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Arthur N. L. Chiu; Luis E. Escalante; J. Kenneth Mitchell; Dale C. Perry; Thomas A. Schroeder; Todd Walton; Committee on Natural Disasters; Commission on Engineering and Technical Systems; National Research Council

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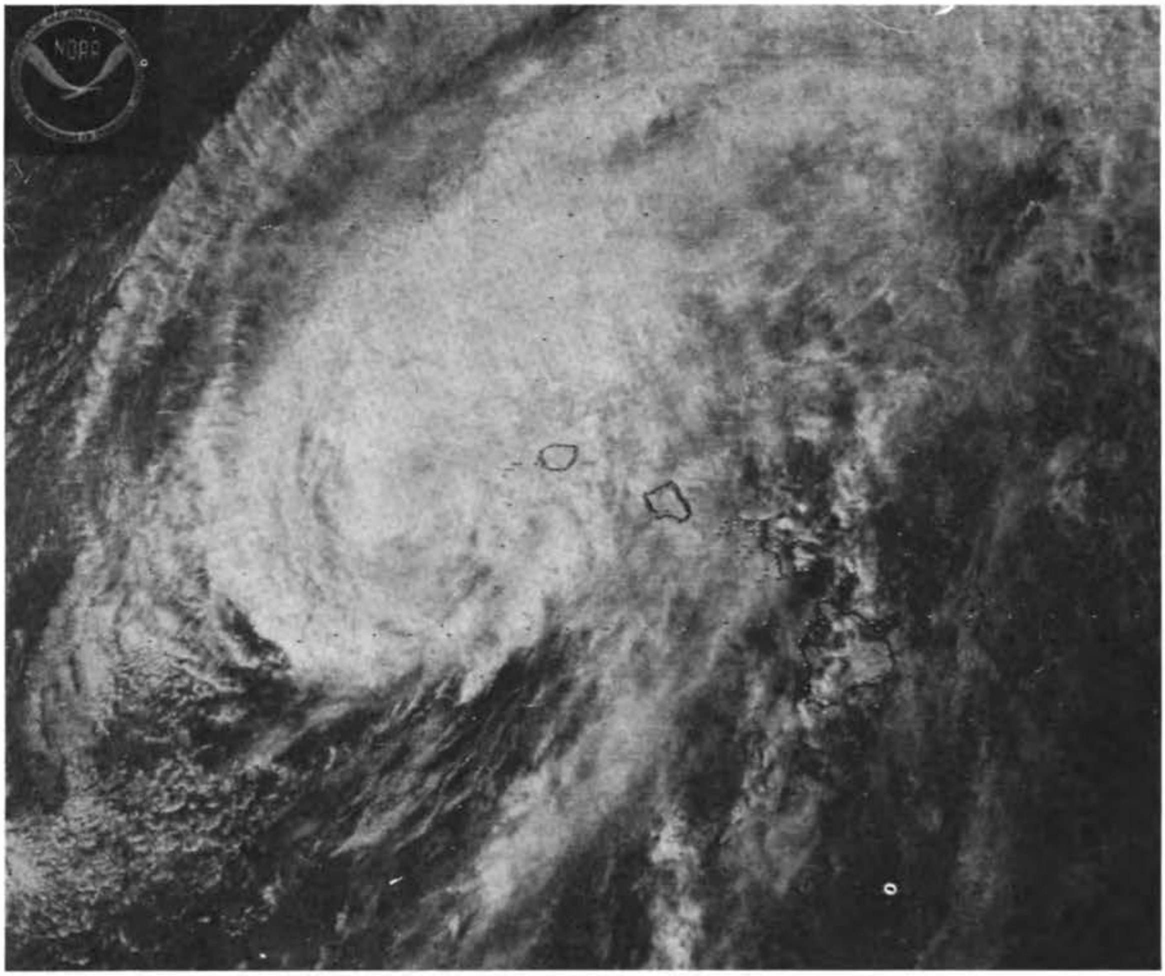

Satellite photograph taken at 2:15 p.m. on November 23, 1982. Hurricane Iwa is in the vicinity of Kauai, which is shown outlined in black (see Figure 1.1).

Hurricane Iwa, Hawaii, November 23, 1982

Prepared by

Arthur N. L. Chiu (Team Leader), Professor of Civil Engineering, University of Hawaii at Manoa

Luis E. Escalante, Senior Power Engineer, Los Angeles Department of Water and Power

J. Kenneth Mitchell, Professor of Geography, Rutgers University

Dale C. Perry, Professor of Civil Engineering, University of Idaho

Thomas A. Schroeder, Assistant Professor of Meteorology, University of Hawaii at Manoa

Todd Walton, Research Hydraulic Engineer, U.S. Army Coastal Engineering Research Center

Committee on Natural Disasters
Commission on Engineering and Technical Systems
National Research Council

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INTRODUCTION AND OVERVIEW

Hurricane Iwa was the most costly storm ever to strike Hawaii, although it was not the most severe. Damage varied from the superficial to complete destruction of homes, buildings, and structures on Kauai, Oahu, and Niihau. No major damage was reported for Maui, Hawaii, Molokai, and Lanai. Figure 1.1 shows the track of the storm; the peak of the storm's fury occurred on November 23, 1982. The study team surveyed the damage on Kauai on December 2-3 and on Oahu on December 4.

METEOROLOGY

In an average year, three storms of tropical storm intensity (wind speeds exceeding 39 mph) or hurricane intensity (wind speeds exceeding 75 mph) either form in or propagate into the central North Pacific (Shaw, 1981). This region is defined by the National Weather Service as being bounded by 140°W longitude, 180°W longitude, and the equator. The Weather Service Forecast Office in Honolulu serves as the Central Pacific Hurricane Center.

The year 1982 was the most active for the formation of tropical storms in the central North Pacific during the satellite era (since April 1960), as four named storms formed west of 150°W. Although the primary season for tropical storms is July through October, in anomalous years storms form as late as November. Two of Hawaii's three most severe hurricanes were November storms--Nina (1957) and Iwa (1982). Iwa was the second hurricane in the postwar era to hit Hawaii directly; the other storm, Hurricane Dot, passed directly over Kauai in August 1959.

DAMAGE TO PROPERTY

Major damage occurred on Kauai at Poipu and Princeville (Figure 1.2). On Oahu damage was less severe, although extensive damage to structures and buildings occurred at Makaha, Schofield Barracks, and Kaneohe (Figure 1.3). Other locations shown on both figures also sustained damage. These areas, and specific locations in Poipu, Lihue, and Princeville, which are shown in Figures 1.4, 1.5, and 1.6, respectively, are discussed in following chapters.

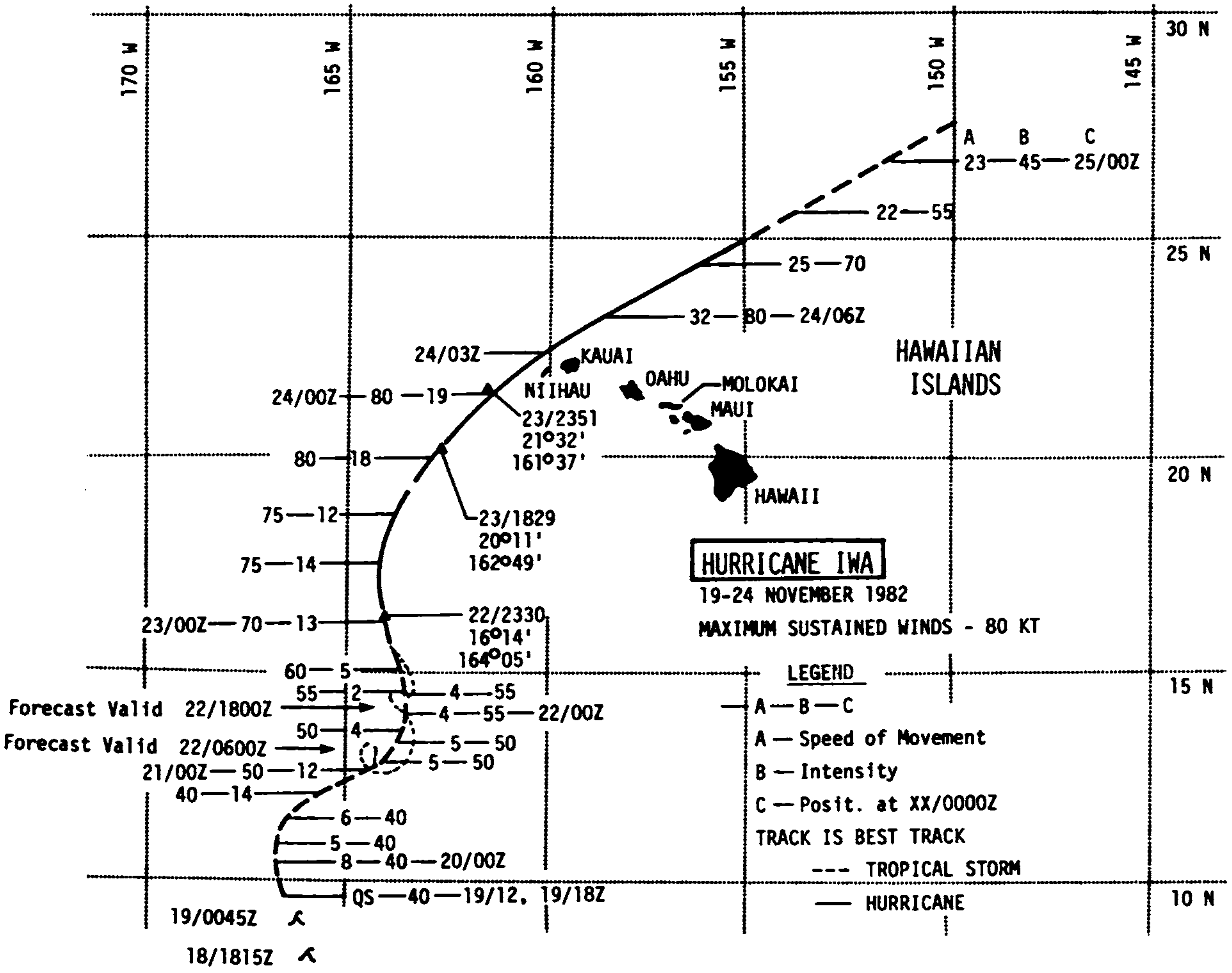

FIGURE 1.1 Track of Hurricane Iwa.

With regard to the direct impact on the residents of Hawaii, the Federal Emergency Management Agency (FEMA) has estimated the damage to single- and multiple-family dwellings shown in Table 1.1. As seen in the table, property damage was much greater than that inflicted by Hurricane Dot, which struck the islands in 1959 and caused property damage slightly in excess of $5.7 million (principally on the island of Kauai).

LIFELINE FACILITIES

The effect of Hurricane Iwa on lifelines was generally severe. Electric power systems sustained severe damage to overhead transmission and distribution lines, which caused the interruption of power delivery to

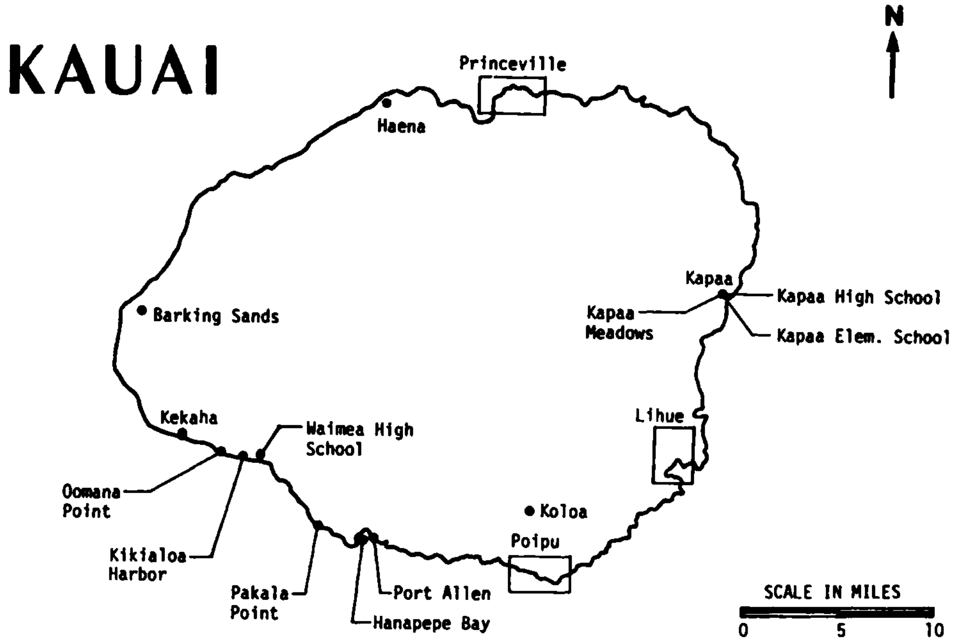

FIGURE 1.2 Locations on Kauai.

