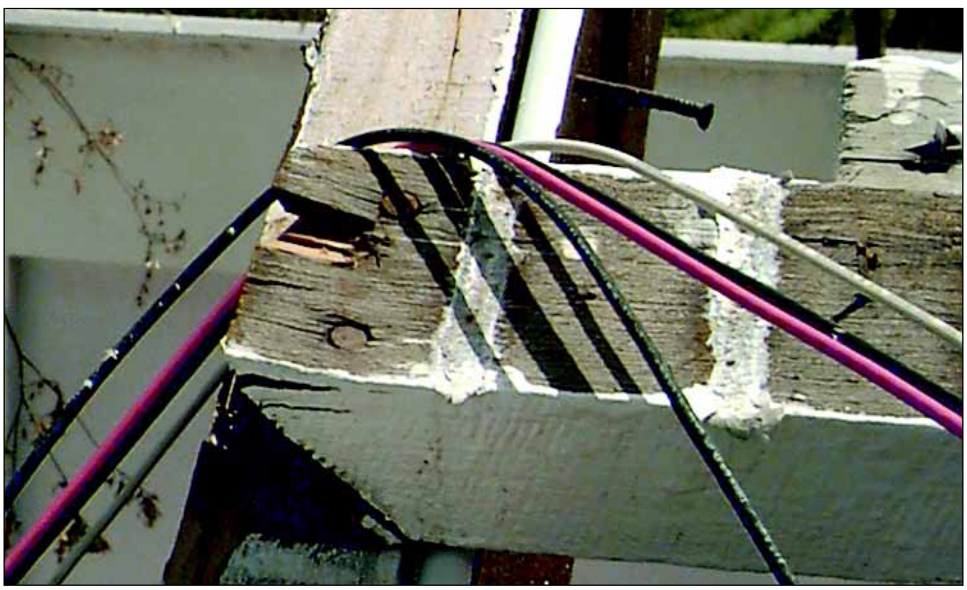

FIGURE 4-10 Nailed roof structure connection from church in Figure 4-9.

4.2.2 Residential Concrete/Masonry Structures with Wood-Frame Roof Structures

Successes and failures in masonry residential buildings were the same as those observed for concrete buildings. Success depended upon the existence of a continuous load path from the roof structure to the foundation for lateral and uplift loads. Conversely, wood-frame roof structures typically did not have a continuous load path to the foundation and widespread failure due to wind-induced uplift was observed. Figure 4-11 shows a typical nail withdrawal failure of a wood-frame roof/masonry wall connection.

FIGURE 4-11 Typical nail withdrawal failure in a wood-frame structure supported by a masonry wall with little uplift capacity at the connection.

Rafters ranged from nominally sized lumber, 2-in by 4-in or 2-in by 6-in that spanned 10 feet to 16 feet, and were spaced from 2-feet to 4-feet on center. Rafters were typically toe-nailed to the sill plate and not connected with hurricane clips or straps. The ridge rafters bore on a ridge beam (although sometimes the ridge beam was omitted). No connection other than nailing was generally made at the ridge line. Self-built trusses were also used. Similar to rafters, these trusses were connected only by nails to the sill plate. These trusses were sometimes manufactured by nailing the truss members together by toe-nailing, or by use of nominal 1-in lumber, or plywood for gusset plates. These self-built trusses were inadequate for the wind loads. As a result, widespread wood-frame roof failures were observed (Figure 4-7).

Corrugated metal was commonly used as a roof covering, typically fastened to nominal 1-in boards or 2-in by 4-in boards used as nailers to the rafters. Nailers were generally attached with two nails (16 penny or smaller) at the rafters. The trusses were generally unbraced or minimally braced for lateral loads and had little or no shear capacity from lateral loads. The attachment of the nailers for the corrugated metal roofing was completely inadequate for the uplift loads on the roofing. Since the majority of these homes had Miami windows, considerable internal pressures also acted on the roof system.

4.3 Wood-Frame Buildings

The BPAT investigated a number of residential wood-frame buildings. Very few of them survived the storm with little or no structural damage.

4.3.1 Commercial Wood-Frame Buildings

No new commercial buildings constructed from wood-framing were observed. As anticipated, many older, nonresidential buildings were damaged due to the lack of both uplift and lateral load paths from the roof system to the foundation.

4.3.2 Residential Wood-Frame Buildings

The BPAT observed many self-built single- and two-story residences. Self-built buildings are those that did not appear to be built to commonly accepted building practices. Very few appeared to have been designed or constructed to the current building regulations. As a result, a large number of wood-frame houses were structurally damaged during the hurricane. Houses built to current building regulations or newer codes weathered the storm successfully with minimal structural damage, but again it is worth noting that most of these houses were not exposed to design wind conditions.

Some residents installed hurricane clips as part of their mitigation efforts after hurricanes in 1995 and 1996. Figure 4-12 shows positive mitigation efforts implemented in a wood-frame house on the island of Culebra in 1996, as observed after Hurricane Georges. Utilization of clips and straps, however, was not typical in wood-frame buildings in Puerto Rico.

FIGURE 4-12 Hurricane clips installed in a wood-frame house on Culebra.

Improperly sized and spaced lumber was used throughout the self-built homes inspected. Some lumber appeared to be salvaged. Even in homes where clips were used, they were often installed with the incorrect number and size of nail. Wind completely destroyed a building constructed by a contractor only two months before Hurricane Georges occurred.

Traditional and inadequate nailing techniques were used on this structure while state-of-the-art clips, brackets, and fasteners were found lying beneath the building. Clips and hangers that were used did not employ the proper nails and failure resulted (Figure 4-13).

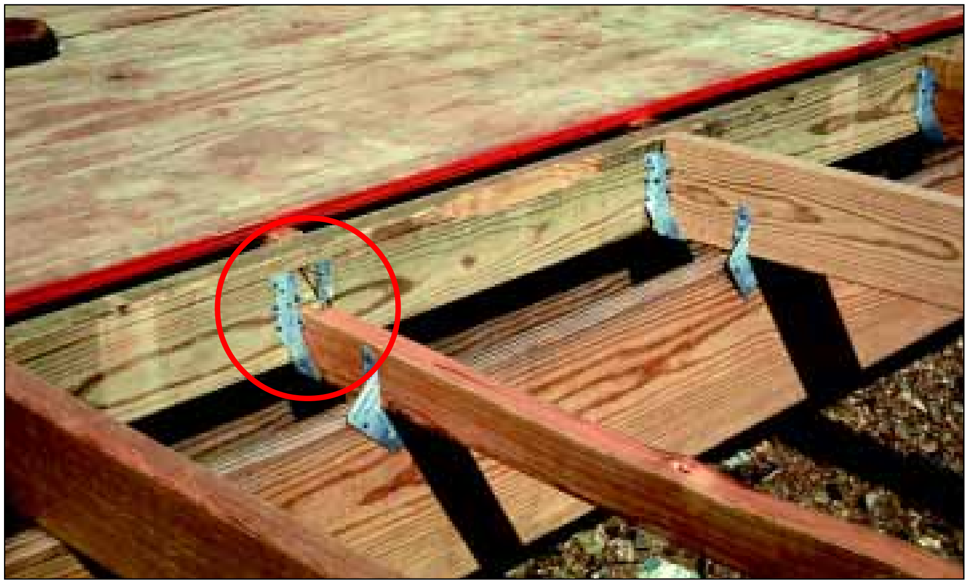

FIGURE 4-13 Example of the failure of wood member in the floor joist hanger due to the use of improper nails. The hurricane clip was used to secure the floor joist to the support beam. This house was located on the island of Culebra.

4.3.2.1 Residential Wood-Frame Walls

Framing layout and construction techniques used in almost all self-built wood-frame homes were not in compliance with Planning Regulation 7. Wall framing was constructed from nominal 2-in by 3-in and 2-in by 4-in studs. These studs were not properly supported laterally and not connected to the sill, bottom, or top plates with straps or connectors (Figure 4-14). The sill plate was inadequately (and often not) connected to the floor system with fasteners capable of resisting lateral and uplift forces. Top sill plates typically were single nominal 2-in by 4-in members that support the roof structure for gravity loading only. Nails appeared to be the primary connector used, with most connections being “toe-nailed.” End column (nominal 4-in by 4-in) members were observed in the wall sections of some wood-frame houses (Figure 4-15).

FIGURE 4-14   Example of wood-frame wall construction that failed during Hurricane Georges. This building was not constructed with any hurricane clips or straps.

FIGURE 4-15   Wood wall column that failed at connection to sill plate. This building was only two months old but was only partially constructed with clips, straps, and fasteners. The proper column fastener in the photograph was found unused beneath the house. This column was from the same house presented in Figure 3-13.

4.3.2.2 Residential Wood-Frame Roof Structures

The wood-frame roof structures discussed in Section 3.4 were found to be of poor quality construction and inadequately designed and constructed to withstand lateral and uplift wind forces. A majority of the wood-frame roof structures observed were gable ended; some of which had a peak with no ridge rafter.

