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).

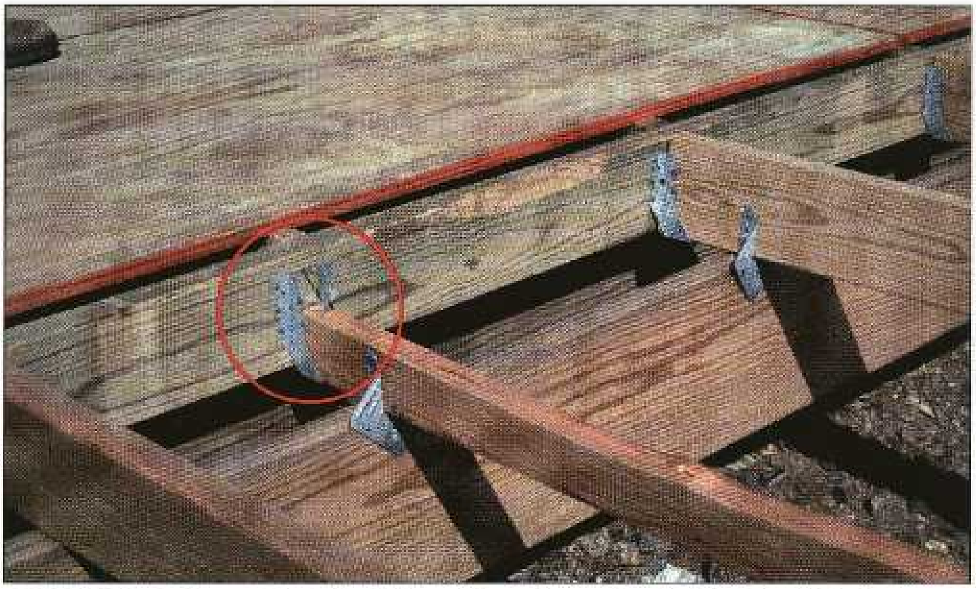

FIGURE 4-13 Example of the failure of wood member in the floor joist hanger due to the use of improper nails. The hurricane clip was used to secure the floor joist to the support beam. This house was located on the island of Culebra.

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.

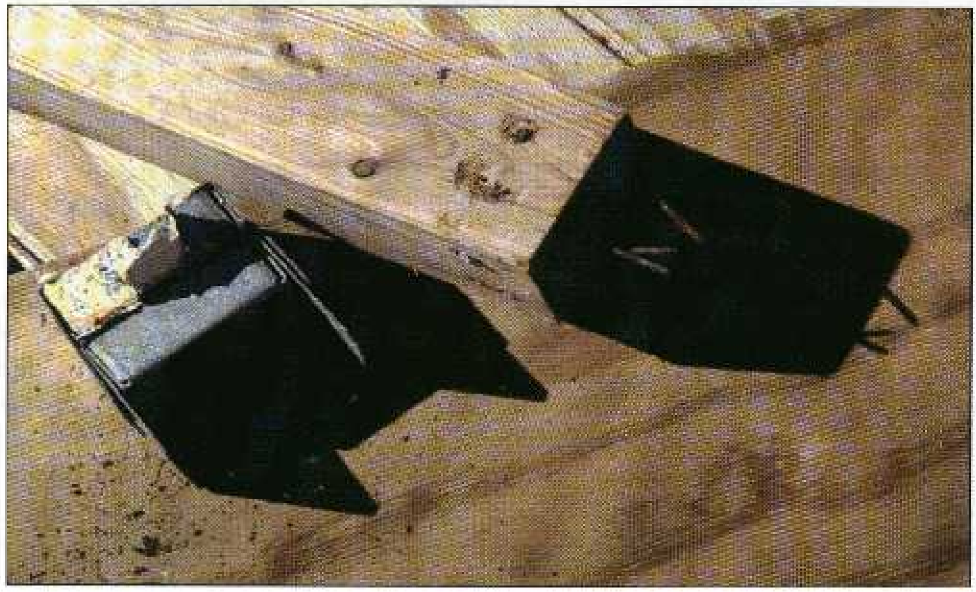

FIGURE 4-15 Wood wall column that failed at connection to sill plate. This building was only two months old but was only partially constructed with clips, straps, and fasteners. The proper column fastener in the photograph was found unused beneath the house. This column was from the same house presented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