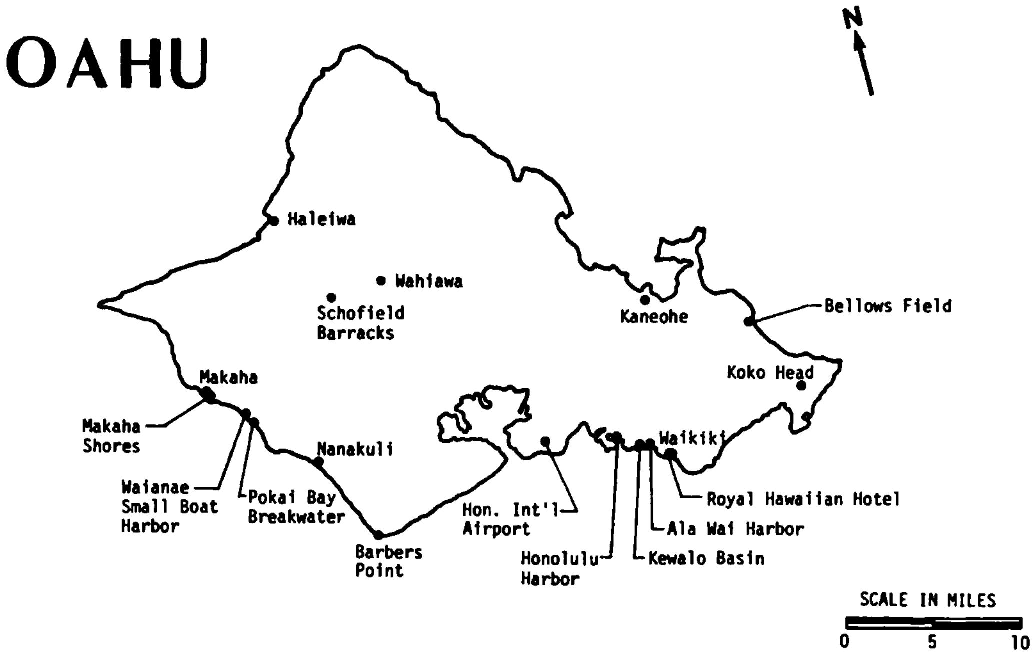

FIGURE 1.3 Locations on Oahu.

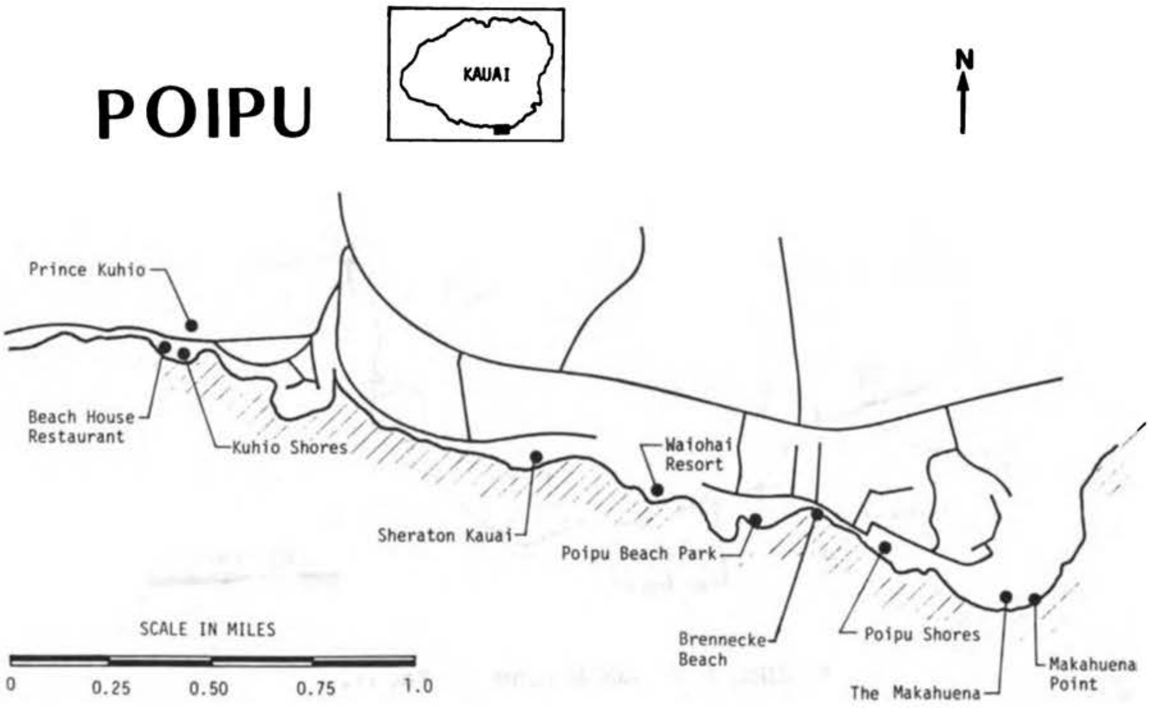

FIGURE 1.4 Locations in Poipu.

industrial, commercial, and residential consumers. Fortunately, power generating plants and transmission and distribution substations were not significantly damaged; restoration of the overhead power lines returned power operations to normal.

Communication systems also sustained severe damage, particularly to overhead telephone cables supported jointly with power lines on wooden poles. Also damaged were microwave antenna towers and some commercial radio antennas. The loss of electric power caused the loss or limited the operation of telephone and radio facilities.

Transportation was affected chiefly by the blockage of roads by surging ocean waves (flooding), fallen power and telephone poles, rocks and sand, and other water- and wind-driven debris. Some sections of coastal roads were destroyed, but, in general, roads away from the coastline sustained little actual damage.

Other lifelines were affected mostly by the loss of electric power and resumed their normal function when power was restored.

ECONOMIC AND SOCIAL COSTS

Iwa was neither a major hurricane nor a disaster that caused numerous deaths. Only one death and a small number of serious injuries were reported. In contrast, the storm produced Hawaii's costliest natural disaster. Overall, the Federal Emergency Management Agency estimated a

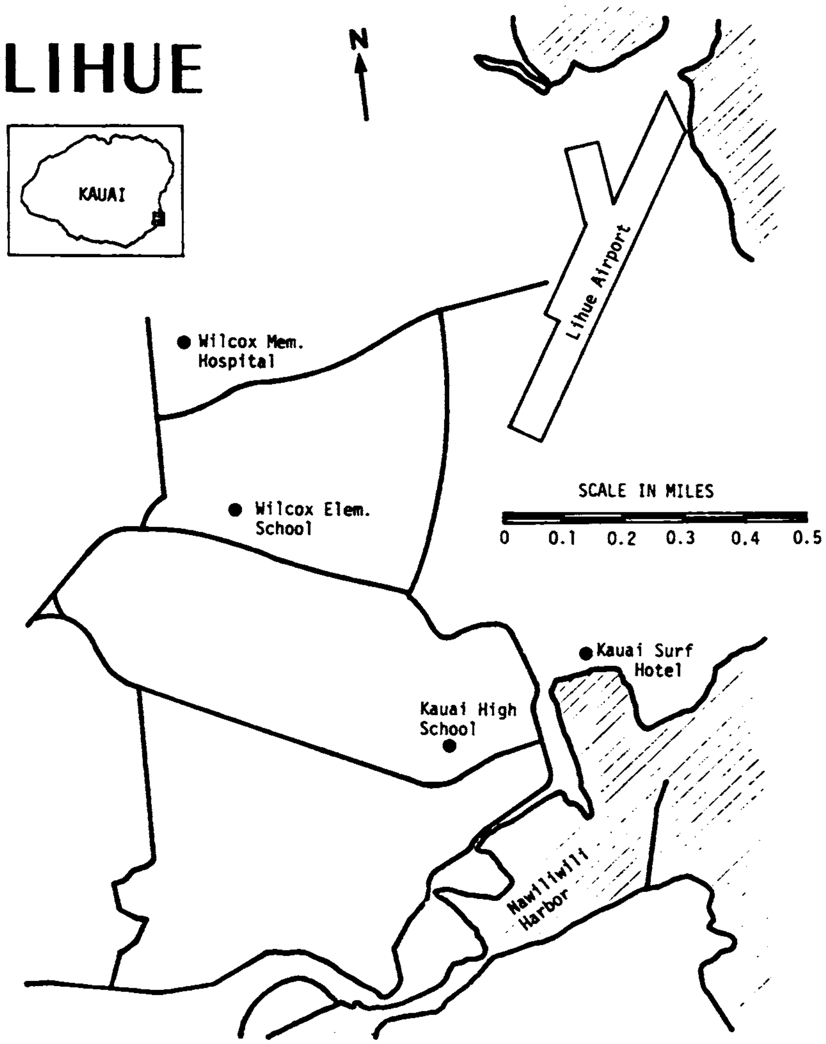

FIGURE 1.5 Locations in Lihue.

loss of $203 million in property damage and other economic losses (Table 1.2). Later assessments released on January 28, 1983, by an ad hoc committee established by Governor George R. Ariyoshi concluded that $234 million of property damage was sustained, with the possibility that further losses in excess of $60 million could occur if Kauai's tourist industry remained depressed for a year after the disaster. The committee also claimed that net economic losses will be more than offset by private insurance repayments, federal disaster assistance aid, increased economic activity, and taxes generated by reconstruction. Losses were expected to be borne disproportionately by a relatively few uninsured residents of impacted areas, whereas benefits will be widely shared throughout the state.

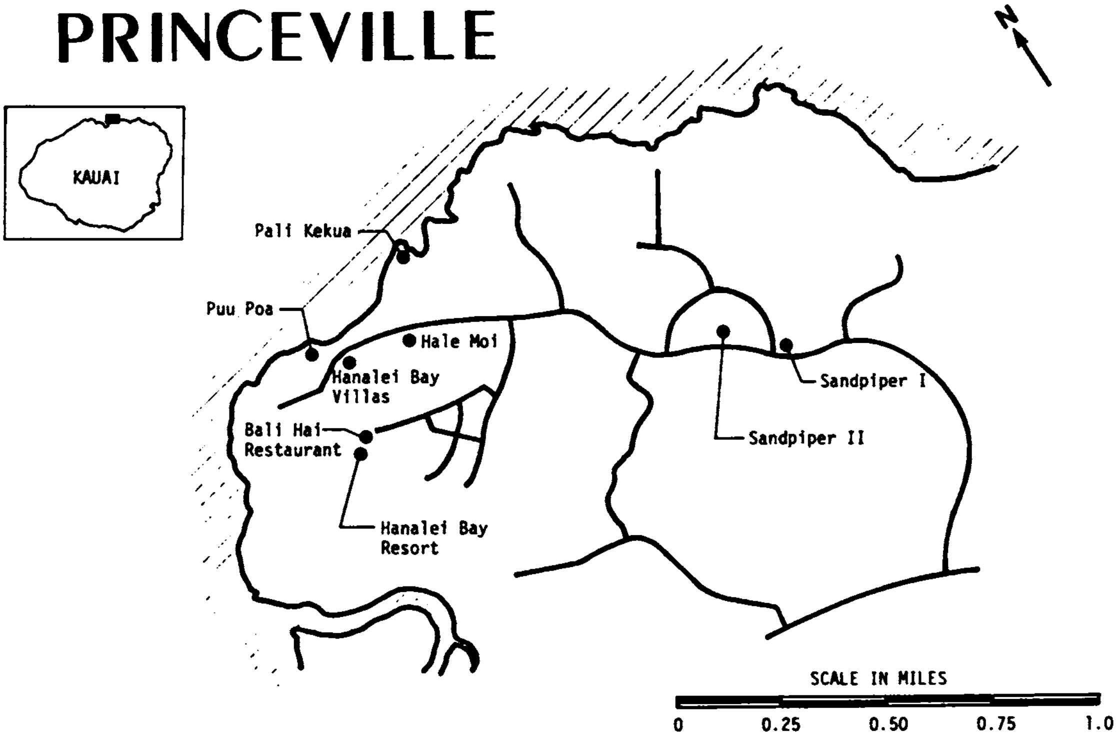

FIGURE 1.6 Locations in Princeville.

TABLE 1.1 Estimated Damage to Single- and Multiple-Family Dwellings

Homes	Kauai	Oahu	Totals
Destroyed	339	126	465
Major damage	327	437	764
Minor damage	1,278	670	1,948
Total number of homes	1,944	1,233	3,177
Value of damage (millions of dollars)	41	27	68

Source: Federal Emergency Management Agency (1982).

TABLE 1.2 Summary Damage Estimates

	Damage (millions of dollars)
Public property	
State and local property	24.3
School buildings	3.6
Highways	2.0
Corps of Engineers (PL 84-99)	2.0
U.S. Army	30.0
Total	61.9
Private property	
Housing	68.0
Business	51.5
Agriculture and crops	21.5
Total	141.0
Total property damage	202.9

Source: Federal Emergency Management Agency (1982).