Roofs were constructed of rafters, self-built trusses or pre-manufactured trusses. Rafter roof systems typically used nominal 2-in by 4-in to nominal 2-in by 6-in members. Lateral support or bracing was only provided by nominal 1-in by 3-in to nominal 1-in by 6-in nailers. Roof rafters and trusses were spaced on intervals ranging from 2-feet to 4-feet on center. Roof nailers for metal roof panels were observed on most wood-framing at 3-feet to 4-feet on center (Figure 4-16). Nailers did not typically provide adequate load capacity for the 110 mph design wind indicated in the 1987 amendment to Planning Regulation 7. In addition, the nailer/joist connections and the nailer/rafter connections observed generally were only connected with one or two nails. This simple nailed connection does not provide adequate resistance to shear and uplift forces that may be experienced during a high wind or seismic event. Figure 4-17 shows a typical self-built, wooden roof truss.

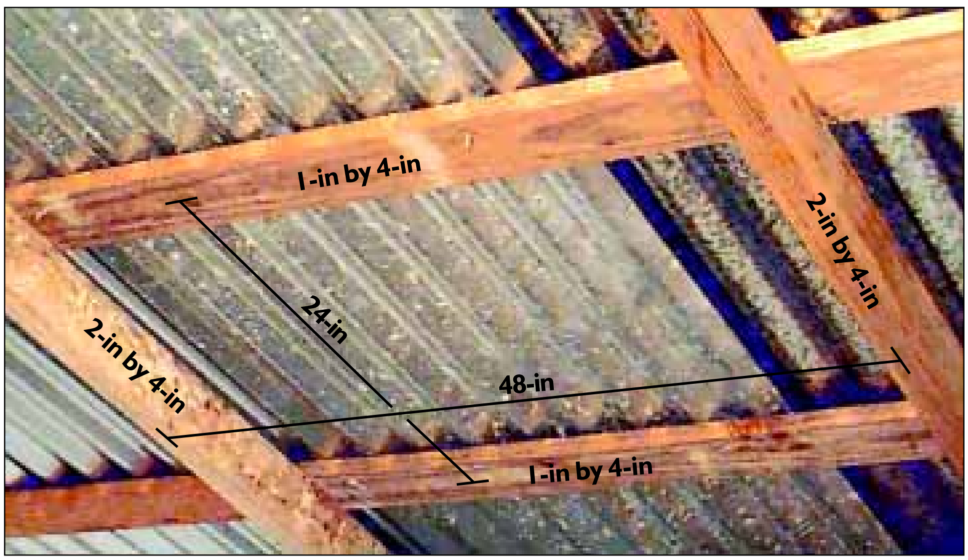

FIGURE 4-16 Typical wooden roof structure with metal roof panels above. Nails connected the metal panels to the nailers and the nailers were nailed to the joists.

FIGURE 4-17 Example of a self-built, wooden roof truss.

4.3.2.3 Residential Wood-Frame Floor Systems and Foundation Connections

The wood-frame buildings the BPAT inspected had varying floor systems and floor system-to-foundation connections. Many floor systems that remained in place after the wood-frame building constructed above was destroyed had minimal connections between the floor system and the foundation. Success of these connections is believed to be due to the failure of the roof and walls before the failure of these typically non-engineered connections between the floor system and the foundation (Figure 4-18). In a few homes, engineered floor system-to-foundation connections were observed (Figures 4-19 and 4-20).

FIGURE 4-18 Example of a non-engineered connection between the building foundation (concrete column) and the floor system. The wooden floor beam is connected to foundation rebar with an improper nailed connection.

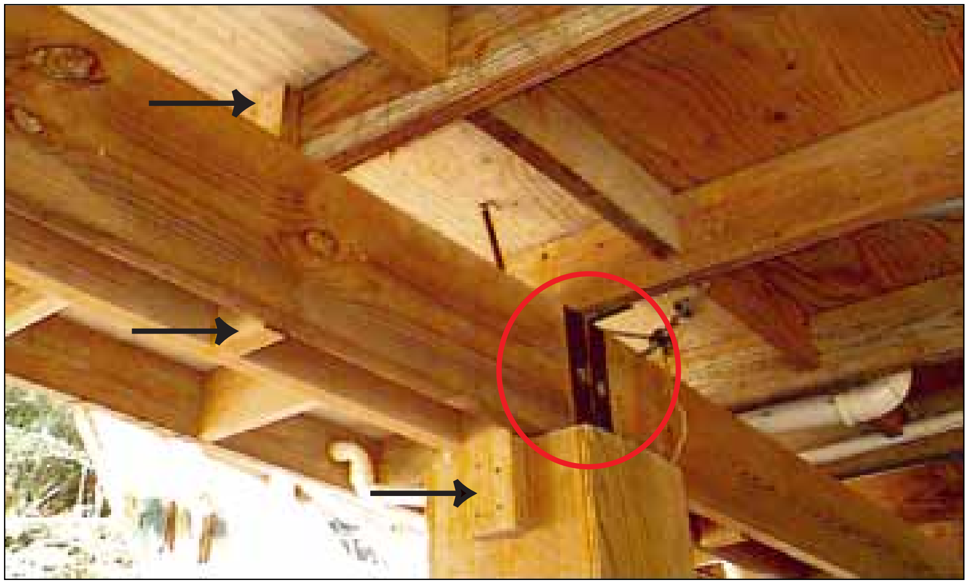

FIGURE 4-19 Example of an engineered connection between the floor beam and a concrete column (concrete column is enclosed in plywood). Vertical members (identified by arrows) provide continuous load path from floor joist to floor beams. Floor beams are connected to concrete columns with metal straps (circled). This house was located on the island of Culebra.

FIGURE 4-20 Example of a successful wood connection between support beam and floor joists. This is the same house shown above in Figure 4-19.

4.4 Hold-Down Cables

Tiedown or hold-down cables were used on some self-built wood-frame homes in Puerto Rico as a low-cost mitigation attempt. Typically, these cables were connected directly to the foundation of the structure although some cables were observed to have their own anchorage away and separate from the structure. Although there may have been exceptions, buildings with hold-down cables survived the effects of Hurricane Georges, but they remain largely untested during design wind conditions. In addition, there has been no engineering analysis of the effects of cable tiedown systems on load paths and structural and nonstructural building components. Hold-down cables are not expected to be effective unless the cables are designed and installed by an engineer or architect.

A majority of hold-down cables observed crossed over the ridge-line of the roof of the house at 10-foot spacing. A smaller percentage was observed running parallel to roof ridge-lines at 4-foot to 6-foot spacing as illustrated in Figure 4-21. The hold-down cables ranged from single strand steel wire to multi-strand steel cables.

FIGURE 4-21 Wood-frame house with metal roof covering with hold-down cables that run parallel (see arrows) and perpendicular to the roof ridge line. This house was set atop a ridge that experienced significant winds. The lack of damage can be attributed to the extra care taken in fastening down the corrugated metal roofing. The strapping would not have prevented buckling of the roofing or uplift at the eave.

4.5 Structural Seismic Considerations

Seismic load designs for commercial buildings and one- and two-family homes were addressed in Puerto Rico's 1987 amendment to Planning Regulation 7. For one- and two-family homes, seismic design is required for structural elements, but is not for the engineering of nonstructural building elements. For commercial buildings, the amendment addressed both topics, structural and nonstructural seismic design.

Nonresidential buildings were not investigated for compliance with the 1987 amendment to Planning Regulation 7 and the current structural seismic guidelines of the 1997 UBC. One- and two-family homes, however, were investigated for their ability to sustain a seismic event. Inspections revealed that most of these homes constructed of concrete, masonry, and wood appeared to lack the lateral stability necessary to survive a design seismic event. Many residential buildings were constructed on piles and columns with no visible lateral bracing. Connections between foundation systems and the building did not appear to have moment capacity required to withstand lateral forces induced by a design seismic event (Figure 4-22). shows an elevated residential building with no lateral support bracing its long columns. Figure 4-23 is a close-up of one of the footings for the tall columns shown in Figure 4-22. This type of small footing "setting" atop a rock outcropping was typical for houses built on hillsides.

FIGURE 4-22 Residential building supported atop tall, unbraced concrete columns. This type of unbraced support column was common in many areas.

FIGURE 4-23 **Footing for tall columns in Figure 4-22. This footing is not adequately anchored to the supporting rock to resist lateral forces that may be induced during a design seismic event.**

5 Building Envelope Performance

Good structural system performance is critical to avoiding injury and minimizing damage to a building and its contents. It does not, however, ensure occupant or building protection. Good performance of the building envelope is also necessary. The envelope includes exterior doors, non-load bearing walls and wall coverings, roof coverings, windows, shutters, and skylights. Historically, poor building envelope performance is the leading cause of damage to buildings and their contents during hurricanes.

5.1 Doors

The BPAT observed a limited number of catastrophic door failures. However, in many cases where the doors were weak, the entire wall failed before the door assembly itself failed. Wind-driven water infiltration between the door and frame was a common problem. Most door assemblies observed did not have weatherstripping, and when it was present it provided limited resistance to rain driven by high winds.

Exterior door failure has two important effects. First, failure can cause a sudden increase in internal air pressure, which may lead to exterior wall, roof, interior partition, ceiling, or structural damage. Second, wind can drive water through the opening, causing damage to interior contents and finishes. Essentials to good door performance include: product testing to ensure that sufficient factored strength to resist design wind loads exists; suitable anchoring of the door frame to the building; and for glazed door openings, the use of laminated glass or shutters to protect against windborne missile damage as discussed in Section 5.4. Missiles are both natural and man-made. Natural missiles include tree limbs, and man-made missiles include items such as building debris, fence debris, refuse containers, and lawn furniture.

