# 1.0 INTRODUCTION

## 1.1 PURPOSE

The purpose of this report is to provide guidance and recommendations for reducing hurricane and flood damage in the future. This purpose is best achieved through learning from successes and failures of building performance. Therefore, this report includes observations of both successes and failures of various building types.

Numerous references to figures are made throughout the text of this report. These figures, primarily photographs, explicitly portray, clarify, or reinforce the technical issues addressed. The figures are presented at the end of each pertinent section. The reader is encouraged to examine these figures while reviewing the report.

This report includes detailed engineering discussions of building failure modes and successful building performance supplemented by graphic examples and illustrated design specifications. It also provides recommendations for enhancing building performance under hurricane conditions and addressing building materials, code compliance, plan review, and construction inspection.

## 1.2 BACKGROUND

In the afternoon of September 11, 1992, Hurricane Iniki struck the Island of Kauai, Hawaii, generating high winds and storm surge over a vast area of the island (FIGURE 1). With wind speeds exceeding those of Hurricanes Iwa (1982) and Dot (1959), Iniki was the strongest and most destructive hurricane to strike the Hawaiian Islands in recent memory.

Although measurements of the storm's wind speeds are subject to continuing analysis, it was evident from the extensive damage observed that wind speeds were

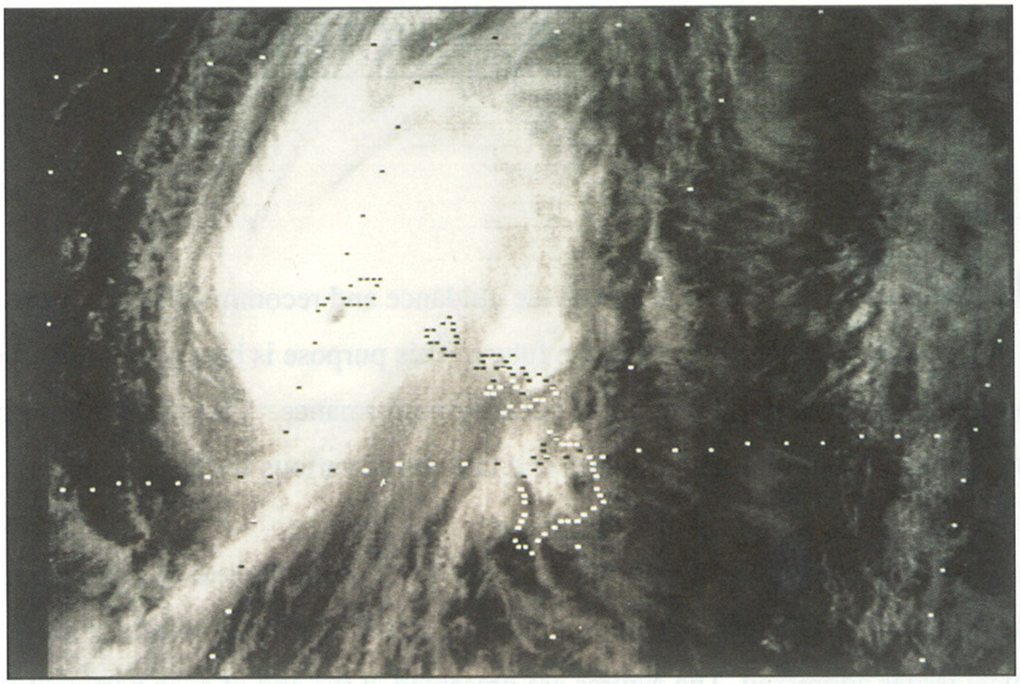

FIGURE 1. *The eye of Hurricane Iniki crossed the Kauai coast just west of Port Allen near Kaumakani just before 4:00p.m. Hawaiian Standard Time on September 11, 1992.*

significant. Preliminary measurements of coastal flooding and deposition of heavy debris considerable distances inland are evidence of the significant storm surge and wave forces associated with the hurricane.

## 1.3 THE BUILDING PERFORMANCE ASSESSMENT TEAM

On September 22, 1992, following a request from the Mayor of Kauai County, the Federal Coordinating Officer for the Iniki disaster tasked the Federal Insurance Administration (FIA) to assemble a team of experts to assess the performance of buildings. Since the 1970s, FIA has gained valuable experience through an ongoing assessment program that focuses on the performance of buildings that have incurred flood and wind damage. These assessments evaluate and support FIA's administration of the National Flood Insurance Program (NFIP), which includes enforcement of requirements governing the reconstruction of substantially damaged buildings in floodplains, regardless of the cause of the damage.