SOCIETAL ASPECTS

The societal consequences of Hurricane Iwa varied among the three impacted islands. Little is known about Niihau--a 70-square-mile privately owned island cattle ranch noted for its youthful, low-income, ethnic Hawaiian population, its lack of modern infrastructure, and its rigid policy of excluding visitors.* Neither the owners nor the residents have released any public information about responses to the hurricane warning or the existence and adequacy of safety measures taken during the storm. Aerial observation by State Civil Defense officials indicated that several wooden houses were destroyed or severely damaged. No on-site damage inspection was made by external observers, but a limited quantity of C-rations were provided to the islanders by Kauai officials.

The keys to understanding Iwa's impact on Kauai are its vulnerable development patterns, the appropriateness of its coastal flood hazard

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*According to the 1980 U.S. Census of Population, the median age on Niihau is 20.2 years, the median household income is $4,922, and 95 percent of Niihau's 226 residents are descendants of Hawaii's original population.

designations, and its socially diverse population. Although impacts of the storm were evident throughout the mountainous interior of this 549-square-mile island, most of the significant damage was confined to a two- or three-mile-wide coastal fringe. This contains Kauai's 38,856 permanent inhabitants; 5,207 resort hotel units; sugar cane plantations; and a narrow, easily disrupted chain of encircling highways, utility lines, and associated infrastructure. Shorefront resorts on the south coast and private homes throughout the coastal fringe bore the brunt of the damage. One in eight homes and 55 to 60 percent of the hotel units were destroyed or damaged, and normal community services were crippled for one to two weeks after the storm by loss of electric power. Many of the south shorefront properties damaged by flooding were located outside tsunami run-up zones that guided the designation of coastal flood hazard areas regulated under the National Flood Insurance Program.

During the two weeks following Iwa, incoming relief workers on Kauai confronted the problems of working among a population that commonly spoke several languages, exhibited complex ethnic and religious allegiances, and displayed some reluctance to accept assistance lest it be perceived as acquiescing to "welfare".* Only gradually did relief officials come to realize the need for special action to publicize and target available services. Rehabilitation and recovery efforts were begun quickly on Kauai without the benefit of a postdisaster recovery plan, and they were speeded by public officials willing to approve temporary suspension of normally required building permits and public hearings and the recommendations of the U.S. Interagency Flood Hazard Mitigation Team against a general moratorium on reconstruction in flood hazard areas.

Although nine out of ten Oahu residents experienced at least short-term electric outages, the direct effects of the storm were confined to approximately 20 percent (150,000) of the island's total population near the west, south, and east coasts and in the interior Schofield Barracks-Wahiawa district. Many of these people expressed concerns about the limited scope of public storm warnings and evacuations. Thirty thousand mostly low-income ethnic Hawaiians and Samoans on the leeward (west) coast suffered disproportionate flood and wind damage to homes and protracted loss of electric power. Here, looting, price gouging, inadequate insurance coverage, persistent and widespread demands for relief funds, and damage to squatter settlements posed particular problems for emergency services personnel and disaster aid officials.

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*Languages spoken on Kauai include, among others, English, Pidgin English variants, Japanese, Tagalog, and Hawaiian. The population is evenly divided among Caucasians (28.5 percent), Filipinos (26.2 percent), and Japanese (25.0 percent), with a 15 percent Hawaiian minority and small numbers of many other groups. Buddhists, Catholics, Protestants, Shintoists, and other religious groups are well represented.

2

METEOROLOGICAL AND HYDROLOGICAL ASPECTS

STORM TRACK AND INTENSITY

Hurricane Iwa developed from a depression first observed by satellite on the morning of November 18, 1982, at 8°N latitude, 166°W longitude (Figure 1.1). Iwa attained tropical storm intensity (sustained winds in excess of 34 knots or 39 mph) at 2:00 a.m. Hawaii Standard Time on November 19; for the next three days the system drifted northward. The National Weather Service Central Pacific Hurricane Center in Honolulu requested that the Air Force reconnoiter the storm on November 22. Based on aircraft data, Iwa was upgraded to hurricane status (sustained winds greater than 65 knots or 75 mph) at 5:00 p.m. on November 22.

At that time the storm was accelerating and moving toward the Hawaiian Islands. Iwa's track as it approached was nearly perpendicular to all historical tropical storm tracks for Hawaii (Shaw, 1981). A hurricane watch was issued for the islands of Kauai, Niihau, and Oahu at 11:00 p.m. on November 22; at 8:00 a.m. on November 23 the watch was upgraded to a warning for Kauai and Niihau. The 8:00 a.m. aircraft reconnaissance placed the storm 180 nautical miles (207 statute miles) southwest of Niihau and moving northeast at 18 knots (21 mph). Sustained winds were estimated at 80 knots (92 mph) with gusts to 110 knots (126 mph). The storm accelerated as it passed to the northwest of Kauai, attaining a translational speed of 32 knots (37 mph) by 8:00 p.m. on November 23. By that time most of the effects of the hurricane were over for Hawaii. The remnant of Iwa drifted northeast across the Pacific and eventually brought some rains to northern California.

METEOROLOGICAL EFFECTS ON THE ISLANDS

Rainfall

Very little rain fell during the passage of Iwa. Although the storm disrupted daily rainfall sampling at sugar plantations on Kauai and Oahu, the accumulated totals, once the gages were read, were less than 3 in. The low rainfall amounts could be due to:

1. The rapid passage of the storm;

2. The relatively low development of clouds over the islands (only one station on Oahu or Kauai reported any thunder);
3. The limited effect of small islands on the storm circulation.

Typically, heavy hurricane rains occur upon landfall over large coastlines or over large islands (e.g., Japan).

Winds

Kauai, Niihau, and Oahu lay in the right-front sector of Iwa relative to the storm track. This sector contains the highest winds and seas in the hurricane. Winds were greatly influenced by island topography. According to eyewitness accounts, some of the strongest winds on Kauai occurred to the lee of Mount Waialeale at Princeville and at Nawiliwili Harbor, which is sheltered in part by the Hoary Head Range (Figure 2.1). The peak-wind reports from stations on Kauai and Oahu are listed in Table 2.1.

Wind data were collected from known sources. Anemometer heights varied from 12 to 37 ft, and wind speeds were adjusted to a common 30-ft height by use of a 1/3 power law. The use of this exponent is based on experimental data and reports (Wu and Chiu, 1983; Chiu and Nakamoto, 1981; Smith and Singer, 1960). Where only gust data were available, sustained winds were estimated by use of sustained speed/peak gust relations for other appropriately exposed sites. The range of peak gust to sustained speed ratios is 1.5 to 1.8, somewhat higher than normally stated (Simpson and Riehl, 1981) but similar to those observed in Hong Kong, where the topography resembles that of Hawaii (C. S. Ramage, 1982). The 6-minute data at Opana, Oahu, were converted to gusts by use of the relation developed by Durst (1960). Makahuena Point, Kilauea Point, and Bellows Field have local exposure problems that limit the applicability of their data.

On Oahu the principal wind damage occurred to the lee of the Waianae Range at Schofield Barracks and to the lee of the Koolau Range at Kaneohe (Figure 2.2). These are the same areas that were damaged by winter storms in January 1970 (Schroeder, 1977) and January 1980 (Haraguchi, 1980). In each storm, winds accelerated to the lee of the mountains, similar to the chinook wind in Boulder, Colorado.

On Oahu most of the peak winds occurred between 6:20 p.m. and 7:00 p.m. as a squall line passed over the island. This squall knocked out the Hawaiian Electric transmission lines in Waimalu Gulch, triggering the massive power outage that plagued Honolulu through November 27.

There was not a single case of sustained hurricane-force winds on either Oahu or Kauai. It is probable that in higher elevations, as well as in regions influenced by local topography, winds exceeded those reported by the observation networks. Population centers lie at lower elevations and in most instances would not have been exposed to sustained 75-mph winds.

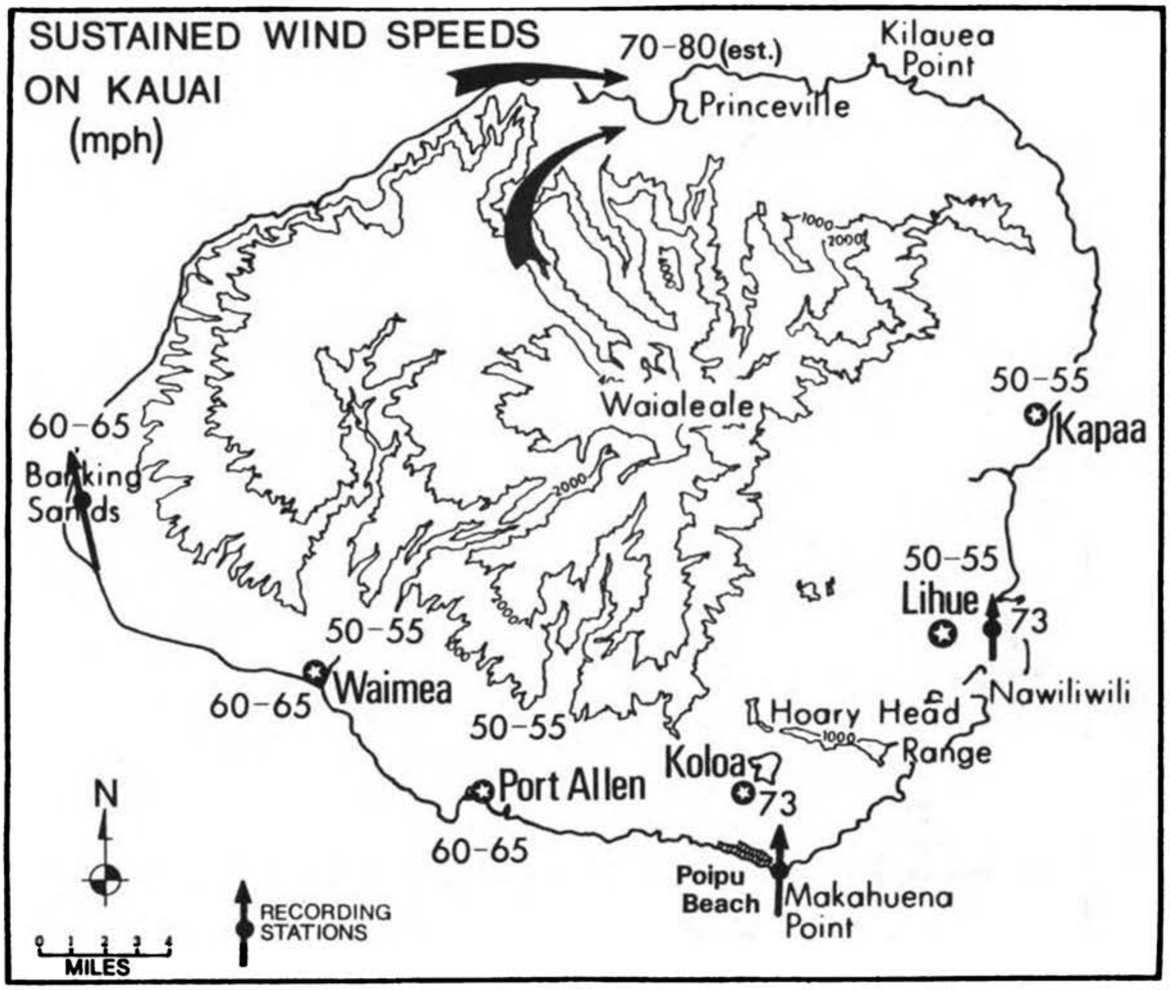

FIGURE 2.1 Wind velocity data (mph) at selected points, Kauai.

Eye of the Storm

Eyewitnesses reported that the eye of the hurricane passed over part of Kauai. Their belief was based on a lightening of the winds, a directional shift in the wind, and some clearing of the skies. Pressure and wind traces at Barking Sands suggest that a pressure trough passed over the site. Satellite imagery and Air Force aircraft indicate that the eye of Iwa was diffuse and possibly breaking up during its passage northwest of Kauai. Reported wind shifts can be explained adequately by topographic effects due to Mount Waialeale and the normal veering of the winds as the storm passed by to the north of Kauai. This report accepts the National Weather Service best track (Figure 1.1).