5.1.1 Glass Doors

A variety of problems with glass doors were observed, including blow-out/blow-in of the door frame and glazing (Figure 5-1), door breakage and loss of glazing from its frame (Figure 5-2), and disengagement of sliding doors from their tracks. These problems were caused by over-pressurization or missile impact.

FIGURE 5-1 This sliding glass door and window assembly in a hotel room was 7' 2" high and 14' long. The head of the frame was attached with four pairs of #12 or #14 screws in plastic sleeves. The sleeves pulled out and the entire length of the frame was pushed inward, resulting in substantial glass breakage. This building was located on Isla Verde in San Juan.

FIGURE 5-2 Missiles broke this wood/glass door and several adjacent window panes.

5.1.2 Personnel Doors

The BPAT observed few instances of door or door frame failure. However, Figure 5-3 illustrates a metal door that was blown out when the frame anchors pulled out. The door was blown out after the louvered window on the building failed, allowing an increase in internal air pressure.

FIGURE 5-3 A missile traveling right to left struck the window louver. The door frame was attached by fasteners into wooden plugs that had been set into holes drilled into concrete. Once the louver failed, the door frame failed.

5.1.3 Security Grilles, Rolling (Overhead) and Garage Doors

Rolling doors and garage doors frequently perform poorly during high winds. In several instances observed in Puerto Rico, large openings were protected with security grilles, rather than rolling or garage doors (Figure 5-4). Very little load is applied to security grilles during high winds because of the large amount of net free open area. As a result, security grilles performed very well. Depending on the grilles, security grilles may stop large airborne missiles. It is important to note that areas with security grilles must be designed as open structures (without a building envelope). This will normally increase wind pressures acting on the structural frame of the building, as well as components and cladding.

FIGURE 5-4 The security grille on this fire station offers greater wind performance reliability than a solid door because very little air pressure is applied to it during high winds. This fire station is located on the island of Culebra.

5.2 Non-Load Bearing Walls, Wall Coverings, and Soffits

Non-load bearing walls and wall coverings generally performed well during Hurricane Georges. The BPAT did observe several types of problems however.

Non-load bearing walls (or door or window assemblies) that fail can cause extensive interior damage because of the development of high internal air pressure and/or wind-driven water infiltration. Figure 5-5 shows the damage that occurred when a portion of the exterior envelope failed. Composite wall panels and their connections, exterior insulation finish system (EIFS), and other types of exterior wall coverings should be tested to ensure the components have suitable strength.

FIGURE 5-5 The gypsum wallboard was blown off this interior partition after the exterior non-load bearing wall was blown away, allowing an uncontrolled, rapid increase in internal air pressure.

5.2.1 Non-Load Bearing Walls and Soffits

The BPAT observed three types of non-load bearing walls: metal panels over light-gauge steel framing, EIFS, and composite wall panels. Problems resulting in water infiltration were observed with each type and are discussed below.

Metal panels over light-gauge steel framing were the most common non-load bearing walls observed. The BPAT noted the loss of metal panels due to an insufficient number of panel fasteners. In one instance, metal panels at the gable end of a building were damaged when a rooftop water tank blew off and struck the side of the building (Figure 5-6).

FIGURE 5-6 Rain entered this hospital on Culebra after a water tank struck the metal wall panels.

A problem with EIFS at an ocean front high-rise was also observed. It appeared that the exterior wall stud tracks were insufficiently attached (Figure 5-7). Failure of the wall system resulted in substantial interior damage.

Buildings clad in EIFS often provide a false sense of security since they appear to be clad in concrete, but may or may not be backed by concrete or masonry. When EIFS is used as a covering over concrete, as shown in Figure 5-11, this is not an issue. However, when EIFS is not applied over concrete, as shown in Figure 5-7, the building could be mistakenly construed as offering a safe area of refuge from high winds. EIFS applied on a steel or wood-frame building as the exterior wall is not an as reliable building envelope as a concrete wall in resisting high winds and missiles. An EIFS not backed by concrete or masonry may be identified by a hollow sound when a person bangs on the panel or by a deflection when a person pushes the panel.

The BPAT observed two buildings with composite wall panels composed of thin metal sheets bonded to a cardboard honeycomb core. The panels were attached with screws from the metal framing into the interior metal skin. On one building, the panels were also used as the soffit. In both buildings, the panels blew off because of insufficient strength of the connections between the composite panels and the structural frame of the building (Figure 5-8).

FIGURE 5-7 **This EIFS wall system was composed of synthetic stucco over 1-in thick expanded polystyrene insulation (EPS) over a layer of exterior gypsum board over 6-in deep steel studs, with a layer of gypsum board on the interior side of the studs. Fiberglass batt insulation was installed within the stud cavity. There were several different planes of failure. Insufficiently attached stud tracks appeared to have been the initial failure point. This building was located on Isla Verde.**

FIGURE 5-8 **Several composite panels blew off from the fascia and soffit of this building at the airport on Isla Grande. Although several screws were installed, the metal into which they were driven was too thin to develop sufficient blow-off resistance to withstand the wind loads.**

5.2.2 Wall Coverings

The BPAT observed four types of wall covering problems:

- Loss of stucco applied over cast-in-place concrete.
- Problems with EIFS coverings.
- Ceramic tiles that were blown off.
- Problems caused by wind scour.

None of these problems resulted in water infiltration; however, with the exception of wind scour, failure of the wall covering resulted in additional debris being added into the wind field.

The loss of stucco applied over cast-in-place concrete was the most common problem observed with wall coverings (Figure 5-9). Rather than cast concrete with a relatively flat and smooth surface, traditional practice in Puerto Rico has been to cast the concrete rough, as shown in Figure 5-10, and apply a stucco finish.

FIGURE 5-9 The stucco was blown off the corner area of this wall, where the suction pressures were high. Note the rough texture of the concrete.

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).

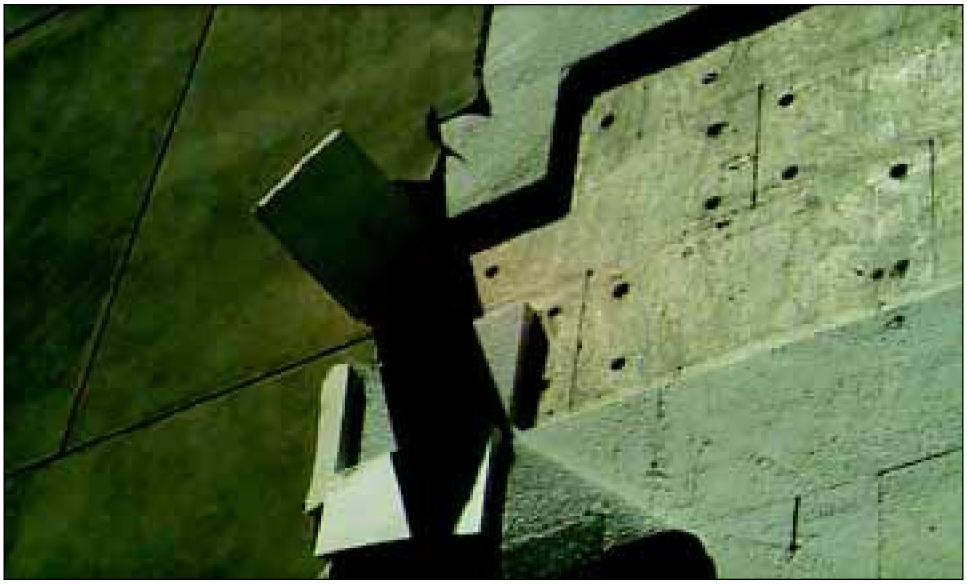

FIGURE 5-11 At this EIFS covering, the synthetic stucco appeared to be well-adhered to the outer EPS layer, but there appeared to be minimal bonding between the two EPS layers. In at least the lower portion of the wall, the first layer was attached with mechanical fasteners deeply recessed into the foam.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

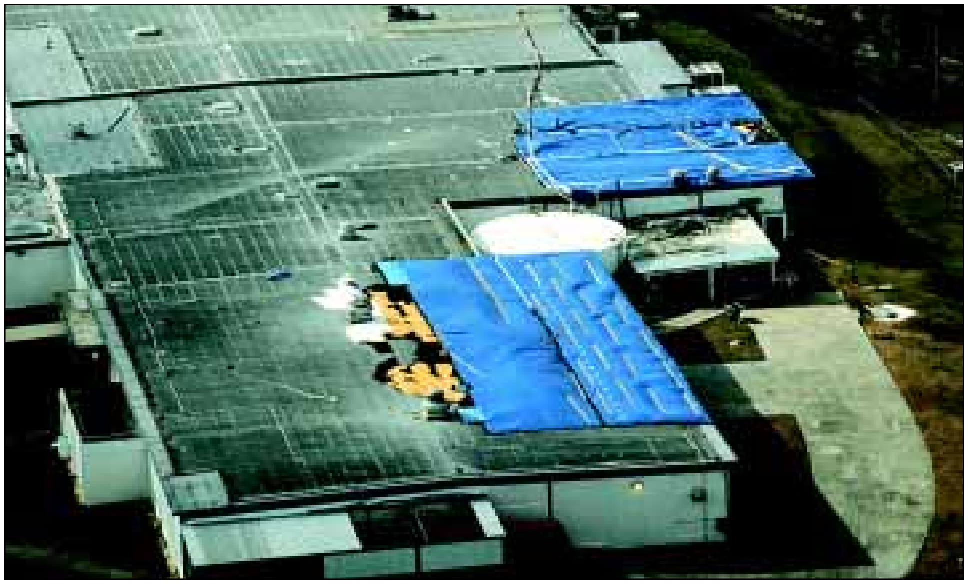

FIGURE 5-22 This built-up membrane had a mineral surface cap sheet. Because of the roof covering damage, this manufacturing facility on the island of Culebra was shut down for approximately two weeks after the hurricane. This building also experienced roof damage during Hurricane Hugo in 1989.