### 1.3.1 Team Composition

The team included field-experienced professionals trained in building design and construction and a cadre of technical and policy advisors. Team members that participated in the field surveys were Federal Emergency Management Agency (FEMA) Headquarters and Region IX staff, representatives of the State of Hawaii Civil Defense System and the Kauai County Engineering and Planning Departments, and Registered Professional Engineers and Architects from both Kauai and Oahu (see Appendix A for complete list).

### 1.3.2 Purpose of the Team

The purpose of the team was to evaluate the effectiveness of past design and construction practices in Kauai County by surveying damage (or lack of damage) caused by Hurricane Iniki. From field assessments of building systems subjected to significant wind and/or water forces, the team sought to diagnose characteristic modes of building system failure and to identify the systems that were successful in resisting those forces. Through this preliminary report and associated training activities, the team also will offer recommendations and guidance on ways to reduce similar damage in the future.

The basis for forming the team, compiling this report, and pursuing further study is the assumption that improved performance of buildings can be attained when:

- observed failure modes can be mitigated using basic and widely recognized practices and standards for new and repair construction;

- observed building successes can be used as evidence to reinforce the use of these practices and standards; and

- Federal, State, and County governments and the private sector work in close cooperation to ensure that repair work and new construction practices will mitigate against future hazards while remaining cost-effective and practical.

### 1.3.3 Team Activities

During the field assessment, the team investigated primary structural systems, i.e., systems that support a building under lateral and vertical loading conditions. The majority of building types observed were one- and two-story wood-frame structures — single-family residential, multi-family residential, and commercial. However, the team attempted to be comprehensive by assessing a wide range of construction types (including metal-frame pre-engineered commercial and industrial structures and resort hotels and condominiums constructed of reinforced concrete and masonry). These structures were observed in locations experiencing a wide range of wind and flood exposure conditions.

Collectively, the team invested a significant number of man-hours in the site surveys, documentation, assessment of damages, formulation of recommendations, and report production. Documentation of findings made during ground-level and aerial surveys included field notes, photographs, and videotaping.

### 1.3.4 The "Team" Concept

Participation by State and County governmental officials and locally based consulting Engineers and Architects in the assessment process is critical because it 1) ensures that all State and local Building Code and other requirements are properly interpreted, 2) enhances the likelihood that local construction practices are fully appreciated and understood, 3) helps establish positive relationships between Federal, State, and local governments and the private sector, and 4) encourages recommendations that are realistic, from both economic and technical standpoints.

Under the "team" concept, local government and its citizens become active participants in a positive and forward-looking technical appraisal and planning process which attempts to improve the future performance of buildings. In this way, team recommendations have a much better likelihood of being considered, adopted, and implemented.

## 1.4 Hurricane Iniki — Storm Conditions

Hurricane Iniki was a small but intense hurricane as it moved northward across the Island of Kauai during the late afternoon hours of September 11, 1992. The eye of Iniki crossed the Kauai coast just west of Port Allen near Kaumakani just before 4:00 p.m. Hawaiian Standard Time (HST). Iniki left behind a path of destruction, with property damage expected to approach 1.8 billion dollars. On Kauai alone, Iniki destroyed or damaged 14,350 homes. Of that total, 1,421 were destroyed and another 5,152 suffered major damage. Damage on Kauai was widespread, with the most severe damage occurring on the south, east, and north ends of the island. Even with such widespread and severe damage, only three deaths were attributed directly to the storm. The low loss of life can be attributed to ample warning time, an excellent response by the State of Hawaii Office Civil Defense System, the evacuation of all coastal areas, and the high level of awareness created by previous press coverage of Hurricane Andrew in Florida and Typhoon Omar in Guam.

As expected from a hurricane of Iniki's intensity, coastal flooding was significant along the southern shoreline from Kekaha to Poipu Beach. Coastal flood heights were measured along the southern shoreline by the U.S. Army Corps of Engineers (COE), Pacific Ocean Division, under contract to FEMA. Although measurements are preliminary and require verification, they indicate stillwater flood elevations ranging from 10.5 to 12.5 feet above mean lower low water (mllw) at Kekaha to 12.5 to over 20 feet above mllw along Poipu Beach. An independent assessment conducted by the Department of Geology and Geophysics, University of Hawaii, confirms the magnitude and extent of the surge heights and penetration.