TABLE 2.1 Observed and Derived Wind Characteristics

Station	Anemometer Height (ft)	Sustained Speed (mph)	Peak Gust (mph)	Direction (degrees)	Duration of Winds Greater than 40 mph (hrs)	Duration of Winds Greater than 50 mph (hrs)	Observer
Lihue Airport, Kauai	20	73 (64)	91 (85)	180	6	5	National Weather Service
Kilauea Point, Kauai	20	50 (E)	73 (68)	180 (E)	--	--	National Weather Service
Makahuena Point, Kauai	20	71 (E)	126 (117)	180 (E)	--	--	National Weather Service
Barking Sands, Kauai	14	62 (E)	111 (93)	150	7	2, 2[a]	Pacific Missile Range
Honolulu Airport, Oahu	25	49 (46)	84 (81)	200	3.5	Less than 1	National Weather Service
Barbers Point Naval Air Station, Oahu	12	58 (43)	98 (78)	210	--	--	U.S. Navy
Wheeler Air Force Base, Oahu	16	64 (52)	89 (78)	210 (E)	6	1.5	U.S. Air Force
Kaneohe Marine Corps Air Station, Oahu	13	69 (52)	112 (92)	215	7	1.5	U.S. Marine Corps
Bellows Air Force Base, Oahu	20	53 (E)	82 (76)	180	--	--	National Weather Service
Opana, Oahu	37	50[b] (54)	55 (E)	250	3	Less than 1	University of Hawaii

Note: This table gives the sustained and peak gust wind speeds in miles per hour for wind sites in Oahu and Kauai. All speeds, other than those in parentheses, are adjusted to an elevation of 30 ft above ground level. E indicates estimated value.

[a] Two distinct periods.

[b] Six-minute average.

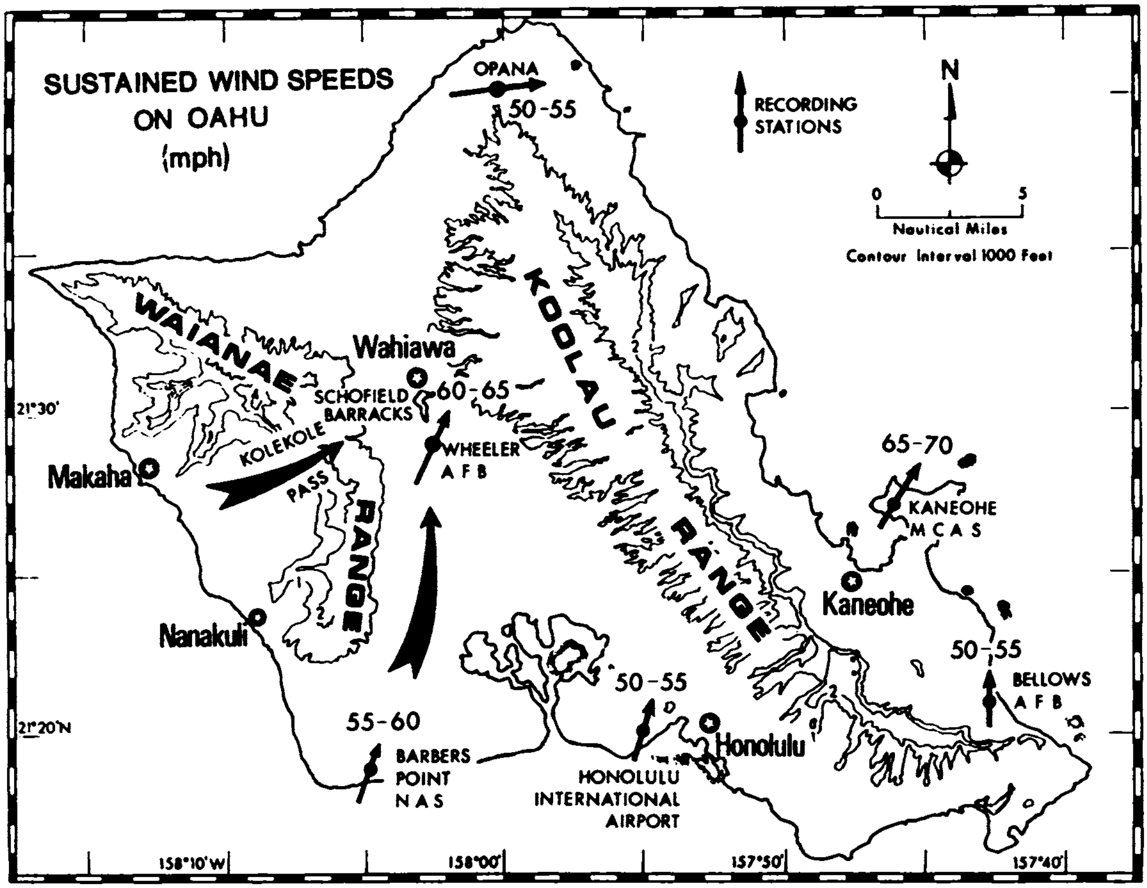

FIGURE 2.2 Wind velocity data (mph) at selected points, Oahu.

COMPARISON WITH OTHER EXTREME WIND EVENTS

Iwa's winds were compared with data for past storms at several sites on Oahu and Kauai. The record sustained wind at Lihue, caused by Hurricane Dot in August 1959, was equaled by the 73-mph peak during Iwa. At Kilauea Point both Hurricane Dot (1959) and Hurricane Nina (1957) produced gusts in excess of those for Iwa--87 mph and 96 mph, respectively.

At Honolulu International Airport the record sustained wind is 55 mph (reduced from 67 mph at 93 ft) during a winter storm. Winds ahead of a cold front gusted to 117 mph at Kaneohe Marine Corps Air Station on January 14-15, 1970. For each location Iwa's winds approach but do not exceed the records.

The only published recurrence interval for any wind on Oahu or Kauai is found in ANSI A58.1-1982; the value is 80 mph with a 50-year recurrence interval. Again, Iwa did not exceed this value.

In terms of wind speeds, it must be concluded that Iwa was not a record storm.

LOSS OF METEOROLOGICAL INFORMATION

The failure of electric power stations on Kauai and Oahu significantly affected the operations of the National Weather Service and the National Earth Satellite Service (NESS). At 3:45 p.m. on November 23, winds at Kokee, Kauai, toppled a crucial microwave link that relayed satellite imagery to the NESS facility at Honolulu International Airport. The National Weather Service was essentially blinded; Hawaii is the only hurricane-prone section of the United States that has no weather radar support. The loss of satellite data caused the Central Pacific Hurricane Center to relinquish its forecast responsibilities to the East Pacific Hurricane Center at Redwood City, California. This situation lasted for approximately nine hours, beginning at 5:00 p.m. on November 23.

The National Weather Service maintains three remote sites on Kauai and two on Oahu with wind-recording capability. These systems are powered by solar panels and functioned throughout the storm, but their data is telemetered through telephone lines that ceased to function on both islands when the electricity system failed. The recorders continued to write over existing data stored in their limited memories, eliminating much valuable wind data. The only information that could be retrieved was the peak wind gust, which is stored on a special memory card and is valid until recalled from memory or exceeded by a later gust.

Weather service and military weather offices were able to continue their routine recording operations throughout the period. Unfortunately, these stations are not always in the most representative sites. A University of Hawaii instrument at Opana, Oahu, benefited from the independent power supply at an adjacent Navy tracking station.

WATER WAVE DATA

The National Oceanic and Atmospheric Administration (NOAA) has a deep ocean data buoy located in the vicinity of 23.4°N latitude, 162.5°W longitude that collects real-time meteorological and wave data. Unfortunately, the data buoy was not operational during the period of Hurricane Iwa due to power problems; therefore the buoy collected no data. It should be noted that the power failure was not due to Iwa.

The Corps of Engineers operates a wave data network on the west coast of the United States and in Hawaii that consists predominantly of Waverider data buoys, which provide a real-time record of surface elevations via transformed buoy accelerations every six hours. The surface record is of 17-minute duration; from this various wave paramemters can be estimated--significant wave height, significant wave period, wave spectral energy.* Two wave gages of this type are in

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*The significant wave height is calculated by statistical methods from the wave spectrum and has been found to be nearly equal to the average height of the highest one third of the waves; this corresponds closely to the wave height reported by an experienced wave observer.

Hawaii: the Barking Sands gage on Kauai and the Makapuu gage on Oahu. Unfortunately, the Barking Sands gage was having operational problems prior to Hurricane Iwa and was not operational during the storm. The Makapuu Point buoy functioned during a portion of the storm but is in an area sheltered from the worst wave action from Iwa. The data of 2:00 p.m. on November 23, after which the gage no longer operated, do show a significant increase in wave height and a shortening of wave period, which is expected from hurricane-generated waves superimposed on swell waves from a distant source. However, the Makapuu gage is more exposed to northerly swells than it was to the waves from Iwa.

TIDE GAGE DATA

A tide gage operated by the University of Hawaii (courtesty of K. Wyrtki) in Kewalo Basin, which is adjacent to Honolulu Harbor, was operational throughout the storm. Figures 2.3 and 2.4 provide data from this analog recording gage, showing the actual analog recording and the recording minus the predicted (astronomical) tide, respectively, for this location. The highest water level occurred shortly after 6:00 p.m. on November 23; the peak of the storm surge (the observed minus the predicted height) was approximately 1 m at this location.

The predicted tide at the time of the highest surge had just passed through its trough and was beginning to rise. Had the peak of the storm surge been coincident with the astronomical high tide, the peak water level would have been approximately 0.5 m higher. Because the tide records filter out the higher-frequency wind wave action, the true high-water level (the wind wave level plus the storm surge) is unknown.

Tide gages operated by NOAA also collected tidal water levels during the period of Hurricane Iwa: one gage was located in Honolulu Harbor on Oahu, and another gage was located in Nawiliwili Harbor on Kauai. The observed and predicted tides for these locations during the period November 22 through November 25 are shown in Figures 2.5 and 2.6. Figure 2.5 provides an observed value of peak surge height equal to approximately 0.65 m, somewhat less than the University of Hawaii gage. The NOAA gage in Honolulu Harbor and the University of Hawaii gage in Kewalo Basin are very close, and the reason for the discrepancy in surge heights between these two gages is unknown.

The NOAA gage at Nawiliwili (data shown in Figure 2.6) provides an observed value of storm surge at Nawiliwili Harbor of 0.4 m. Nawiliwili is on the sheltered east side of Kauai, which explains in part the low observed value of storm surge in this location. It should be noted that the peak of the storm surge in this particular location occurred shortly after 4:00 p.m. on November 23 at a time of low astronomical tide. Had the peak of the storm coincided with high tide, the actual water level would have been over 0.4 m higher.

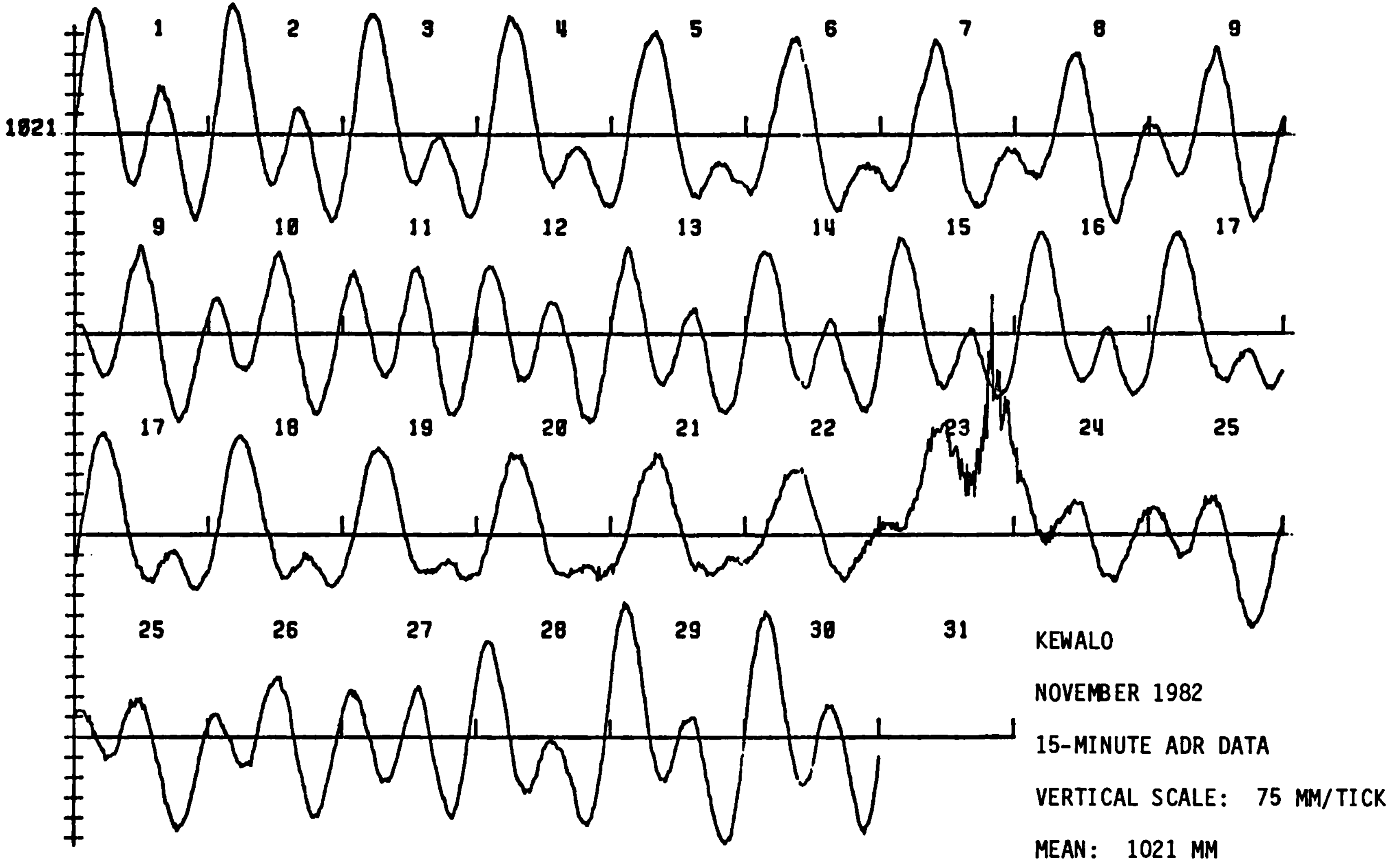

FIGURE 2.3 Kewalo Basin tide gage data (observed tide) for November 1982. Source: Klaus Wyrtki, Department of Oceanography, University of Hawaii at Manoa.