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.

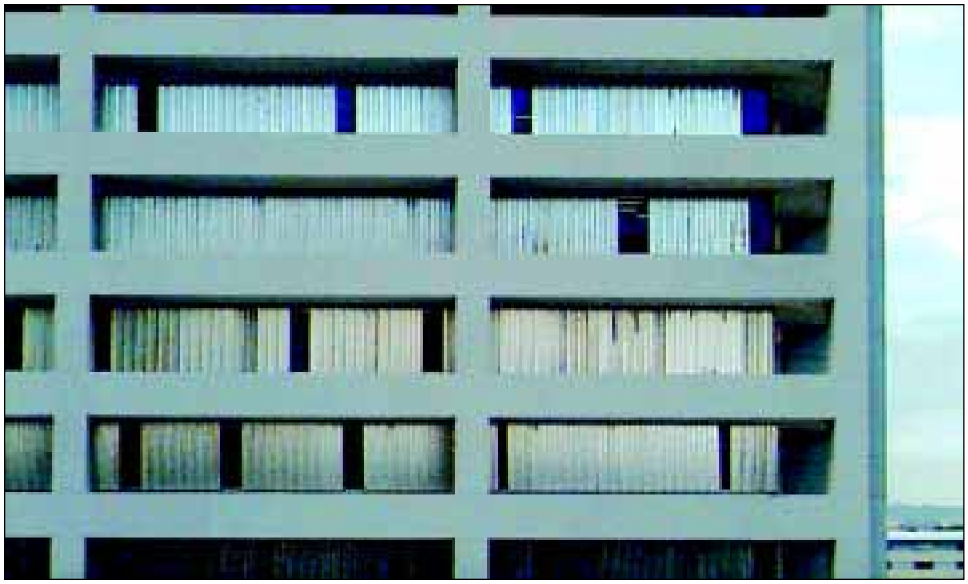

FIGURE 5-39 Steel shutters were used on this mid-rise building, which had a narrow balcony in front of the windows. Since wind speed increases with building height, the shutters on the upper floors can receive very high wind loads. The length of the shutters on this building requires the shutter panels 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 are 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.

6 Exterior Mechanical and Electrical Equipment

Hurricane Georges caused few problems to Puerto Rico's exterior-mounted mechanical and electrical equipment. The most commonly observed problem was blow-off of exhaust fan cowlings, as shown in Figure 6-1. Many residences and other buildings have water storage tanks on their roofs and most appeared to have performed well. However, as documented in Section 5.2.1, one tank blew off and damaged a hospital. Solar hot water heaters are located on many buildings and they also performed well. One solar heater that did not is shown in Figure 6-2.

FIGURE 6-1 This exhaust fan lost its cowling.

FIGURE 6-2 This roof had several solar hot water heaters that successfully weathered Hurricane Georges. However, the unit in the foreground was damaged.

During Hurricane Georges, an emergency generator at a water treatment plant was flooded by a nearby river, rendering the generator unusable. As shown in Figure 6-3, the water rose approximately 2 feet above the generator room floor.

FIGURE 6-3 Flood water entered this generator room and reached a height of about 2 feet, as indicated by the red line. This facility is located in Jayuya.

Several residences in Puerto Rico have overhead electrical service to a service mast mounted on a free-standing concrete pylon. From the service mast to the building, the service was underground, as shown in Figure 6-4. The advantage of this type of service mast versus one mounted through the roof is that if the mast deflects or is torn away, the roof is not damaged.

FIGURE 6-4 This service mast is mounted on a concrete pylon. This form of service connection was successful in eliminating roof damage when the overhead service blew down.

7 Electrical Distribution System

The electrical distribution system in Puerto Rico, which is installed on wood or concrete poles, was severely damaged by Hurricane Georges. The loss of electrical service to water treatment plants resulted in widespread disruption of the delivery of water, which directly affected people's personal lives. Loss of electrical service also resulted in major economic disruption and significantly increased disaster response needs.

Damage of the distribution and in the transmission systems fell into the following areas:

- Broken wood poles: This was caused by too great a load on the pole, including too large a span or various heavy communication lines on the poles (Figures 7-1 and 7-4).
- Leaning poles (wooden and concrete): This was considered minor damage and was easily corrected by straightening and properly embedding the poles in the ground (Figure 7-2).
- Broken concrete poles: Round spun concrete poles generally perform better than the reinforced concrete poles that are widely used in Puerto Rico. There was evidence of spalling and cracking of reinforced concrete poles indicating a probable quality control problem (Figure 7-3).
- Fallen poles: This was a result of improper embedment. Additional damage occurred to the conductors, causing progressive failure to other poles.

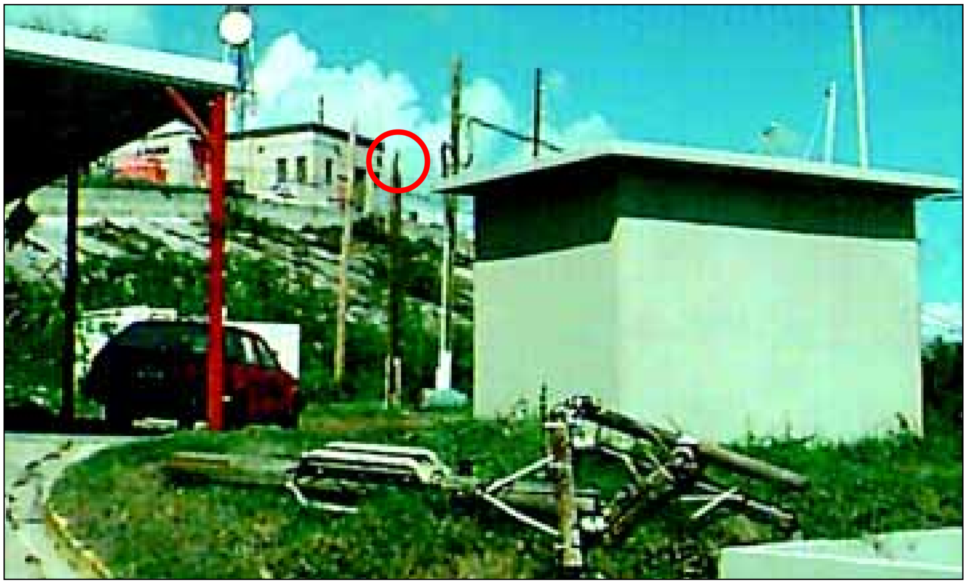

FIGURE 7-1 Damaged wood pole. The portion of the wood pole in the foreground broke from the pole (circled) in the back of the picture.

FIGURE 7-2 Leaning wood pole due to inadequate embedment.

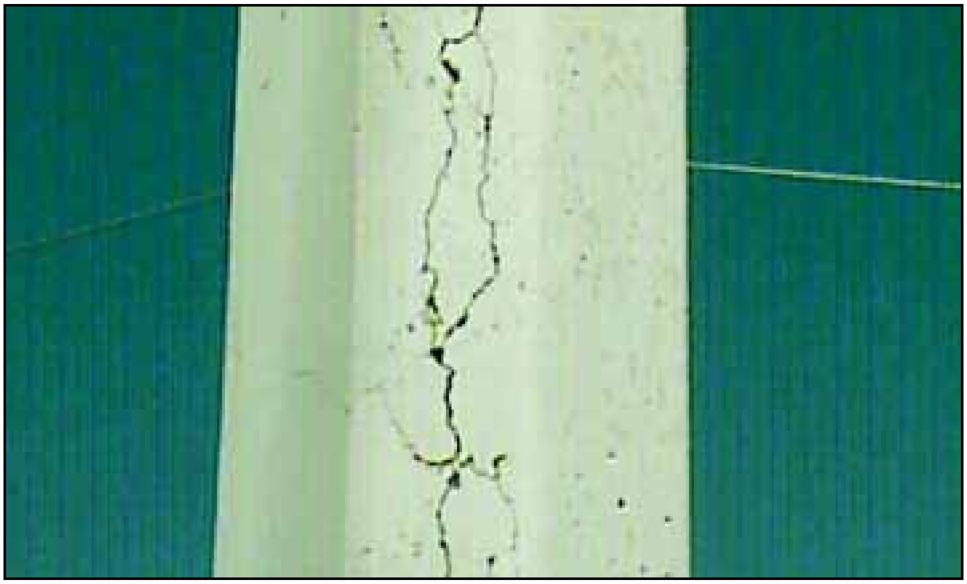

FIGURE 7-3 Observed crack in concrete pole that appears to be a quality control problem.