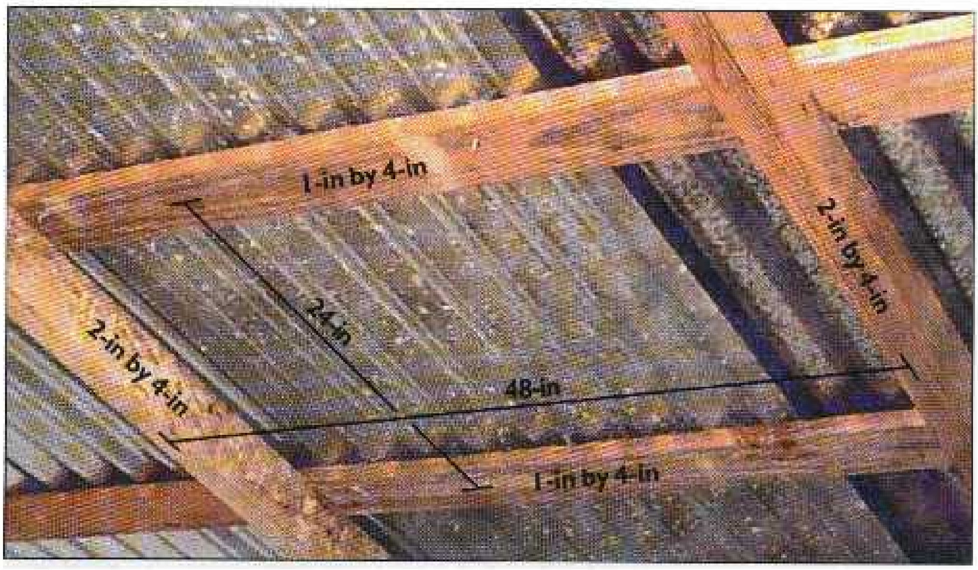

FIGURE 4-16 Typical wooden roof structure with metal roof panels above. Nails connected the metal panels to the nailers and the nailers were nailed to the joists.

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).

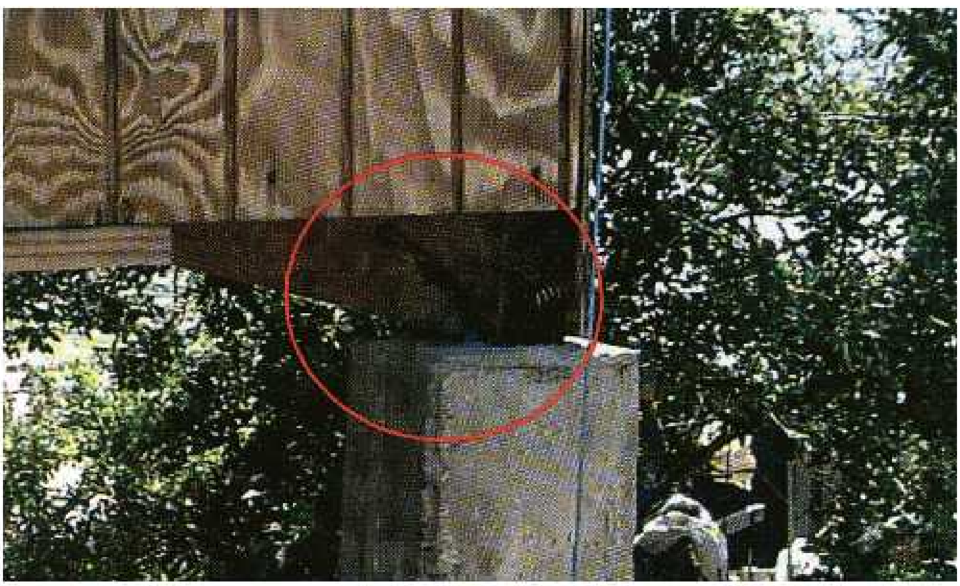

FIGURE 4-18 Example of a non-engineered connection between the building foundation (concrete column) and the floor system. The wooden floor beam is connected to foundation rebar with an improper nailed connection.