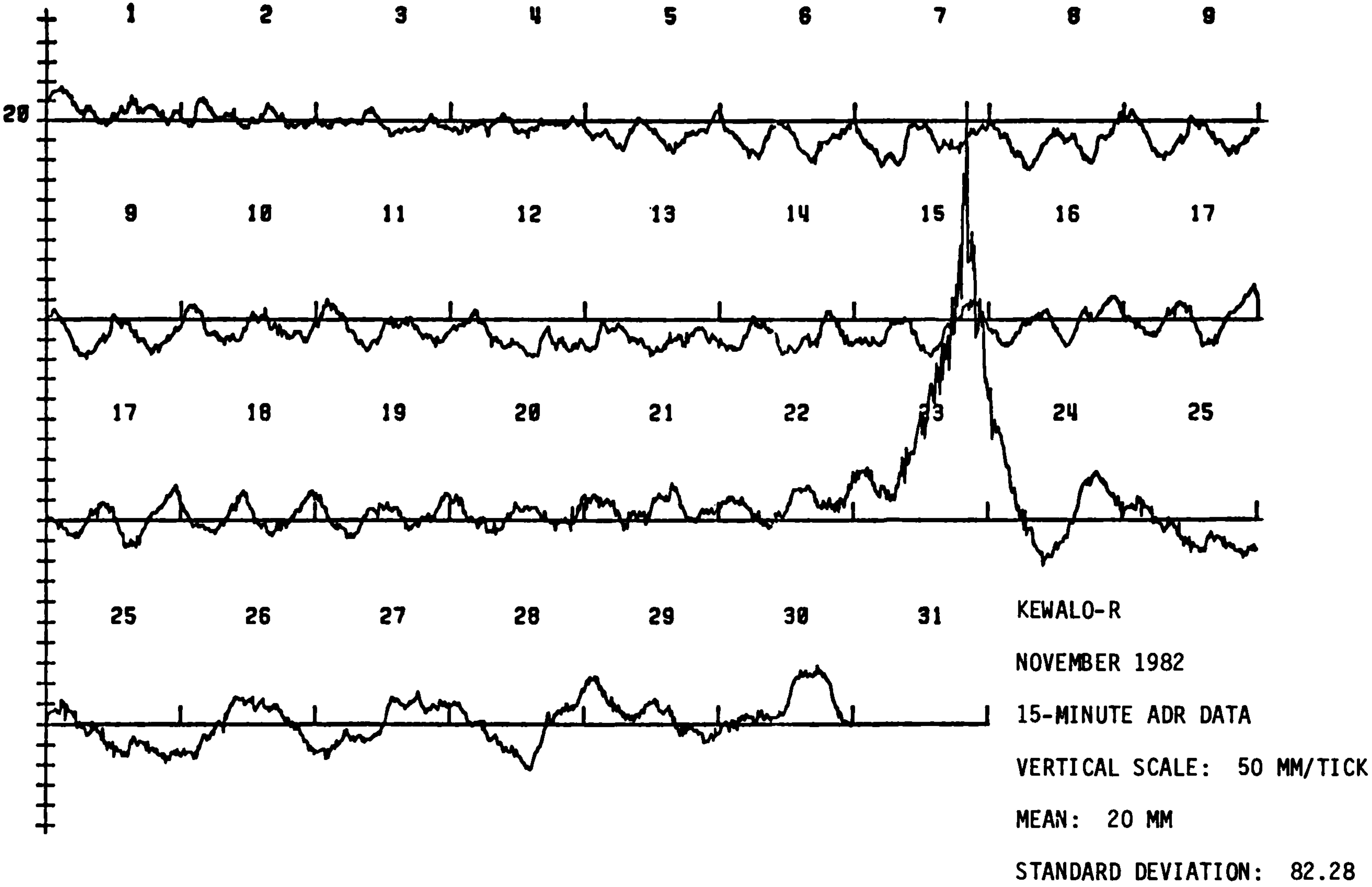

FIGURE 2.4 Kewalo Basin tide gage data (observed minus predicted tide) for November 1982. Source: Klaus Wyrtki, Department of Oceanography, University of Hawaii at Manoa.

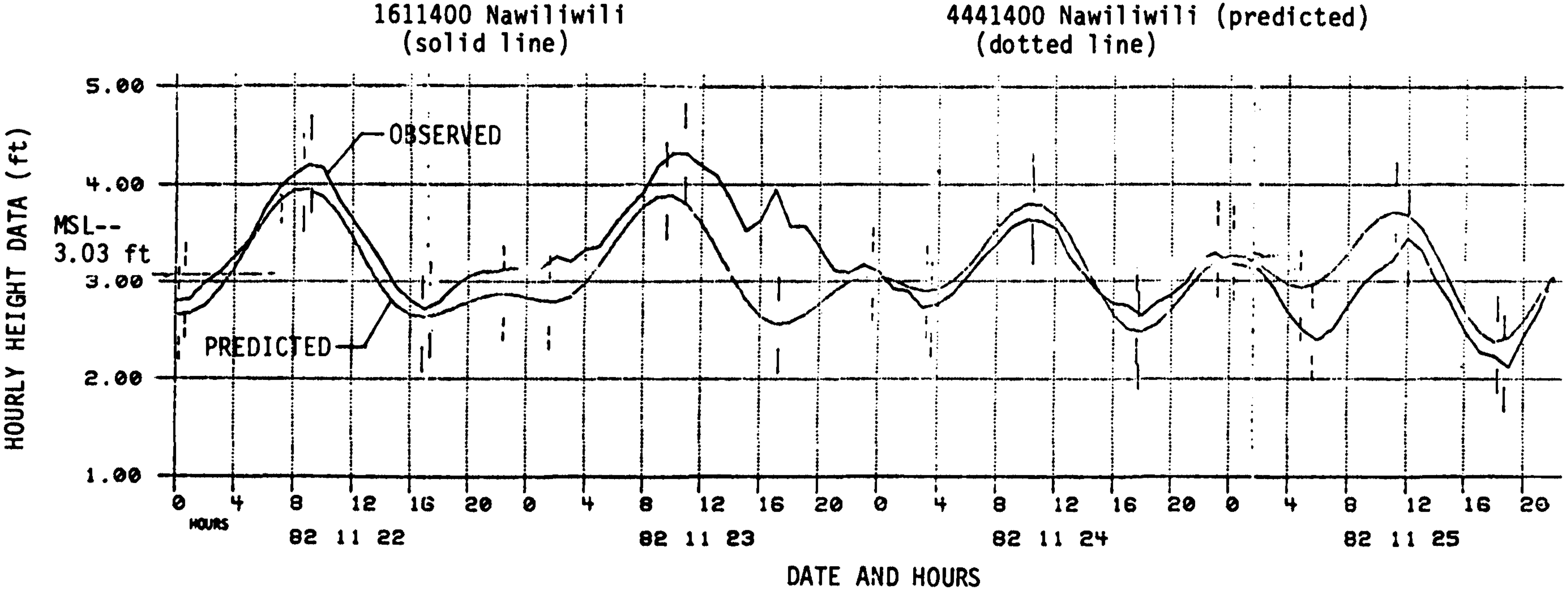

FIGURE 2.5 NOAA tide gage, Honolulu, Hawaii (observed and predicted tide).

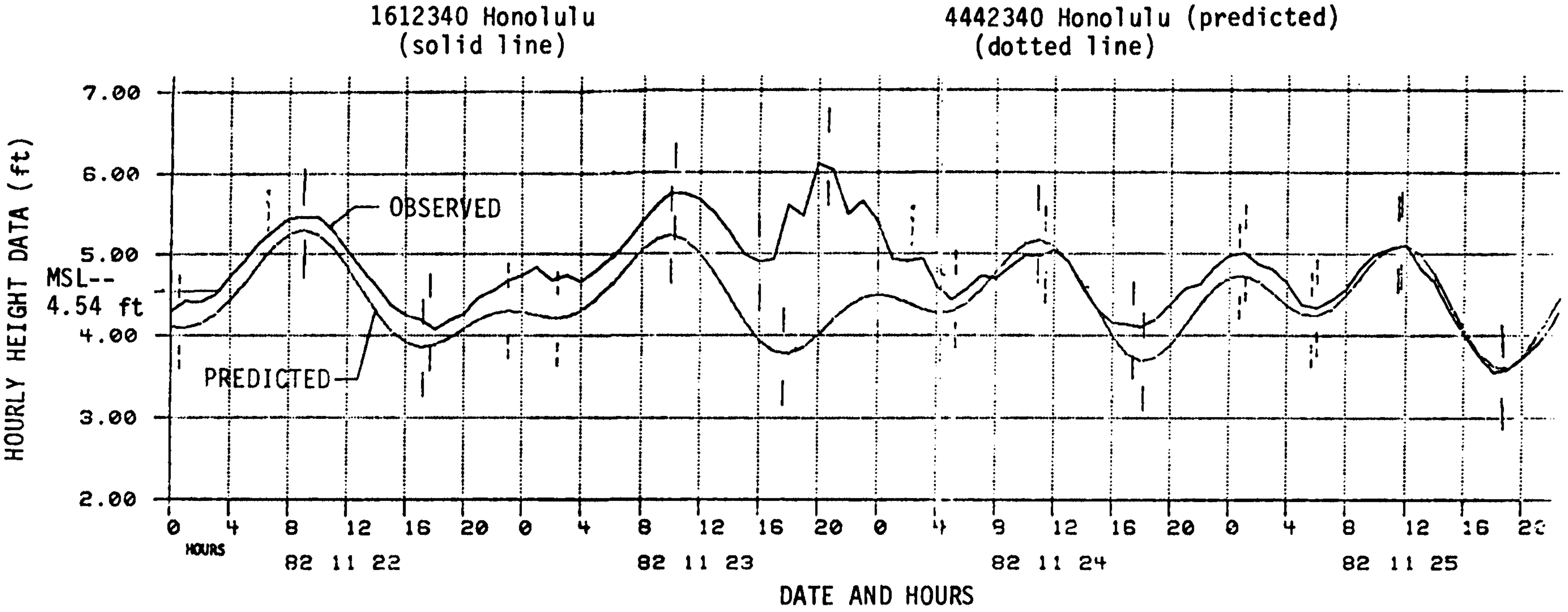

FIGURE 2.6 NOAA tide gage, Nawiliwili, Hawaii (observed and predicted tide).

3

BUILDINGS AND STRUCTURES

STRUCTURAL ASPECTS: AN OVERVIEW

Nature of Damaging Forces

Before proceeding to a general discussion of the performance of the large number of buildings and structures affected by Hurricane Iwa, it will be expedient to discuss the nature of the damaging forces generated by this storm. For the purpose of this report, these forces have been classified into two categories: (1) those associated with storm surge, wave action, and subsequent flooding along the coastal areas, and (2) those associated with wind and rainfall. A brief discussion of the magnitude and extent of the forces inflicted by Iwa follows.

Storm Surge, Wave Action, and Flooding

The hydraulic forces from hurricane events that inflict damage to buildings and structures can be broadly categorized as follows (Dames and Moore, 1980):

1. Buoyant (uplift) forces associated with partial or total submergence of a structure or portion thereof.
2. Wave forces generated by the velocity of flow against a structure or portion thereof.
3. Impact or missile forces produced by waterborne debris.
4. Hydrostatic forces generated by a differential water pressure on opposite sides of a building wall or structural assemblage.

In addition to these forces, which may produce varying degrees of structural and nonstructural damage, water damage due to flooding and rainfall normally accounts for a substantial portion of the total damage figure.

Elevation of the water level under hurricane conditions depends on a number of interrelated factors:

1. Astronomical tide due to the gravitational influence of the sun and moon on the ocean.

2. Wind setup due to shear stress on the water surface created by the tangential component of the wind.
3. Pressure difference setup due to the difference in pressure within the storm system and the ambient atmospheric pressure at the ocean surface.
4. Resonant setup due to the dynamic resonant interaction between the motion of water in the ocean basin and the moving storm.
5. Wave setup due to the time-averaged excess momentum flux of waves (a low-frequency superelevation of water due to the indirect effects of high-frequency wind waves).
6. Wind wave action due to high-frequency wind waves.