FIGURE 7-4 New wood pole replaced after the hurricane; utility lines are still being attached to the pole. Inset shows wood pole grade marking. This #3 pole was typical of those used throughout the island.

8 Conclusions

The conclusions of this report are intended to assist the Government of Puerto Rico in shaping its post-Hurricane Georges construction strategy and assist designers, contractors, and building owners in the construction of hazard-resistant buildings. These conclusions are based solely on the BPAT's observations, an evaluation of relevant codes and regulations, and meetings with the Government of Puerto Rico.

8.1 General Conclusions

Hurricane Georges was a strong Category 2 hurricane when it hit Puerto Rico. The successful performance of buildings in more severe events should not be assumed based upon the lack of damage observed from Hurricane Georges.

A large number of residential buildings in Puerto Rico experienced structural damage from the high winds of Hurricane Georges. In addition, a large number of residential buildings in SFHAs were damaged from floodwaters. The BPAT did not identify the history of these buildings and how they were permitted, designed, or constructed. However, the BPAT understands that housing is often built by owners without a building permit or design services. When the BPAT observed improper construction practices or siting, the houses were described as self-built. These self-built houses received the majority of damage observed from Hurricane Georges. The severe damage to these self-built houses could have been avoided if more buildings had been constructed to existing Planning Regulation 7 (building code) and Planning Regulation 13 (floodplain management).

The BPAT observed a large number of "concrete" houses constructed with a structural system consisting of walls with a concrete frame, masonry infill, and a concrete roof deck as described in Section 3.4.1. The first floors of these houses were often supported on long, slender concrete or masonry columns, which pose a significant collapse hazard if the island experiences a major earthquake.

A limited number of mid- and high-rise buildings were inspected by the BPAT. The damage observed at these buildings was to nonstructural elements, including damage to glazing, curtain walls, interior walls, and damages to finishes from windborne rain. Some building owners reported that they expected to lose the use of their buildings for repair periods of up to two months, resulting in significant business losses. Building envelope damage resulted from loads on the components and windborne debris that broke glazing. Future damage can be reduced if components and cladding are designed and constructed to the newly adopted 1997 UBC and wind provisions of ASCE 7-95.

ARPE has proceeded with several important actions following Hurricane Georges in an effort to increase public safety and reduce property damage from future natural hazards. These actions include:

- At the request of ARPE, the International Conference of Building Officials (ICBO) conducted and completed a peer review of ARPE in January 1999. This peer review evaluated the new needs created by Hurricane Georges as well as the re-engineering effort currently underway.
- Revised planning regulations based on the 1997 UBC were adopted as emergency regulations in December 1998.
- ARPE is positioned to make recommendations concerning building regulations to the new Certification and Building Board of Puerto Rico that is expected to be created in March 1999 under proposed legislation submitted by the Governor to the Puerto Rico Legislature.
- ARPE and FEMA are implementing a strategic plan to provide the necessary training to make the transition to these new building regulations.

8.1.1 Mitigation Efforts

Effective mitigation measures reduced the demands on the response and recovery stages following Hurricane Georges. More importantly, however, effective efforts diminished the stress on the lives of inhabitants and the occupants of buildings during and after the storm.

The most prevalent and successful mitigation measure the BPAT observed was the use of concrete and masonry for the construction of the exterior walls and roof. Reinforced concrete and masonry envelopes almost without exception provided excellent resistance to wind forces and windblown debris. They were also extremely reliable and durable, as illustrated in Figure 8-1.

FIGURE 8-1 The three concrete/masonry buildings in this photo appeared to be undamaged. However, the building with the wood-frame roof structure experienced significant damage.

Although the BPAT observed many wood-frame building failures, as illustrated in Figure 8-2, wood-frame buildings perform well in high winds if effective mitigation measures are taken during design and construction. This is illustrated in Figure 8-3.

FIGURE 8-2 This wood-framed house was nearly totally destroyed. This is in remarkable contrast to the nearby building shown in Figure 8-3.

FIGURE 8-3 This wood-framed house is close to the house shown in Figure 8-2. The wind flow was essentially identical at these two sites, hence the successful performance of the one building is attributable to the attention given to design and construction. The value of mitigation is clearly illustrated in these two starkly different cases.

Effective mitigation considers the structural and nonstructural aspects of a building. If the building structure is designed for the wind loads and remains undamaged, large losses can still occur to the building interior and its contents from damage to windows, siding, or the roof covering (the building envelope as discussed in Section 5). Exterior-mounted mechanical and electrical equipment are also susceptible to flood and wind damage and must be protected, as discussed in Section 6.

Effective mitigation also considers the natural hazard risks to the building. For example, if concrete houses are built for wind-resistance, but elevated on long, slender columns, they pose a threat of collapse during a major earthquake. If effective mitigation measures had been implemented more extensively in the design and construction of buildings, the widespread devastation of Hurricane Georges would have been substantially reduced.

8.1.2 Wind Mitigation for Existing Buildings

The BPAT inspected a few older residences that had been retrofitted prior to Hurricane Georges. The BPAT found that the mitigation measures that were taken were not as effective as they could have been. The most common mitigation measure observed was the installation of metal framing connectors between rafters and bearing walls (Figure 4-12). However, in each of the observed buildings, the mitigation effort did not address the weak connections of the metal roof panels to the wood nailers, or the weak connections between the nailers and rafters. Hence, only part of the load path between the roof covering and the foundation was strengthened. Because the attachment of the roof covering system was not upgraded along with other mitigation efforts, most of the houses inspected experienced significant roof covering damage and subsequent damage to their interior and contents. The BPAT concluded that mitigation measures would have been more successful if they were part of an overall mitigation plan and if each measure had been completely, rather than partially, carried out.

When existing building are to be strengthened, mitigation efforts are planned, ranked, and executed so that the most vulnerable parts of a building are addressed first. For example, if a complete load-path retrofit is not possible then strengthening the roof covering is accomplished first. Since a weak roof covering typically fails at lower wind speeds than the rest of the structure—and the failure of the roof covering usually results in interior damage from rain—strengthening the roof covering will reduce future losses in weaker hurricanes.

After mitigation efforts have been prioritized, they must be executed correctly and completely. For example, if additional metal roof panel fasteners or metal framing connectors are necessary, the fasteners must be the correct type, size, and spacing and used over the entire roof to achieve maximum effectiveness from the mitigation effort.

8.2 Planning Regulations in Puerto Rico

The following subsections discuss the BPAT's conclusions regarding the planning regulations in Puerto Rico governing the design and construction of buildings that were in effect when Hurricane Georges occurred. Regulations are organized into three groups: wind, seismic, and floodplain management provisions.

Planning Regulation 7 of Puerto Rico, which was in effect at the time Hurricane Georges struck, was originally adopted in 1968 and amended in 1987. The seismic and wind load provisions of the 1987 amendment are based on the 1982 UBC. The materials chapters reference national standards such as ACI for concrete (ACI-318-83) and masonry (ACI-531-79), and AISC (AISC-78) for steel construction, with amendments for seismic design. By comparison, the newly adopted 1997 UBC (which now serves as the building code) references updated national standards such as ACI-318-95 for concrete and AISC-LRFD-93 and AISC-ASD-89 for steel construction, both with amendments for seismic design.

8.2.1 Wind Provisions of Planning Regulation 7

A substantial amount of wind engineering research has been completed since Planning Regulation 7 was amended in 1987. As a result, Puerto Rico's wind load provisions were out of date during Hurricane Georges. Of particular concern were the lack of consideration for wind speedup due to abrupt changes in topography and the low loads prescribed for residential windows, doors, and roofs.

The BPAT observed that many failures occurred on buildings that did not comply with Planning Regulation 7. Most of these failures likely could have been avoided if the buildings had complied with the code. However, in many cases, Planning Regulation 7 criteria significantly under-predicted loads, which can result in failure even for code-complying buildings. For buildings to perform well during high-wind events, and remain economical, their wind design must be based upon current criteria derived from ongoing wind engineering research, including post-disaster forensic engineering investigations.

In response to the BPAT's conclusions, an emergency regulation to repeal Planning Regulation 7 and adopt the 1997 UBC as the building code for Puerto Rico was implemented by the Governor of Puerto Rico and approved by the Planning Board in December 1998. The 1997 UBC, with specified amendments that include the use of ASCE 7-95 for determining design wind loads, addresses most of the wind provision deficiencies that existed under Planning Regulation 7. The deficiencies that were not addressed are covered in Section 9.

8.2.2 Seismic Provisions of Planning Regulation 7

Planning Regulation 7 was also out of date with regard to seismic design provisions. It referenced standards that were nearly 20 years old. Significant improvements in seismic design provisions have taken place as a result of engineering research and lessons learned from recent earthquakes.

The Government of the United States is attempting to improve the seismic safety of federally owned, leased, assisted or regulated buildings through compliance with *Executive Order 12699: Seismic Safety of Federal and Federally Assisted or Regulated New Building Construction*. EO12699 was signed in 1990 and seeks to ensure that federally owned, leased, assisted or regulated new building construction is designed and constructed in accordance with appropriate state-of-the-art seismic design standards. The Executive Order requires use of seismic design standards "substantially equivalent" to the most recent or immediately preceding versions of the NEHRP Recommended Provisions.

