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.

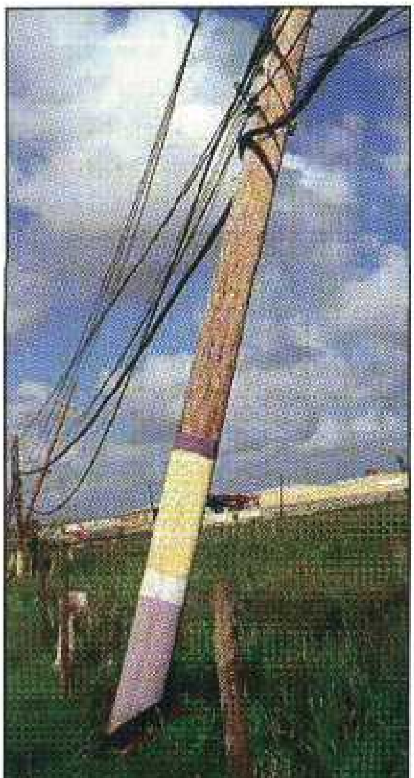

FIGURE 7-2 Leaning wood pole due to inadequate embedment.

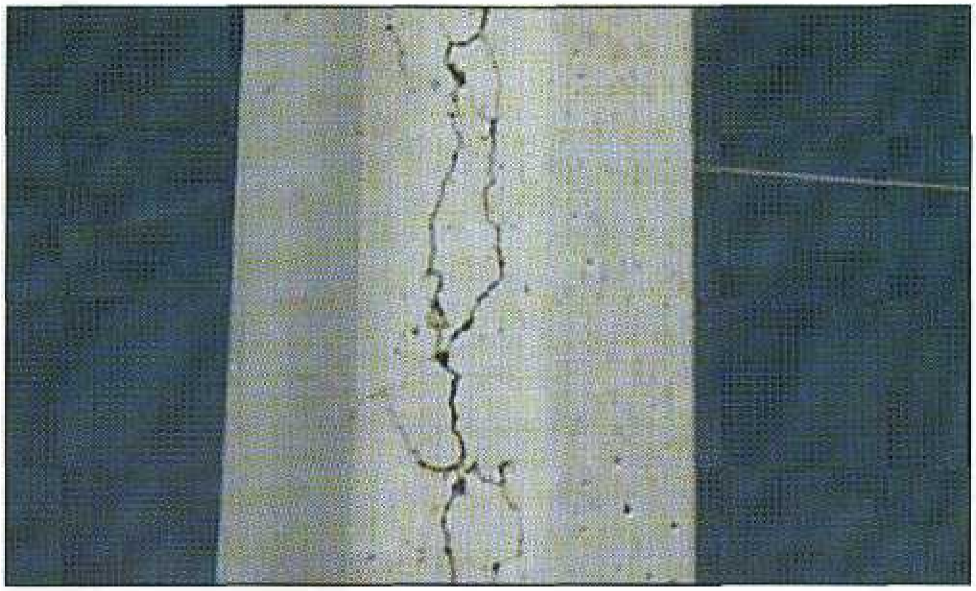

FIGURE 7-3 Observed crack in concrete pole that appears to be a quality control problem.

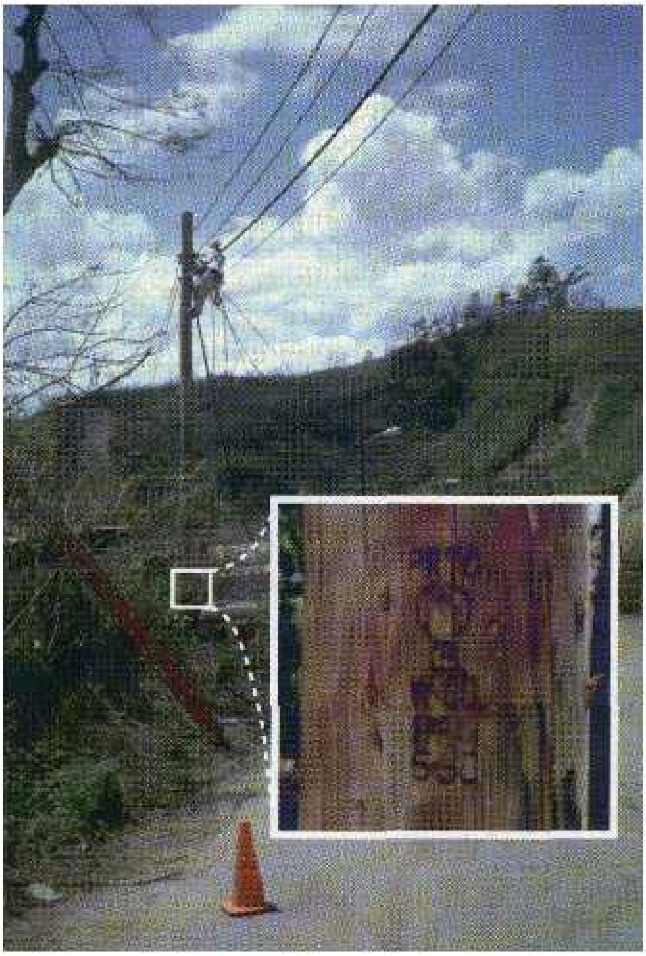

FIGURE 7-4 New wood pole replaced after the hurricane; utility lines are still being attached to the pole. Inset shows wood pole grade marking. This #3 pole was typical of those used throughout the island.