The storm surge generally refers to the departure from normal water level predominantly due to the action of wind, but it does not include the direct effects of wind wave action. In terms of the components defined above, storm surge would refer to the rise in water level due to items 2 through 5. Water levels measured by tide gages typically filter out the high-frequency wind wave action, recording components 1 through 5 only.

The elevation of the storm surge in an ocean basin depends on the intensity of the storm, its path or track, the overwater duration, the variation in atmospheric pressure, the storm's speed of translation, its size, and the characteristics of the basin (e.g., the basin's size, shape, water depth, bottom configuration, and roughness). The size of the storm relative to the size of the basin is also important. Further information on the terminology or effects of storm surges can be obtained from the U.S. Army Corps of Engineers (1977) or Simpson and Riehl (1981).

The County Planning Department of Kauai mapped a debris line for the island of Kauai after the passage of Hurricane Iwa. This debris line extended up to 300 yd inland of the 100-year flood boundary determined by the Federal Emergency Management Agency (FEMA) in a flood insurance study of the developed areas along the southerly coast of Kauai. In general, the 100-year flood elevation on the southerly shore of Kauai was established to be 6 to 14 ft above mean sea level. The coastal high hazard or V zone set by FEMA, which establishes the 100-year water and wave limit and 100-year flood elevation boundary in Hawaii, was adopted from a tsunami study of the island by the Pacific Ocean Division of the Corps of Engineers (see the section "FEMA Hawaiian Island Coastal Flood Insurance Study"). This study did not incorporate tropical and extratropical storm hazards (storm surge combined with wave action) into its water level exceedence curves due to sparse information on hurricanes affecting the islands, although Hurricane Dot passed directly over Kauai in 1959 and Hurricane Nina skirted Kauai in 1957, creating surf estimated to be as much as 35 ft on the southerly shore of the island (Shaw, 1981).

In localized areas where the land juts out into the sea, the effects of wave damage may have been more severe than at adjacent areas due to wave convergence on these projections. Typically in Hawaii, these points of land are the most favored for development of resort hotels, condominiums, and private residences due to the better access to the ocean.

No debris line survey was made by the County Planning Department or any other agency for the island of Oahu. In many of the areas visited by the team, the debris line from Iwa went beyond the landward limits of the established FEMA coastal 100-year flood zone.

Wind and Rainfall

Wind-induced loads are usually categorized in terms of those global forces to be considered in the design of the gross building or structure (main wind-force resisting systems) and those high localized forces that must be considered in the design of the parts or portions of the structure (components and cladding). In the aggregate, the highest percentage of damage costs for other than timber-framed structures normally comes from forces in this latter category.

Substantial losses also occur indirectly as the result of water damage to the interior and contents of buildings due to the rainfall that normally accompanies hurricane storms and that may penetrate the building and cause extensive damage after only relatively minor cladding damage.

Unfortunately, it was not possible to obtain statistics separating damage due to storm surge, wave action, and flooding from that induced by wind and rainfall. However, careful scrutiny of the damage values reported by FEMA (1982) and discussed in Chapter 1 suggests that the wind-induced damage was indeed significant. This fact is somewhat disturbing in light of the meteorological data presented earlier (Table 2.1 and Figures 2.1 and 2.2), which indicate that, for the most part, the wind speeds on both Kauai and Oahu were substantially less than of hurricane force and only marginally higher (for a few isolated regions) than those prescribed by applicable building codes. Thus it would appear that much of the damage must be explained by either poor construction practices, poor design, or inadequate provisions in the building code.

The data collected and analyzed by the team indicate, however, that three factors relating to the wind environment were partially responsible for the high percentage of wind damage:

1. Wind speeds were amplified by local topographic effects, such as at Makahuena Point and Princeville on Kauai (Figure 2.1) and at Kaneohe and the Wahiawa areas on Oahu (Figures 1.3 and 2.2).
2. Sustained wind speeds in excess of 50 mph occurred for approximately five hours on Kauai, and sustained speeds greater than 40 mph were recorded for over seven hours on Oahu. This is a significant factor because experience has shown that damage to roof coverings tends to depend strongly on the number of cycles of repetitive loading.
3. Meteorological data and eyewitness reports confirm that strong winds were generated from more than one direction at some geographical locations during the passage of the hurricane.

Wind tunnel tests have verified that component and cladding loads depend strongly on the direction of the wind relative to the orientation of the building. Thus, during the passage of Iwa, many structures and buildings were subjected to strong winds from a number of different directions. Terrain and topographic effects on wind speeds also vary with wind direction.

Classification of Damage

Type and Extent of Damage Due to Storm Surge, Wave Action, and Flooding

Damage inflicted by hydraulic forces and flooding extended along the southerly coast of Kauai from Kekaha to Poipu (Figure 1.2) and along the entire westerly and southerly coast of Oahu from Makaha to Koko Head (Figure 1.3). In general, offshore and harbor structures that had been designed to withstand high wave forces performed satisfactorily. On Kauai, the breakwater at Nawiliwili Harbor and revetment at Kekaha experienced only minor damage. Other harbor and offshore structures fared less well--for example, the small-boat harbor at Port Allen (Figure 3.1).

The team observed that, for the most part, buildings, structures, and single-family dwellings along the beachfronts were not designed to resist storm surge and wave action. Figure 3.2 shows the devastation of part of a hotel at Poipu Beach. However, a number of engineered reinforced concrete and masonry structures situated close to the water were observed to withstand the large hydraulic forces with no apparent structural distress, even though in most cases the structures were not designed for wave forces. The Makaha Shores Condominium on Oahu (Figure 3.3) was gutted by waves over a large portion of the first-floor elevation but sustained only water and minor missile damage to the interior and contents of the building. This type of water damage was typical of that sustained by most engineered buildings subjected to high storm surge and wave action along the shorelines of Kauai and Oahu.

Damage to beachfront homes was extensive on both Kauai and Oahu. Many single-family dwellings along the coastlines consist of conventional timber framing set on concrete slabs on grade. Reinforced concrete masonry walls or columns with timber-framed roofs are also used extensively. Those homes sited near the water sustained damage varying from water damage to the interior and contents to complete devastation of the building. Some homes were transported off their foundations by the storm surge and wave action and deposited inland as far as 100 yd (Figure 3.4). Many others were destroyed either by wind or wave action and the debris then transported inland.

Type and Extent of Damage Due to Wind and Rainfall

Wind-induced damage on Kauai and Oahu varied from superficial cladding damage to roofs and walls (minor loss of shingles and roofing tiles, glass breakage, etc.) to total destruction. For the purpose of this report, the wind-induced damage is divided into three categories:

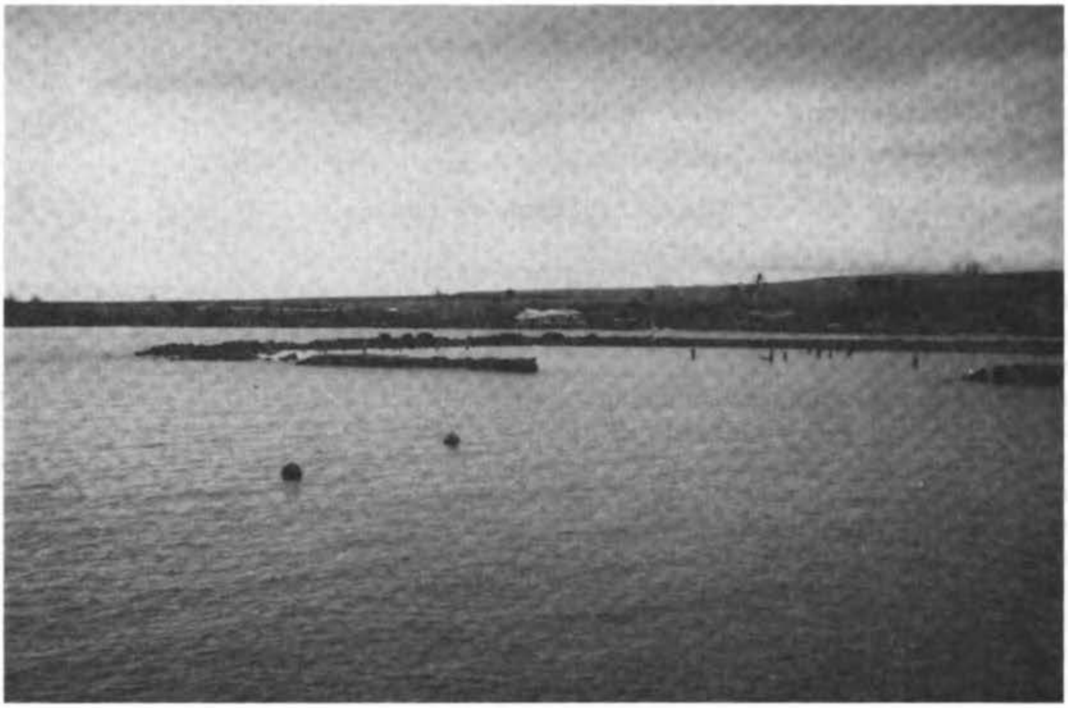

FIGURE 3.1 Damage to small-boat harbor breakwater at Port Allen, Kauai.

FIGURE 3.2 Damage at Sheraton-Kauai on Poipu Beach.

FIGURE 3.3 Makaha Shores Condominium, Oahu.

FIGURE 3.4 Damaged beachfront residence at Makaha, Oahu (note that home was transported off concrete slab foundation 100 yds inland by storm surge and wave action).

1. Cladding damage due to inadequately fastened roof coverings and siding materials, failures of glass windows and doors, etc.
2. Cladding damage due to windborne debris striking the building or structure.
3. Catastrophic failures (partial or complete collapse of main wind-force resisting systems).

Although accurate statistics were not available, the team observed that each of the above categories constituted a substantial portion of the wind-induced damage. Cladding damage due to inadequately fastened roof coverings quite possibly accounted for the highest percentage of the total. The use of lightweight roofing materials such as light-gage corrugated metal sheeting (aluminum, steel, or copper) and tongue-and-groove or ship-lap wood sheeting spanning between roof beams is commonplace in Hawaii. A basic single-family dwelling on Kauai, for example, may consist of conventional timber framing with light-gage metal sheeting for roof cladding (Figures 3.5 and 3.6). Many of the older industrial and military buildings that sustained damage on Kauai and Oahu during the passage of Iwa were timber-framed structures, again clad with lightweight roofing and siding material (Figure 3.7).

Failure of roof coverings in the areas affected by Iwa was widespread. Roofing shingles, gravel from pitch-and-gravel roofs, and lightweight sheeting panels of wood or metal were blown from the roofs into the wind, creating an extremely high hazard to life and property during the five to six hours of strong winds. Much of the glass breakage in many well-designed buildings was due to windborne debris.

After the loss of portions of structures--for example, roofs, doors, windows, or walls--accompanying or subsequent rainfall damaged their interiors and contents. The team also found it interesting that although solar energy units were observed on many of the residential units in the areas of high wind, no instances of failures of these units were noted.

Catastrophic failures due to wind were limited to older, timber-framed industrial and military buildings clad with light-gage metal sheeting, timber-framed single- and multiple-family dwellings clad with lightweight roofing materials, and temporary buildings not anchored to foundations. The structural integrity of many of these buildings and structures depended on the ability of the sheeting and purlin system or the sheeting and girt system to function adequately as shear diaphragms (i.e., as roof diaphragms or shear walls, respectively). For example, loss of the light-gage metal roof sheeting was undoubtedly the primary cause of the large number of warehouses destroyed or heavily damaged at Schofield Barracks (Figures 3.8 and 3.9).

With a few exceptions, modern preengineered metal buildings were observed to respond satisfactorily (Figure 3.10), demonstrating that light-gage metal sheeting can be properly attached to maintain structural integrity during high winds. The exceptions noted were for buildings constructed with natural ventilation for which fluctuations in internal pressures were apparently not considered in the design (Figures 3.11 and 3.12). The forces causing the outward collapse of the side walls or doors and portions of the roofs of these buildings were undoubtedly due to a combination of suction on the side walls and roof

FIGURE 3.5 Damage to residential development at Kapaa Meadows, Kauai.