Since NEHRP Provisions define Puerto Rico's location as a high seismic zone, EO 12699 also includes residential and commercial buildings that receive federal assistance. Therefore, to comply with EO12699, codes substantially equivalent to the 1997 NEHRP Provisions must be used in the design, construction, and inspection of new buildings where Federal financial assistance is used. Currently, the 1997 Uniform Building Code (UBC) meets this requirement.

Puerto Rico's Planning Regulation 7 was not "substantially equivalent" as defined by EO12699. As such, any new construction that receives federal funds must exceed the requirements of the 1987 amendment to Planning Regulation 7. In response to these issues, Puerto Rico repealed Planning Regulation 7 and adopted the 1997 UBC as the building code for

Puerto Rico. Through the CIAPR, Puerto Rico has developed a well-conceived plan for earthquake recording instrumentation. Therefore, this existing plan for earthquake recording instrumentation remains in place in lieu of the 1997 UBC seismic instrumentation provisions.

8.2.3 Floodplain Management Provisions of Planning Regulation 13

In August 1978, the Government of Puerto Rico entered into the NFIP, which was created to make affordable flood insurance available to property owners in communities agreeing to enact and administer floodplain management regulations that meet minimum NFIP program requirements. The Government of Puerto Rico adopted these provisions as Planning Regulation 13 and they are now regulated by the Puerto Rico Planning Board and ARPE. Therefore, since 1978, new and substantially improved buildings in SFHAs in Puerto Rico must be built in such a manner as to reduce flood hazards.

The Government of the United States has also implemented *Executive Order 11988: Floodplain Management* in an effort to update design and construction practices for federal buildings. EO11988 requires federal agencies to undertake sound floodplain management practices when spending federal funds or making regulatory or policy decisions. These requirements must also be considered in the delivery of federal disaster assistance.

The BPAT concluded that Planning Regulation 13, along with EO11988, gives the Puerto Rico Planning Board and ARPE the ability to permit, oversee, and regulate construction in SFHAs to minimize the risk of property loss from severe flood events. However, the Planning Board and ARPE will continue to experience difficulties in both the disaster and non-disaster environment with unauthorized and un-permitted construction that is common in the SFHAs.

8.3 Regulatory Administration and Enforcement

The ICBO's peer review of ARPE assessed its efforts to administer and enforce planning regulations related to building design and construction. The review evaluated ARPE's current needs—and identified unmet needs—to respond effectively to the massive amount of reconstruction necessary following Hurricane Georges and new construction in the future. The peer review resulted in recommendations in the areas of policies, procedures, practices, training and education, facilities, salary, benefits, promotion, and office automation. Since the completion of the peer review, FEMA, ICBO, and ARPE have been working closely together to develop a plan that meets the identified unmet needs. Both short- and long-term needs will be addressed in this plan.

The BPAT's limited investigation of current building construction practices, construction permitting, and enforcement of the building regulations identified unregulated and illegal construction, provisions in existing statutes, regulations, policies, and practices that allow for unregulated construction and improvements of residential buildings. The BPAT concluded that the extensive damage observed in residential construction from Hurricane Georges was due to a lack of enforcement of Planning Regulation 7.

According to the regulations, all construction projects in Puerto Rico require construction and use permits. Although the value of a project dictates the amount of documentation that must be submitted, many buildings have been constructed without any permits. Loopholes in the regulations and a lack of enforcement of the permitting regulations have led to the construction of additional unregulated, insufficiently designed and constructed buildings. In addition, conflicts between the permitting process in Puerto

Rico and the NFIP have not been addressed and have lead to the construction of buildings that were legally constructed from a permitting perspective, but are non-compliant with the NFIP and Planning Regulation 13.

ARPE faces difficult challenges in both the disaster and the non-disaster environment with un-permitted floodplain construction. Un-permitted floodplain development was previously observed in the May 1998 CAV conducted by FEMA's New York and Caribbean Regional Offices. The CAV found that many floodplain structures in Puerto Rico were at risk from flooding because they had been either built in violation of Planning Regulation 13 or subsequently altered without permits. Flooding associated with Hurricane Georges made that risk a reality and, consequently, many structures suffered significant—and unnecessary—damage.

8.4 Training and Continuing Education

As described in Section 8.3, the ICBO peer review of ARPE included recommendations on training and education needs. Unmet training needs were identified for ARPE staff, design professionals, technicians, builders and contractors, the banking and mortgage industries, the insurance industry, and public policy decision makers. As part of the peer review process, ARPE and FEMA developed a comprehensive plan to provide the necessary training to each of these groups with the goal of ensuring that the transition to a new building code progressed smoothly and that the post-Hurricane Georges reconstruction process was not interrupted.

8.4.1 Government of Puerto Rico Personnel

New residential construction activity in Puerto Rico is expected to increase dramatically during the next few years as severely damaged or destroyed housing is replaced. ARPE is currently determining the additional resources that will be required for space, management, and, most importantly, trained personnel. ARPE may be able to bring on trained code personnel to help them immediately, but as a long-term solution, ARPE must consider hiring and training additional staff.

8.4.2 Design Professionals and Building Contractors

Continuing education for design professionals and contractors is an effective vehicle for improving building regulation compliance. Under the comprehensive training plan, a variety of sources are being mobilized to provide training in building regulations and construction practices, including local engineering/architectural groups, professional engineering societies, model code organizations, the academic community, and building trade associations. The ability to develop this professional training is enhanced by the strong presence of Puerto Rico's academic and professional societies.

8.5 Structural

Structural building elements that were not designed or engineered to Planning Regulation 7 requirements of 110 mph (fastest-mile) design winds resulted in many residential structure failures. The BPAT observed buildings apparently designed to this standard that survived Hurricane Georges with no structural damage. However, as previously stated, this hurricane was not a design wind event for the island and the buildings constructed to Planning Regulation 7 are still considered vulnerable to forces from future wind, flood, and seismic events. The recent adoption of the 1997 UBC and the ASCE 7-95 wind provisions will help to improve the structural performance of buildings in Puerto Rico.

The non-engineered, self-built homes the BPAT observed performed poorly during the hurricane due to a lack of a continuous load path from the roof system to the foundation. A lack of compliance and enforcement of Planning Regulation 7 has resulted in a large number of buildings incapable of carrying the prescribed load. Marginally engineered buildings constructed from materials capable of withstanding design loads, reinforced concrete and masonry, performed well and did not experience significant structural damage. In instances where concrete and masonry construction combined with wood construction in the same building, the wood structures often failed while the concrete and masonry structures did not. Fully engineered buildings, the larger commercial buildings, constructed of steel and reinforced concrete and masonry, performed well and generally did not experience structural damage.

8.5.1 Structural Seismic Conclusions

Based upon discussions with ARPE, the BPAT understands that permitted buildings must be designed by engineers or architects. In addition, design professionals in Puerto Rico carry additional responsibilities for inspection of construction that, in areas outside Puerto Rico, are normally the responsibility of the building department. For this reason, the mid- and high-rise buildings the BPAT inspected were assumed to be professionally designed by engineers and architects and met the minimum structural seismic regulations in effect at the time of the building design. For more recently constructed buildings, this assumed they were in compliance with the seismic provisions of the 1987 amendments to Planning Regulation 7.

Most residential buildings (specifically, single-family homes) were not observed to be in compliance with current codes and regulations. Many of these residential buildings are susceptible to damage from seismic events of even less than the design event specified in Planning Regulation 7. Foundation systems comprised primarily of tall, slender columns with no intermediate bracing and shear wall systems that support the building in only one lateral direction were common on the island.

8.6 Architectural

The failure to design and/or test architectural components for the wind load prescribed in Planning Regulation 7 was the primary cause of building envelope problems from Hurricane Georges. However, some of the building envelope failures were likely due to inadequacies in the wind load provisions in Planning Regulation 7, particularly for one- and two-family houses. For these houses, Planning Regulation 7 prescribes a load of 36 psf for doors and windows, and 60 psf for roof edges. In comparison, using ASCE 7-95, the load on doors and windows varies between 54 psf and 81 psf, depending upon exposure and location of the opening (i.e., near a corner or away from the corner). For a moderately-sloped roof with an overhang, using ASCE 7-95—depending upon the exposure—the load on the roof covering varies between 134 psf and 164 psf at the corners, and 88 psf to 110 psf at the eaves, rakes, and ridges (assuming the house has Miami windows). The recent adoption of the 1997 UBC, along with the ASCE 7-95 wind provisions, will address these concerns.

The amount of damage that water infiltration caused was reduced because of the primary construction materials used. The most notable examples were found in flooring and walls. In place of carpet, concrete or vinyl was typically found in houses; instead of gypsum board, the walls were generally masonry. Cleanup and minor cosmetic repairs were still necessary, but costly removal and replacement of water-susceptible materials was avoided.

8.6.1 Doors

Some of the poor door performances the BPAT observed were due to inadequate design or application of the attachment of the door frame to the wall. These vital connections are often overlooked by designers and not given sufficient consideration by contractors. Several glass doors were damaged by missile impact. To avoid impact damage, glass doors must be protected with shutters or glazed with impact-resistant glazing (i.e., laminated glass).

Security grilles were observed to offer good wind performance. They offer greater wind-resistance reliability than rolling or garage doors because of the large amount of net free open area.