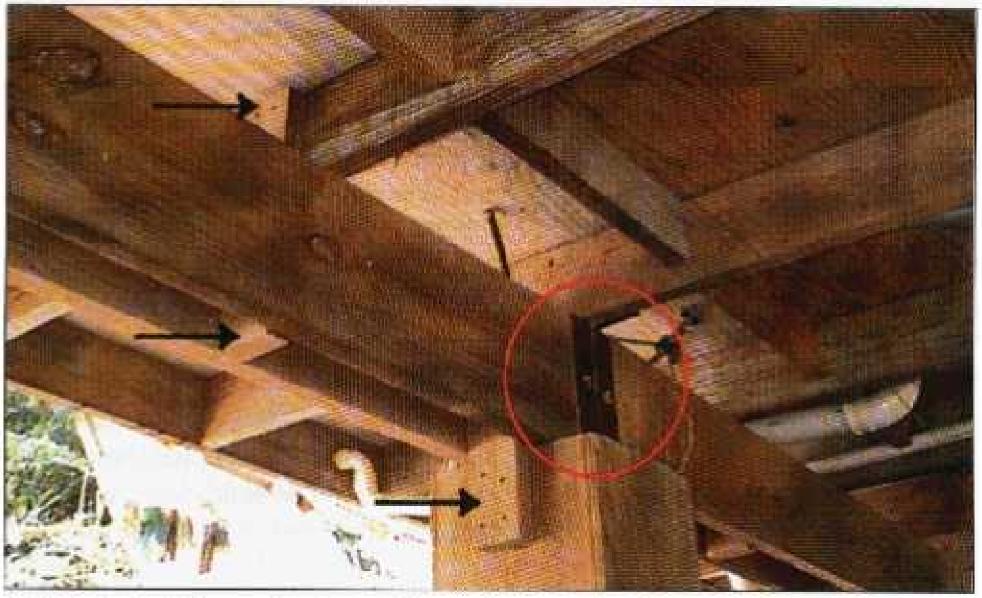

FIGURE 4-19 Example of an engineered connection between the floor beam and a concrete column (concrete column is enclosed in plywood). Vertical members (identified by arrows) provide continuous load path from floor joist to floor beams. Floor beams are connected to concrete columns with metal straps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

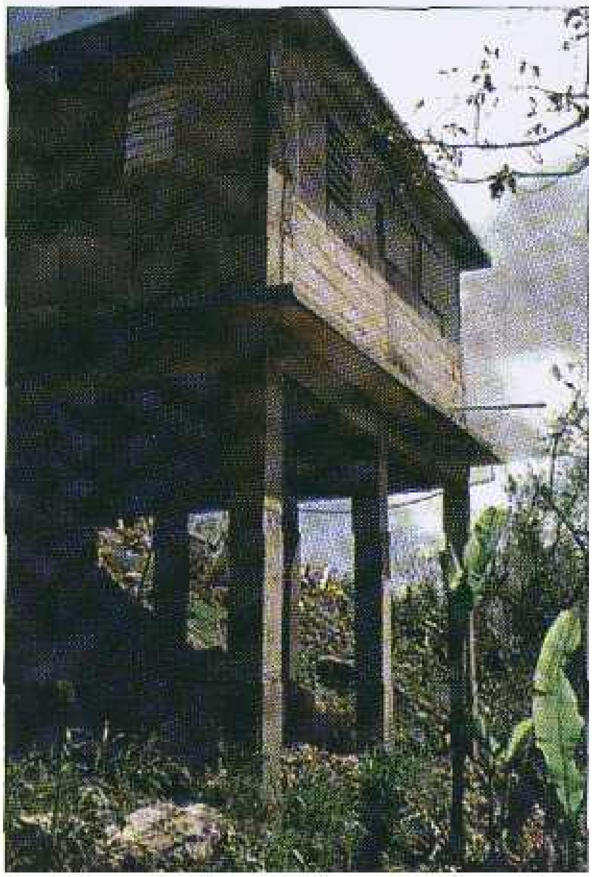

FIGURE 4-22 Residential building supported atop tall, unbraced concrete columns. This type of unbraced support column was common in many areas.

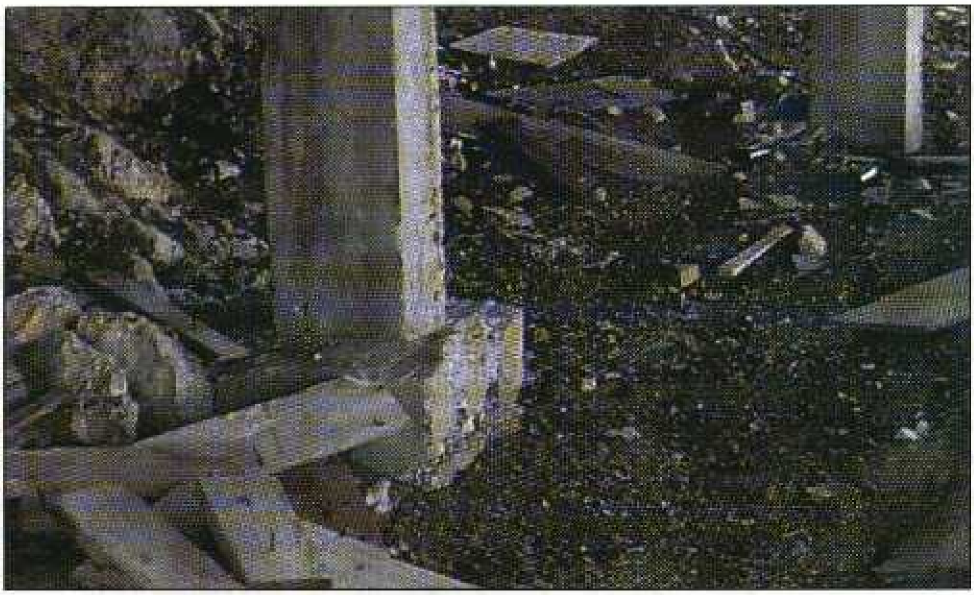

FIGURE 4-23 Footing for tall columns in Figure 4-22. This footing is not adequately anchored to the supporting rock to resist lateral forces that may be induced during a design seismic event.