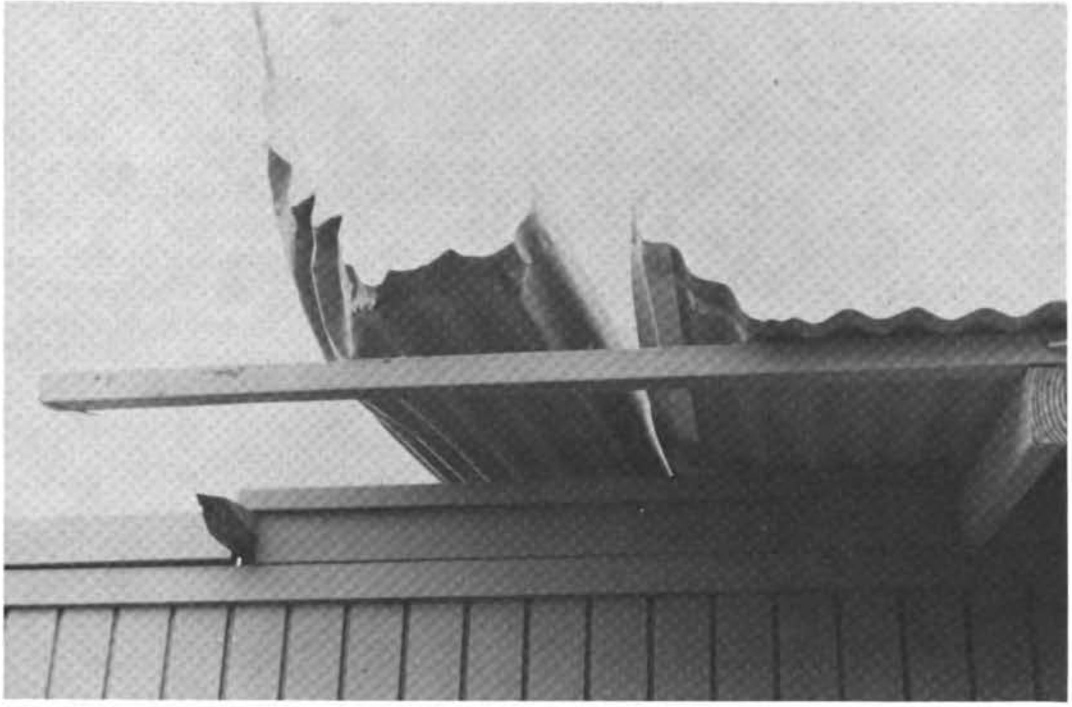

FIGURE 3.6 Light-gage corrugated metal sheeting used as roof covering.

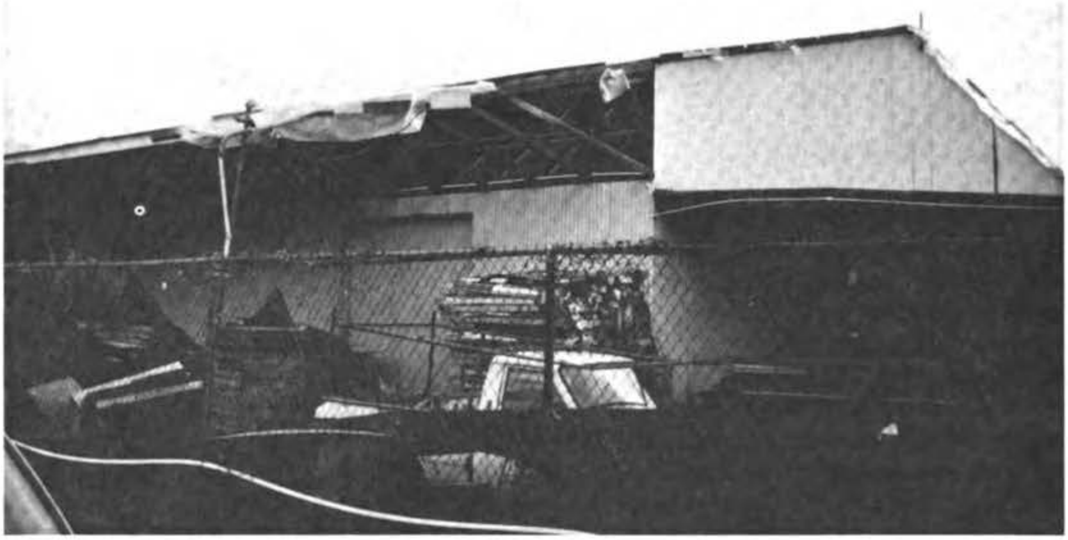

FIGURE 3.7 Damage to warehouse building, Kauai.

FIGURE 3.8 Damage to warehouse buildings at Schofield Barracks, Oahu.

FIGURE 3.9 Damage to timber-framed building clad with light-gage metal sheeting (note that most of the damaged building had been removed at the time the photograph was taken).

FIGURE 3.10 Preengineered metal buildings at Kauai (no observed damage).

FIGURE 3.11 Damaged preengineered metal building at Kauai (note natural ventilation built into windward wall).

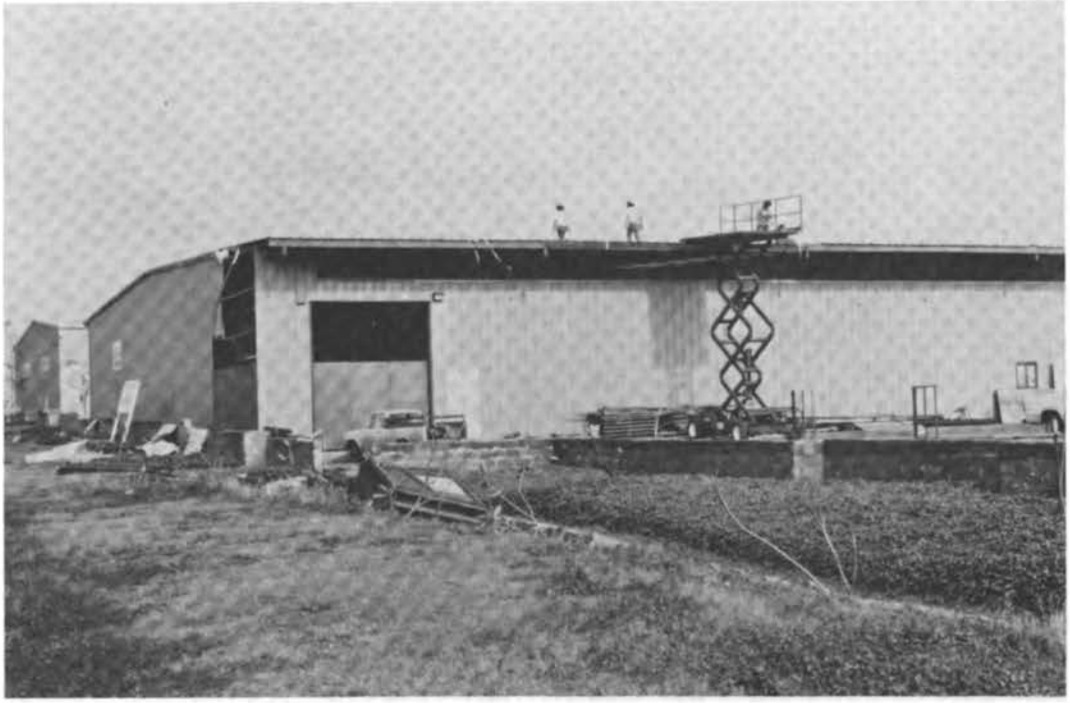

FIGURE 3.12 Damaged preengineered metal building at Kauai (note natural ventilation built into windward wall, damage sustained by roof and side wall, and roll-up doors blown off tracks).

coupled with a high internal pressure produced as a result of the wind entering the planned openings on the windward faces. Note that the roll-up door on the windward face of the building shown in Figure 3.12 was blown off its tracks. Unfortunately, this is an all too common mode of wind damage for preengineered metal buildings.

Generally, the performance of fully engineered buildings (e.g., hospitals, multistory hotels, and state and government office buildings, which are built of reinforced concrete or reinforced concrete and masonry) was observed to be satisfactory. Wind-induced distress was limited to minor cladding damage caused, for the most part, by windborne debris. A large number of instances were reported, however, of glass sliding doors adjacent to lanais (verandas) being blown in or sucked out of their supporting tracks. The favorable climate, scenic flavor, and resort atmosphere of Hawaii encourage architects and builders to use a high percentage of glazed areas (windows and sliding glass doors) in the walls fronting the shorelines (areas of high wind).

Of particular concern to the team was the wind damage to school buildings on Kauai. Waimea, Kapaa, and Kauai high schools were all used as storm shelters to house residents of the island during the passage of Iwa. A number of buildings at these locations sustained damage varying from major roof damage to complete collapse. No buildings on Kauai have been classified as hurricane resistant, although a number of public and privately owned structures on the island would qualify. On the other hand, a survey had been made of some possible hurricane-safe shelters on Oahu (Office of Civil Defense, 1982).

Building Codes and Regulations

Coastal High Hazard Flood Provisions

Kauai The building regulations and ordinances in the County of Kauai prior to Hurricane Iwa were the minimum standards set forth in the FEMA regulations governing construction in flood-prone areas (Zoning Ordinance, Kauai, 1976). These are the minimum necessary provisions that a county must meet before being admitted to the Flood Insurance Program.

In 1980 FEMA published the results of a study specifying guidelines for residential construction in tsunami-prone areas with special emphasis on Hawaii (Dames and Moore, 1980). A similar document for the design of residential buildings in the coastal high hazard areas was also published (Federal Emergency Management Agency, 1981) to provide guidance for the design of residential structures in areas subject to tropical and extratropical storm surges and wave action. Neither of these documents was used in establishing building codes on Kauai.

Oahu The County of Honolulu had passed specific ordinances governing building requirements in flood-prone areas prior to Iwa (Zoning Code, Oahu, 1980). This set of regulations, in addition to meeting the minimum requirements necessary for the county to be included in the Flood Insurance Program, also incorporated the guidelines established by the 1980 Dames and Moore study.

Wind Load Provisions

The majority of engineered buildings and structures affected by Hurricane Iwa apparently were designed in accordance with the wind load provisions of the older editions of the Uniform Building Code (International Council of Building Officials, 1979) for a basic reference pressure of 20 psf. These provisions, which have remained essentially unchanged since their adoption in the 1955 edition of the code, prescribe a design load of 15 psf for low-rise structures with heights less than 30 ft and increase in a stepwise fashion for various height zones above the 30-ft level. If one retraces the basic assumptions involved in the development of the appropriate provisions of this code (Brekke, 1959), the 20-psf reference pressure corresponds to a design speed of 60 mph at a height of 30 ft above mean ground level.

In 1982 the International Conference of Building Officials approved new wind load provisions (International Council of Building Officials, 1982), which represent a radical departure from those contained in the old document. The provisions of this edition of the code are currently being considered for adoption in Hawaii. A basic design wind speed of 80 mph (fastest speed) has been suggested. The difference in design wind speeds of 60 and 80 mph is misleading, however, as the basic assumptions used in arriving at design loads are quite different for these two versions of the code (Perry et al., 1981).

The major shortcoming of the old version is that the wind loads to be used in the design of components and cladding were not specifically addressed. Presumably, such elements would be designed for the same loadings as those used for the main wind-force resisting systems. Experience has shown and wind tunnel tests have confirmed, however, that wind-induced pressures are not well organized with respect to either time or space. Furthermore, the effect of localized turbulence decreases with increasing area. Thus the loading experienced by a structural component having a relatively small tributary area (e.g., a purlin, girt, or fastener) may be much higher than that seen by the main wind-force resisting systems, (e.g., wall corners, roof eaves, ridges, and rakes) and must be considered in the design process. As these loads increase with decreasing tributary area, the loads on the individual fasteners may be extremely high in some locations.

The new version of the code attempts to come to grips with the problem of component and cladding design and provides separate pressure coefficients for the design of elements and components and for primary frames and systems. Coefficients are also given for localized areas at surface discontinuities of the building, and an increase in loading is required for the design of fasteners. Pressure coefficients have been adjusted to provide for fluctuations in internal pressure that may occur due to planned or unplanned openings in a structure (e.g., failure of a door or window).

FEMA Hawaiian Island Coastal Flood Insurance Study

To establish the existing coastal 100-year flood zones for Hawaii, open-coast tsunami water levels were generated by probability distribution methods using historical data of the 10 highest tsunami water levels for the period 1837 to 1979 where such data exist, and by synthetically generated tsunami water levels using a hybrid finite element numerical model where little or no historical data exist (Houston and Butler, 1979). Use of the model yields open-coast tsunami elevations for various flood frequencies. Open-coast tsunami water levels were then propagated inland along transects using an inundation model (Bretschneider and Wybro, 1976) to obtain the inland limits of tsunami flooding. The 100-year tsunami inundation area is divided into two zones. Where the depth of the water from the 100-year tsunami exceeds 4 ft, the area is identified as a V zone (a zone with wave velocities potentially destructive to residential construction). The remainder of the area lying within the inundation limits of the 100-year tsunami has a depth of flooding less than 4 ft and is identified as an A zone. The coastal high hazard area consists of all areas identified as V zones. FEMA requires special performance standards for construction in these areas.

Both of the studies cited above note that their investigations are first attempts to establish tsunami water levels and inundation limits. Considerable research is needed to confirm (for present use) and improve (for future use) the technology for predicting tsunami flooding. More definitive tsunami inundation models exist for all of the Pacific islands (Farrar and Houston, 1979; Houston and Butler, 1979) but were not used to establish the existing FEMA flood levels.