8.6.2 Walls

The BPAT observed several problems with stucco blown from concrete. This could have been avoided by improving the workmanship of the concrete surface and leaving it exposed or having it painted. Poor performance of exterior metal wall coverings was primarily attributed to failure to test and/or adequately design wall assemblies for the wind load. Poor EIFS performance was related to workmanship in at least one instance. In another case, it was related to workmanship or failure to test and/or design the wall assembly for the wind load prescribed in Planning Regulation 7.

8.6.3 Roof Coverings

Liquid-applied roof coverings over concrete decks and plywood decks provided excellent wind performance. Sprayed polyurethane foam roofs also performed well. This system, however, was not commonly used and many of these roofs required recoating.

The BPAT found that corrugated metal roof coverings generally were attached insufficiently. This is the prevailing roof covering in Puerto Rico, and it experienced the greatest number of failures. In many cases, the plane of failure was between the metal panels and the wood nailers, while in others it was between the nailers and joists/trusses or between the joists/trusses and bearing walls. Several roofs were very corroded.

Many exposed concrete roofs leaked during the hurricane. Unless protected with a roof covering, these decks could eventually experience problems with corrosion of the slab reinforcement.

As demonstrated in other hurricanes, and again demonstrated by Hurricane Georges, aggregate from built-up roofs can be picked up by hurricane winds and cause significant glass damage, both to the building with the aggregate roof surfacing as well as nearby buildings. Several built-up membrane roofs experienced partial membrane blow-off. Inadequate attachment of the metal edge flashing/coping was the likely source of these problems. Although roof tiles are not in widespread use, the BPAT observed that roof tile performance was typically poor.

8.6.4 Glazing

Broken glazing was the most common type of damage in low-, mid-, and high-rise buildings. Some glazing was lost due to over-pressurization while windborne debris (missiles) caused other glazing to break. Over-pressurization problems were primarily attributed to failure to test and/or adequately design assemblies for the wind load. Missile impact problems were primarily attributable to lack of missile criteria in Planning Regulation 7.

8.6.5 Shutter Systems and Impact-Resistant Glazing

Shutter systems were placed over windows on many buildings prior to the hurricane. Many of these systems appeared to offer sufficient resistance to missiles and wind pressures. However, in numerous cases observed, shutter systems afforded limited resistance to missiles and many were susceptible to blow-off. Some shutters had the potential to deform and break the glass they were intended to protect. Furthermore, Miami windows are not very resistant to wind-driven water or high energy missiles and they should not be considered to be storm shutters.

In one instance, the BPAT observed a room, which had been used as a shelter, that was fully glazed on three sides and protected by shutters. Because of a concern of failure during Hurricane Georges, as indicated by excessive deflection and vibration, occupants were sent to other areas of the building during the storm. Areas used as shelters must be specifically designed for this very purpose and contain only small areas of fully protected glazing.

The BPAT observed only one example of impact-resistant glazing (i.e., laminated glass). Although the glass broke, it remained in the frame as intended.

8.6.6 Weatherstripping

The BPAT concluded that greater attention must be paid to weatherstripping doors and windows and the water resistance of the joints between walls and door and window frames. This was not a major issue during Hurricane Georges because it was overshadowed by the poor performance of the building envelope or structure. However, unless this type of water leakage is addressed, water damage will occur even on buildings with envelopes and structures that perform well otherwise. Although the amount of water that can enter around doors and walls is minor compared to the amount that can enter through breached windows or roofs, a sufficient amount of water can enter and cause notable damage.

8.6.7 Seismic Resistance of Nonstructural Elements

The BPAT concluded that the design of seismic resistance of nonstructural elements in Puerto Rico, including ceilings, non-load bearing exterior walls, and non-load bearing interior partitions often receive insufficient attention. Where suspended ceiling tile was removed because of water or wind damage, the BPAT observed that nonstructural elements were not connected to structural members with seismic resistant connectors.

8.7 Exterior Mechanical and Electrical Equipment

Greater attention to the attachment of rooftop equipment is also required. Cowlings on exhaust fans were susceptible to blow-off. On-site strengthening is necessary unless equipment manufacturers respond with units of adequate strength.

For buildings located in floodprone areas, mechanical and electrical equipment must be elevated above the BFE. Electrical supply via a service mast mounted on a freestanding concrete pylon was effective in preventing damage to buildings when overhead service dropped during the hurricane. Finally, there is typically a lack of sufficient attention to the design of seismic resistance of mechanical and electrical equipment.

9 Recommendations

The recommendations of this report are intended to assist the Government of Puerto Rico in shaping its post-Hurricane Georges construction strategy and assist designers, contractors, and building owners in the construction of hazard-resistant buildings. These recommendations are based solely on the BPAT's observations, an evaluation of relevant codes and regulations, and meetings with the Government of Puerto Rico. The recommendations apply primarily to the building code used in Puerto Rico at the time Hurricane Georges occurred and the newly adopted 1997 UBC. They also apply specifically to residential buildings, specific nonresidential buildings observed during the course of the investigation, and mid- and high-rise building envelopes.

9.1 General Recommendations

A disaster in a community offers an opportunity to reflect on the things that are important in our lives. Out of this reflection, a community can decide to take a stand against future natural disasters and promote sustainable development and disaster-resistant communities by committing to rebuild their homes, schools, businesses, and infrastructure consistent with effective mitigation techniques and approaches.

As the people of Puerto Rico rebuild their lives, homes, and businesses there are a number of ways they can avoid the effects of future natural hazards. Some of these opportunities include:

- Buildings designed to the new building regulations that provide greater protection against hurricanes and earthquakes.
- New buildings permitted, built, and inspected to meet the new building regulations.
- An upgraded electric power system so that power is quickly restored and critical services such as water and sewage treatment can continue to be provided.
- A retrofit of existing buildings so their envelopes are not breached during a hurricane and do not collapse in an earthquake.
- Special building precautions in areas with known hazards (such as floods, landslides, and tsunamis) or avoiding these areas altogether.

More specific recommendations are included in the following subsections. Mitigating future losses, however, will not be accomplished by simply reading this report; mitigation is achieved when a community actively seeks and applies methods and approaches that will lessen the degree of damage sustained from natural hazards. Figure 9-1 illustrates a full range of successes and failures observed in a single community after Hurricane Georges.

FIGURE 9-1 This photograph illustrates successes and failures in residential buildings observed after Hurricane Georges. A residential concrete building with no structural damage is seen in the center of the picture. At top right is a wood-frame building that is completely destroyed around a center room that was constructed of masonry. Other buildings in the photograph have damage that ranges from the total loss of the wood-frame building to the success of the concrete building.

9.2 Training and Continuing Education

The success and failure of buildings observed during Hurricane Georges offers important learning opportunities for Puerto Rico. Of greatest importance is the assurance that all buildings are permitted and appropriately designed, inspected, and constructed. The Government of Puerto Rico has adopted as emergency regulation the 1997 UBC, which more completely addresses the natural hazard risks of Puerto Rico than Planning Regulation 7. Adopting the 1997 UBC is a significant change for government officials, design professionals, and contractors involved in the building industry and requires a significant training effort for these groups.

9.2.1 Government of Puerto Rico Personnel

To facilitate training of government personnel, ARPE completed a peer review by an independent third party, ICBO, the authors of the UBC. This peer review identified existing training courses and materials currently available that meet, or can be altered to meet, the immediate training needed by ARPE to implement the 1997 UBC. Training includes train-the-trainer courses so that ARPE can develop its own internal training resources.

9.2.2 Design Professionals and Building Contractors

The Government of Puerto Rico should continue to support positive mitigation education efforts undertaken by the Puerto Rico Civil Defense, Colegio de Ingenerios y Agrimensores, Colegio de Arquitectos, and the University of Puerto Rico College of Engineering in Mayagüez. The recently published *Huracanes en Puerto Rico: Guía de Mitigación de Daños* provides useful information for design professionals and local homebuilders. This document should be reviewed and updated to ensure that it is compliant with the new building code and regulations. It should be reissued so that all parties involved in the building industry, from the design professional to the homeowner, will have accurate and useful information to mitigate against natural hazards.

Programs such as the conferences sponsored by the Colegio de Ingenieros y Agrimensores on building envelope protection systems should be continued. New programs educating design professionals and builders should be developed to share state-of-the-art mitigation techniques that are being used throughout the United States for all natural hazard events (flood, wind, and seismic).

ARPE, the Colegio de Ingenieros y Agrimensores, the Colegio de Arquitectos, FEMA, and ICBO are working together to develop a training schedule for the sections of the 1997 UBC that address natural hazards.

9.3 Codes and Regulations

Important improvements and revisions to the building code and planning regulations of Puerto Rico have taken place since Hurricane Georges. However, additional mitigation should still be implemented to improve the built environment.

9.3.1 Planning Regulation 7

ARPE and the Government of Puerto Rico have had numerous meetings with FEMA to discuss the preliminary findings of the BPAT and to identify ways to improve the building regulations and the enforcement of these regulations. As part of these efforts, the Government of Puerto Rico has adopted the 1997 UBC with local amendments as emergency regulation. In addition, Puerto Rico is also proceeding with legislation that will remove the exceptions that allowed some buildings to be built without a permit.