A determination of actual wind speeds during Hurricane Iniki proved to be highly variable. This may be due to varying degrees of exposure as a result of ground surface irregularities, the distance between anemometer ( a gauge for recording wind velocity) sites, and the potential inaccuracy of anemometers at excessively high winds. Wind speeds were recorded at the Pacific Missile Range Facility at Barking Sands, Lihue Airport, and one other station on the island. The strongest winds were reported from Port Allen eastward, with Makahuena Point reporting east winds at 70 knots (81 mph), with gusts to 105 knots (121 mph) when the power failed. The peak gust at Makahuena Point, which was extracted from the data recorder after the fact, reached 124 knots (143 mph). At Lihue Airport, the strongest sustained wind was southeast at 84 knots (97 mph) at 3:52 p.m. HST and southwest at 78 knots (90 mph) at 5:10 p.m. HST. These wind speeds, however, do not account for higher wind speeds that may have existed along highly exposed ocean promontories such as Makahuena Point or ocean-fronting high bluffs such as at Princeville. Wind speeds can also be amplified above these actual recorded base conditions by channeling through mountain gorges or as a result of the effects of other landforms with extreme topography.

On October 8, 1992, members of the team met with various experts involved in the assessment of the winds generated by Iniki. The team learned that the sustained wind speeds at low altitude were recorded in excess of the 80-mph basic code design (FIGURE 2). However, it is important to understand that the basic wind speed of Hurricane Iniki was not beyond that which a building can be designed for with reasonable likelihood of successful performance.


FIGURE 2. *Hurricane Iniki produced substantial wind speeds at low altitudes in excess of the 80-mph base condition.*

## 1.5 National Flood Insurance Program Requirements

Currently, Kauai County is participating in the regular phase of the NFIP. County participation in the NFIP makes federally backed and reasonably priced flood insurance available to residents. As a condition of flood insurance availability, the county agreed to and has adopted regulations that meet or exceed NFIP minimum standards. The NFIP standards call for enforcement of prudent construction practices in flood hazard areas. These practices pertain to the construction of new and substantially improved buildings and to the repair of substantially damaged buildings in flood hazard areas as designated on the Flood Insurance Rate Map (FIRM). The cornerstone of the NFIP requirements is that the lowest floors of buildings must be elevated to or above flood heights shown on the FIRM.

The flood hazard designated on the FIRM for southern Kauai is based on a hybrid system of the 100-year tsunami and wave runup recorded from Hurricane Iwa (1982). The 100-year tsunami is the basis for the rest of the State except for Southern Oahu.

Along some oceanfront property such as Poipu Beach (FIGURE 3) and Hanalei (FIGURE 4), Coastal High Hazard Areas have been mapped. These areas are designated as V zones (velocity zones) on the FIRM. A V zone is an area subject to 100-year coastal flooding with waves 3 feet or greater in height. Consequently, additional design considerations are necessary for construction in V zones. Such considerations include use of pile and column foundations, leaving the area under the elevated building open to allow for free passage of velocity flood waters, and ensuring that foundation embedment is sufficient to withstand erosion and localized scour.

Buildings in flood hazard areas that are determined to have been "substantially damaged" during Iniki, for whatever reason (e.g., wind or flood), must be repaired or reconstructed to NFIP standards for new construction. A building is substantially damaged when the cost to fully repair the building equals or exceeds 50 percent of its pre-damaged market value.

## 1.6 BUILDING CODE REQUIREMENTS FOR WIND HAZARDS

Kauai County was, at the time of the hurricane, using the 1985 version of the Uniform Building Code (UBC). The UBC, in Chapter 23, "General Design Requirements," requires that buildings be "designed and constructed to resist the wind effects determined in accordance with the requirements of this section," this section being Section 2311, which deals with wind design. However, an exception is granted earlier in the Code, in Section 2303, "Design Methods," which states "Unless otherwise required by the building official, buildings or portions thereof which are constructed in accordance with the conventional framing requirements specified in Chapter 25 of this code shall be deemed to meet the requirements of this section." Chapter 25 of the 1985