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.

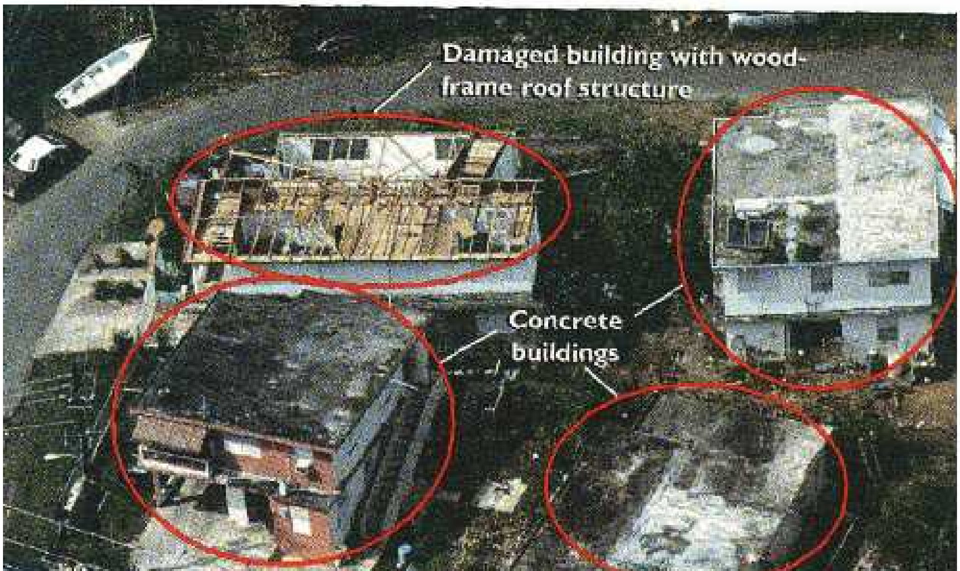

FIGURE 8-1 The three concrete/masonry buildings in this photo appeared to be undamaged. However, the building with the wood-frame roof structure experienced significant damage.

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.

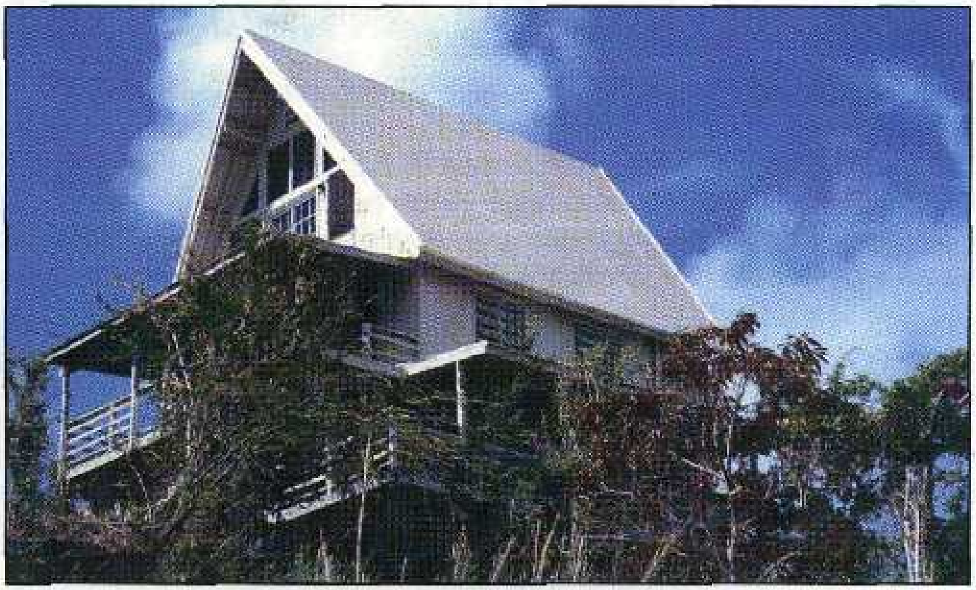

FIGURE 8-3 This wood-framed house is close to the house shown in Figure 8-2. The wind flow was essentially identical at these two sites, hence the successful performance of the one building is attributable to the attention given to design and construction. The value of mitigation is clearly illustrated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