ARPE anticipates that this new Certification and Building Board of Puerto Rico, under proposed legislation, will be in place by March 1999. One of the Board's responsibilities will to be to consider and adopt updated building regulations, including the formal adoption of the 1997 UBC, with amendments, as the new building code for Puerto Rico.

Furthermore, the BPAT agrees with the Government of Puerto Rico's decision to adopt the 1997 UBC as an interim step toward adopting the International Building Code (IBC) when it becomes available. The following local amendments are also recommended for consideration to ensure that the 1997 UBC fully addresses factors affecting the built environment in Puerto Rico:

1. In Chapter 15, Roofing: Require uplift testing, including prescriptive criteria for corrugated metal roofing, prohibit aggregate surfaced roofs (unless they are double surfaced or the parapet is of a minimum height), and provide prescriptive criteria for metal edge flashings/copings. Tile roofs should be prohibited because of the large volume of windborne debris they can create. If this is not acceptable, add provisions from the SBC, plus prescriptive criteria.
2. Appendix Chapter 34, Repairs after a natural disaster: This should be looked at to determine if Puerto Rico wishes to expand this to address nonstructural envelope damage that frequently occurs following hurricanes.

3. Adopt the *Uniform Code for the Abatement of Dangerous Structures.*
4. Appendix Chapter 15, Reroofing: Normal re-roofing during the life of a building offers attractive opportunities for hazard mitigation of hurricanes. This appendix chapter should be adopted.
5. Chapter 23, Wood: Require preservative treatment or naturally decay-resistant wood be used for termite resistance.
6. Chapter 24, Glass: Require wind-resistance testing per ASTM E 1233. Add provisions related to missile impact resistance (use load criteria from Southern Building Code Congress International (SBCCI) STD 12 and test per ASTM E 1886).[1]

9.3.2 Floodplain Management Provisions of Planning Regulation 13

ARPE and the Puerto Rico Planning Board should use information gathered by the CAV in May 1998 and from the damage of Hurricane Georges to continue to educate homeowners on the risks involved in building in floodprone areas. A renewed effort in enforcement of Planning Regulation 13, specifically in the permitting process and during the rebuilding process, may result in a significant reduction in property loss from future flood events.

Procedures should also be in place to address situations when homeowners enclose ground level areas of buildings that were once properly elevated and flood resistant but are now non-compliant. In addition, a renewed effort is necessary for enforcement of Planning Regulation 13. Specific improvements should be made in the permitting and inspection processes during non-disaster times, but this is also especially important during the post-hurricane rebuilding process. During rebuilding efforts homeowners understandably rush to repair the damage to their houses, but their repairs often are not in compliance with the NFIP and Planning Regulation 13. Proper new construction, retrofitting of existing structures, and rebuilding of damaged buildings will result in significant reduction in property loss and human suffering from future flood events.

Approximately 434,000 people live in identified floodplains in Puerto Rico. But there are approximately only 41,000 flood insurance policies currently in force, covering about 135,000 individuals[2]. Hurricane Georges has provided Puerto Rico with an important opportunity to increase public awareness of flood risks. Purchasing flood insurance is one of the simplest actions communities and businesses can take to mitigate flood risk. It should be noted, however, that despite previous flood events, few of the eligible individuals in Puerto Rico have taken advantage of the NFIP group policies that were purchased following previous Presidentially-declared disasters under the Individual and Family Grant Program. FEMA and the Government of Puerto Rico must explain more effectively the benefits afforded by current flood insurance group policies in affected communities.

[1] A new ASTM missile load standard is nearing completion. When it becomes available it is recommended in lieu of STD 12.

[2] According to the 1990 census, average people per home and average people per family are as follows: 3.31 people per home and 3.69 people per family. Source: Census Office of the Planning Board.

9.3.3 Evaluation, Submittals, and Product Approval

A number of the BPAT's recommendations relate to building construction but they are more appropriately addressed outside the building code. The BPAT recommends that the planning board evaluate the merit of the following recommendations:

1. Issue a guideline for determining wind loads related to loads on rooftop heating, ventilation, and air conditioning (HVAC) equipment (guidance for this is not provided in ASCE 7-95).
2. Consider product approval/submittals for components and cladding. Exterior Insulated Finishing Systems should require testing per ASTM E 1233 and perhaps include prescriptive criteria.
3. Corrosion protection for clips, fasteners, metal panels, and flashing within 3,000 feet of salt water could be addressed through product approval. It could also be addressed through an amendment to the building code.

9.4 Essential Facilities

Puerto Rico's essential facilities should be evaluated for their vulnerability to natural hazard events. These facilities are critical to government response following a natural hazard event. The BPAT recommends that these buildings be evaluated under the provisions of the new building code in an effort to minimize the possibility of these facilities experiencing failures and loss of services during natural hazard events. Structures observed to perform at an unacceptable level should be retrofitted to improve building performance. This study should not be limited to such facilities as fire stations, police stations, and emergency operations centers, but should also include hospitals, emergency shelters (short- and long-term), and all buildings classified as essential facilities in ASCE 7-95.

9.5 Residential Buildings

The BPAT recommends the Government of Puerto Rico address vulnerabilities in residential construction through final adoption of the building code, as well as aggressive enforcement of these new regulations, to greatly improve the disaster resistance of residential buildings. Specifically, the design and construction of wood-frame buildings must be updated to greatly reduce the widespread damage that occurred to these structures during Hurricane Georges. Proper construction techniques and materials incorporated into the construction of these wood-frame buildings will greatly reduce their vulnerability to damage during natural hazard events. Construction of concrete and masonry structures should be regulated and inspected to ensure that they meet the new building code requirements, especially those regarding structural seismic issues. Finally, siting of residential buildings out of floodprone areas or requiring proper elevation through permitting enforcement will help to prevent damage and loss of property due to flooding.

9.6 Structural and Architectural Performance

The new building code will provide the building community with the tools to guide, evaluate, and regulate the construction and improvements of buildings in Puerto Rico. Based on the BPAT's recommendations, the Government of Puerto Rico has adopted through emergency regulation a number of changes to the building codes and regulations that will improve the disaster resistance of both structural and architectural building systems. Puerto Rico must continue its proactive approach to updating such codes and regulations to minimize the damage that may occur during future flood, wind, or seismic events. Failure to update and improve the building environment, and the regulations that govern it, may result in repetitive damage and cost to Puerto Rico that otherwise could have been prevented.

Model building codes often quantify loads that act on structures based on the recurrence interval of a particular natural hazard event: flood, wind, or earthquake. For natural hazard events, design flood conditions are based upon 100-year recurrence interval events. Design wind events are based on 50- or 100-year recurrence interval events. Design seismic events are based typically on 50-, 200-, or 500-year recurrence interval events. Although recurrence intervals are a useful concept to define natural hazards, they are frequently misapplied to explain risk. Table 9-1 shows the risk (the probability of experiencing different events during specified yearly periods) and compares it to recurrence intervals. This, or similar tables, can be used by building owners to identify acceptable risks. Once the owner has determined an acceptable risk, the designer can choose the appropriate recurrence interval to use in design based on the life of the building. Based on an acceptable risk to the owner, the designer may choose a design event that is less frequent than required by the building code. For example, if the owner is building a 30-year building and wants a less than 6% chance of it failing in a hurricane, the designer would design for a 500-year recurrent interval.

TABLE 9-1 The probability of experiencing different events during specified yearly periods.

Life of Building or Length of Period (Years)	Frequency/Recurrence Interval (Year Event)				
	10	25	50	100	500
10	65%	34%	18%	10%	2%
20	88%	56%	33%	18%	5%
30	96%	71%	45%	26%	6%
50	99+ %	87%	64%	39%	10%
100	99.9+ %	98%	87%	63%	18%

This table can also be used to broadly identify risk during a period of time. For example, during the next 20 years, there is a 45% chance that there will be an event with a recurrence interval of equal to or greater than a 50-year event. Puerto Rico has a 45% chance of seeing a hurricane as severe or more severe than Hurricane Georges in the next 30 years.

9.7 Electric Power Distribution

The BPAT recommends that the Government of Puerto Rico perform a study on the electrical power distribution system. The present system was improved after hurricanes in the 1990's severely damaged the system. However, considerable damage was noted throughout the entire system after Hurricane Georges, indicating that improvements can still be made to reduce the system's vulnerability to natural hazard events.

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Appendix A

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Appendix B

Presidential Disaster Declarations In Puerto Rico

Declaration Date	Cause	Declaration Number	Emergency Number
8/1/56	Hurricane	62	
5/26/64	Extreme Drought Conditions	170	
10/12/70	Heavy Rains and Flooding	296	
8/29/74	Extreme Drought Conditions		3002
11/30/74	Flooding	455	
9/19/75	Tropical Storm Eloise	483	
9/2/79	Hurricane David	597	
5/31/85	Storms, Mud/land slides, Flooding	736	
10/10/85	Severe storms, Mudslides, Flooding	746	
7/10/86	Heavy Rains, Flooding, Mudslides	768	
12/17/87	Severe Storms, Flooding	805	
9/21/89	Hurricane Hugo	842	
1/22/92	Severe Storms, Flooding	931	
9/16/95	Hurricane Marilyn	1068	
9/11/96	Hurricane Hortense	1136	
11/21/96	Gas Leak Explosion		3124
9/21/98	Hurricane Georges	1247	3130

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