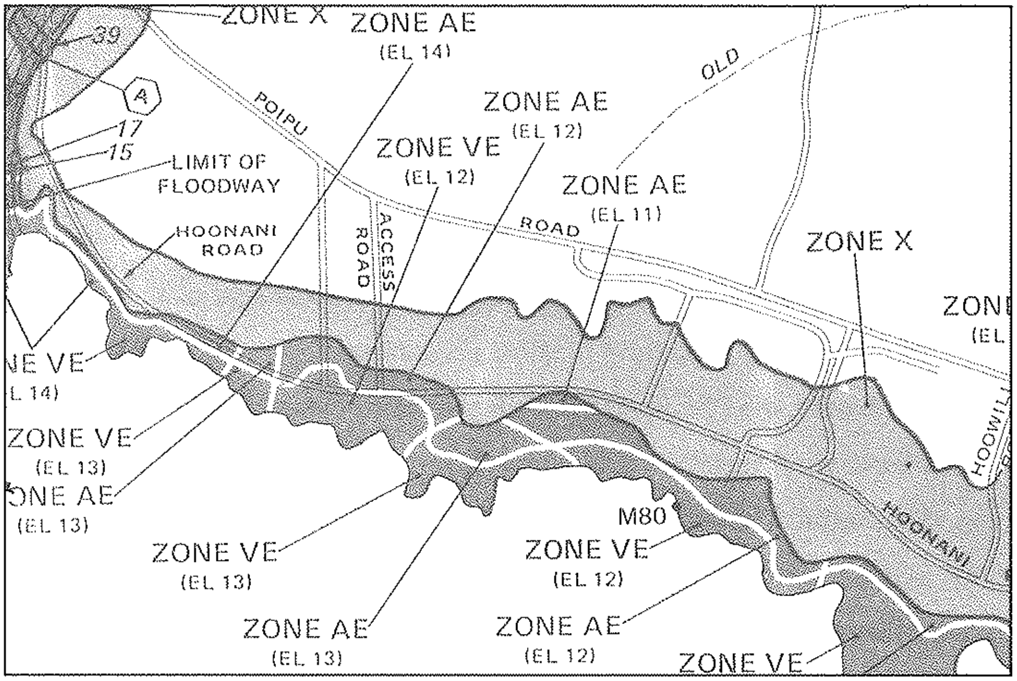


FIGURE 3. *Portion of Flood Insurance Rate Map (FIRM) for Kauai County covering the Poipu Beach area. Note predicted 100-year flood heights of 12 to 14 feet above mean sea level.*

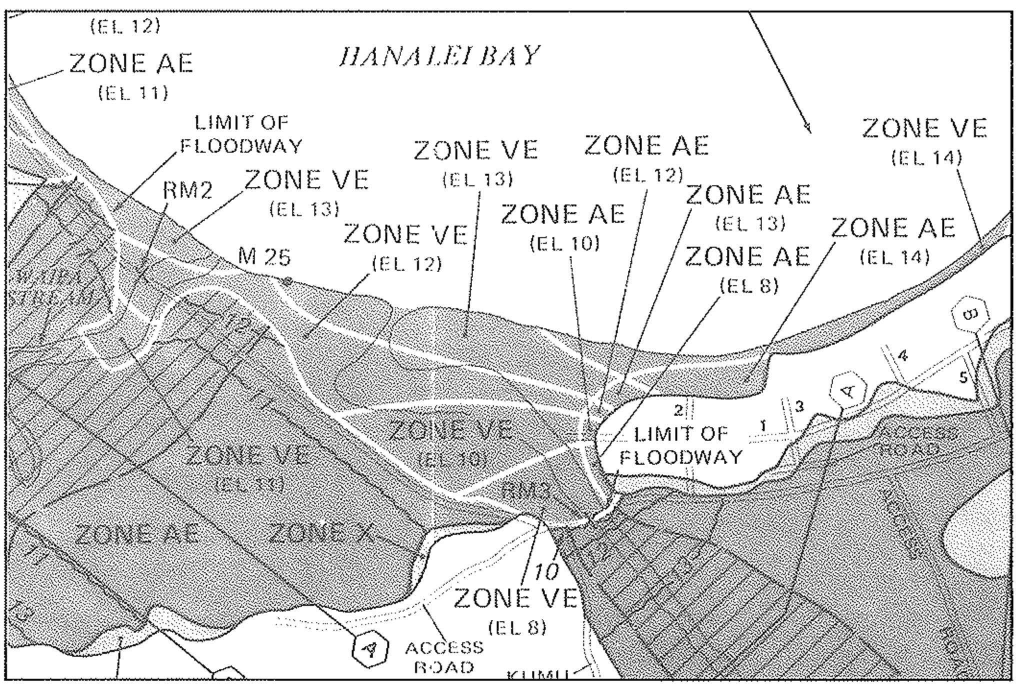


FIGURE 4. *Various flood hazard zones, including velocity (V) Coastal High Hazard zones, on the Kauai County FIRM (Hanalei example).*

UBC contains provisions which implicitly address the quality and design of wood members and their fastenings.

On December 7, 1992, Kauai County adopted Appendix Section 2518 of Chapter 25 of the 1991 UBC, which specifically addresses design and construction of light-frame timber buildings in high-wind areas. Appendix Section 2518 applies to regular-shaped buildings which have roof structural members spanning 32 feet or less, are not more than three stories in height, are of conventional light-frame construction, and are located in areas with a basic wind speed from 80 through 110 miles per hour. This appendix addresses shortcomings in design and construction practices due to reliance on implicit provisions in the 1985 UBC. Appendix Section 2518 of the 1991 UBC is very explicit in its requirements and contains graphical presentations not contained in older versions of the Code. Compliance with Appendix Section 2518 will help reduce wind-related damages in the future, and the County is to be commended for this prudent action.