The tsunami water levels for the islands (for a specific return period such as 100 years) were noted to be quite high on the northern sides of the major islands due to the influence of extreme tsunami-generating events, for instance events in the Aleutian Islands area. The corresponding tsunami-generated water levels are quite low on the southern sides of the major islands, except for the island of Hawaii, and are comparable to water levels generated by tropical and extratropical storms.

The FEMA study did not incorporate tropical and extratropical storm-generated water and wave levels due to the alleged rarity of severe storms (in particular, hurricanes) affecting Hawaii and due to the fact that, based on historical data, tsunami levels appear to be the controlling flood events on the northern side of the islands. In recent years two hurricanes have affected Hawaii: Hurricane Nina passed to the south of the islands in 1957, and Hurricane Dot passed directly over Kauai in 1959. The possibility of tropical and extratropical storm-generated surge and wind waves altering the water level probability curves for Hawaii, on the southern sides of the islands in particular, should not be excluded.

Iwa was not the first hurricane to generate high wave action on the southern side of Kauai, although wave action from Iwa appears to have been more severe than that of earlier storms. High wave action caused by the 1957 and 1959 hurricanes caused damage in the Hanapepe Bay area and eroded shoreline areas at Kekaha. The December 1959 storm sent waves, reportedly as much as 30 ft high at the shoreline, across the coastal highway at Kekaha (U.S. Army Corps of Engineers, 1970). Hurricanes appear to follow cyclic trends in many areas (Russell and Schueller, 1971) and may have both important short-term and long-term effects on probabilistic water levels for the Pacific islands in general. The fact that three hurricanes have affected Hawaii since 1957 (within 25 years) suggests that their effects cannot be deemphasized in a flood study without additional research.

DAMAGE ON KAUAI

Introduction

The degree of damage inflicted on Kauai by Hurricane Iwa ranged from superficial flooding due to storm surge and minor losses of cladding materials (shingles, roof tiles, glass windows, etc.) due to winds to total destruction. Damage inflicted by storm surge, wave action, and flooding was particularly heavy along the southerly coast from Kekaha to Poipu (Figure 1.2). Wind-induced damage was widespread throughout the populated areas of the island, with the maximum damage occurring at those regions where topographic effects amplified wind speeds. Approximately one out of every eight homes sustained some form of damage.

The photographs in this section of the chapter depict the type and intensity of damage observed by the team and are arranged in a general geographical order beginning at Kekaha and continuing around the coastline in a counterclockwise direction to the Princeville resort development. Wherever possible the damage has been classified according to the nature of the damaging forces, either hydraulic forces and flooding or wind and rainfall. In some areas, damage was inflicted through a combination of the two.

Damage Due to Hydraulic Forces and Flooding

Harbor and Offshore Structures (Kekaha to Nawiliwili)

Kikialoa Harbor, a small-boat harbor approximately 1.5 miles east of Kekaha, sustained extensive damage to the breakwaters, marginal wharf, shoreline revetment, and harbor support facilities. An estimate of the cost to restore this harbor to its predisaster condition is $500,000. Fortunately, no boats were moored in the harbor during the passage of Iwa.

The Port Allen outer breakwater, designed by the Corps of Engineers and constructed in the 1930s of keyed basalt stone, experienced major damage on its outer end, where 130 ft of breakwater were totally destroyed and a navigation beacon lost. Prior to Hurricane Iwa the Port Allen breakwater had survived the 1957 and 1959 hurricanes with very minor damage and reportedly had successfully withstood attacks by storm waves estimated to be up to 20 ft high (Palmer, 1960). The small-boat harbor breakwater at Port Allen (a state facility) was severely damaged (Figure 3.1), and 44 of 45 boats in the harbor were either destroyed, sunk, or damaged beyond repair. One boat survived by pulling its moorings and riding out the storm. Many of the damaged boats were deposited on higher ground by the storm and could have provided a rough estimate of the high water level in this area if their locations had been surveyed and leveled to known benchmarks.

The Corps of Engineers-designed breakwater at Nawiliwili experienced only minor damage. Fifteen boats greater than 18 ft in length were sunk or destroyed by wave action in the harbor. Most of the damage in the harbor was caused by wave action generated by strong westerly winds channeled through the bay parallel to the Hoary Head Range (Figure 2.1). Coast Guard Chief Thomas Betsko at the Nawiliwili Coast Guard Station estimated wind gust speeds of 100 to 110 mph after the speeds went off the scale (80 mph maximum) of his handheld wind indicator.

(The Pacific Ocean Division of the Corps of Engineers in Honolulu, Hawaii, has prepared damage reports for the harbors on Kauai, but they were not available at the time of writing this report.)

Residential Structures

Single- and multiple-family dwellings near the water were extensively damaged along a 20-mile stretch of the southern coast of Kauai from Oomana Point at Kekaha to Brennecke Beach near Makahuena Point. Many beachfront homes were completely destroyed by wind or wave action or a combination of these two or were washed off their foundations and transported inland by storm surge and wave action (Figure 3.13). Some homes hit other dwellings inland, inflicting considerable damage. The porch of a house at Makahuena Point was torn away by a wave that may have crested 30 ft above mean sea level (Cox, 1983). Severe flooding occurred to homes as far as 150 yd inland.

Seawalls of unreinforced lava rock, gravel, and grout (Figures 3.14 and 3.15) were no match for the waves, and large sections were destroyed. Portions of the beachfront roads were undermined and destroyed both at the Oomana Point area and at Brennecke Beach (Figure 3.16); slabs of asphalt road material were transported as much as 100 yd inland by storm surge and wave action.

Hotel Resort Developments

A four-mile stretch of shoreline from the area near Kuhio Shores to Poipu Beach (Figure 1.4) provides a scenic setting for a large number of Kauai's luxury hotels and condominiums. Many of the units are built very near the shoreline and thus were subjected to the maximum storm surge and wave action.

Figure 3.17 shows the extensive damage sustained by a number of buildings. The four-story building in the right-hand corner is the Kuhio Shores; the structures in the center of the photograph are the Prince Kuhio Condominiums. On the left side of the figure near the water can be seen the remains of the Beach House Restaurant, which was almost completely demolished; a small portion of the roof remains (Figure 3.18).

The Kuhio Shores is a shear wall structure constructed of reinforced concrete masonry with reinforced concrete floor slabs. Figures 3.19

FIGURE 3.13 Damage to beachfront single-family dwellings on Kauai.

FIGURE 3.14 Damage to seawall at Poipu Beach, Kauai.

FIGURE 3.15 Damaged unreinforced grouted lava rock seawall.

FIGURE 3.16 Undermined and destroyed section of Hoone Road at Poipu Beach, Kauai.

FIGURE 3.17 Damage to Kuhio Shores Resort development, Kauai (note proximity of buildings to shoreline).

FIGURE 3.18 Damage to Beach House Restaurant at Kuhio Shores, Kauai.

through 3.23 show the extensive damage sustained by this building as it was subjected to storm surge and wave action. Considerable erosion was observed under the lightly reinforced floor slab and around the footings. Some of the footings were founded on sand rather than extending to the lava rock formation below and failed after scouring action of the waves destroyed their support. Much of the first-floor area was gutted by waves, and a number of the bearing walls sustained heavy damage from waterborne debris (Figures 3.19 and 3.20). The maximum water height was estimated to be at least 2 ft above the finished first-floor level, which was at 8 ft above mean sea level. Light wind damage was observed at the upper levels of this building. Although the proximity of this structure to the water would have resulted in extensive water damage in any event, some of the damage could have been mitigated by either extending and keying the footings into the lava rock formation or by providing a protective seawall to prevent scouring of the foundation. It is doubtful, however, that all of the reinforced concrete masonry unit walls could have withstood the combined action of hydraulic forces and impact from waterborne debris, since a number of the rear nonbearing walls parallel to the beachfront failed (Figure 3.23).

The Sheraton-Kauai Hotel, at the center of the Poipu Beach area, is approximately one mile eastward along the coastline. This hotel complex, consisting of an older section of 170 rooms immediately adjacent to the shoreline and a new section of 230 rooms, sustained major damage, as can be seen from the aerial photograph of Figure 3.24. A portion of the older section consisted of one- and two-story timber-framed structures on concrete slab and substructure. At the ground-level elevation, concrete lanais (verandas) cantilevered from each building approximately 6 ft. These units were constructed about 12 years ago and were either completely destroyed or damaged beyond repair by the storm surge and wave action, which left in some cases only the concrete slabs (Figures 3.25 and 3.26). The reinforced concrete lanais were obviously subjected to large hydraulic uplift forces, subsequently either being folded completely backward 180 degrees or collapsing vertically after repeated pounding by the waves. Close inspection of the units revealed that the mud sill of the stud walls was only power nailed to the concrete slabs.

The beachfront Drum Lounge building shown in Figure 3.27 was completely flooded by storm surge and lost almost all of its roof covering due to wind forces. Inadequate nailing of the roofing planks was apparently the cause of failure of the roof covering, as the wind speeds were estimated to be in the range of values prescribed by the code (see the next section). Three-story reinforced concrete masonry unit structures, constructed about five years ago near the beachfront areas, fared better, although substantial water damage to the interior and contents of the ground-level floors occurred (Figure 3.28). Most of these units were constructed with sliding glass doors on the beachfront side, which were destroyed by waves or waterborne rocks and debris (Figure 3.29).

The newer section of the Sheraton-Kauai shown at the top of the photograph of Figure 3.24 was partially shielded from wave action,

FIGURE 3.19 Damage to Kuhio Shores Condominium, Kauai (note scouring of footings).

FIGURE 3.20 Damage at first-floor level of Kuhio Shores Condominium, Kauai (note variable thickness of floor slab and reinforcing steel exposed at bottom of slab).

FIGURE 3.21 Damage to bearing walls of Kuhio Shores Condominium, Kauai (note large boulders transported to interior of building by storm surge and wave action).

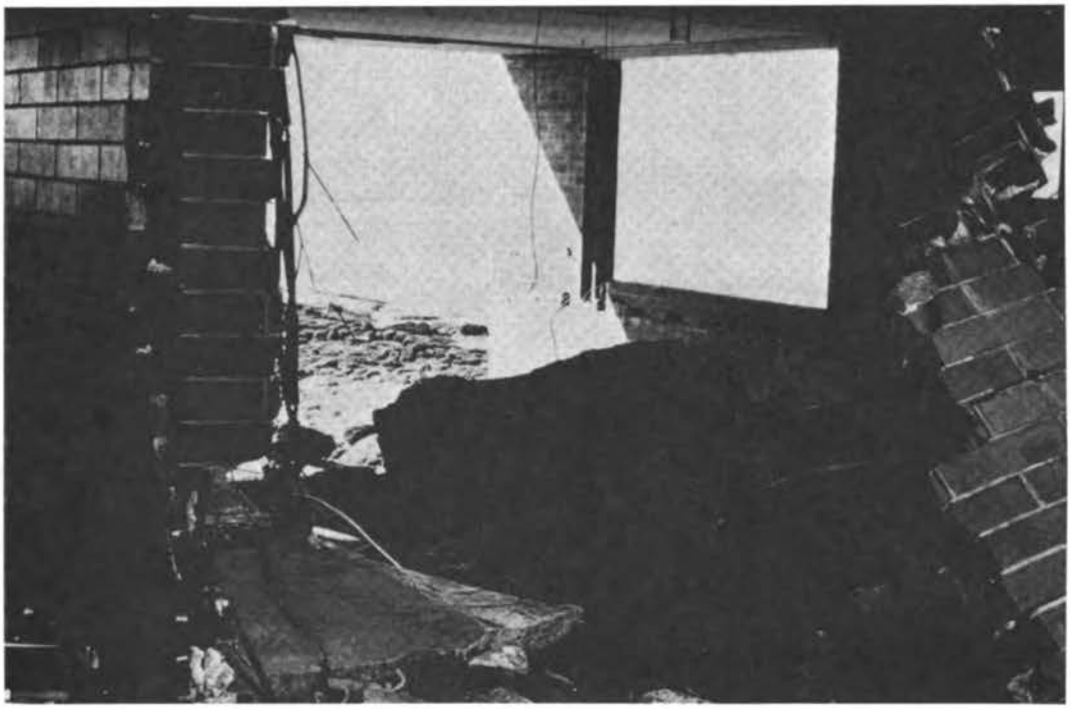

FIGURE 3.22 Damage to nonbearing wall of Kuhio Shores Condominium, Kauai.

FIGURE 3.23 Damage to footing, Kuhio Shores Condominium, Kauai.

FIGURE 3.24 Damage to Sheraton-Kauai at Poipu Beach due to storm surge, wave action, and wind.

FIGURE 3.25 Remains of two-story hotel unit at Sheraton-Kauai (note lanai slab bent backwards 180 degrees).

FIGURE 3.26 Damage to timber-framed unit at Sheraton-Kauai.

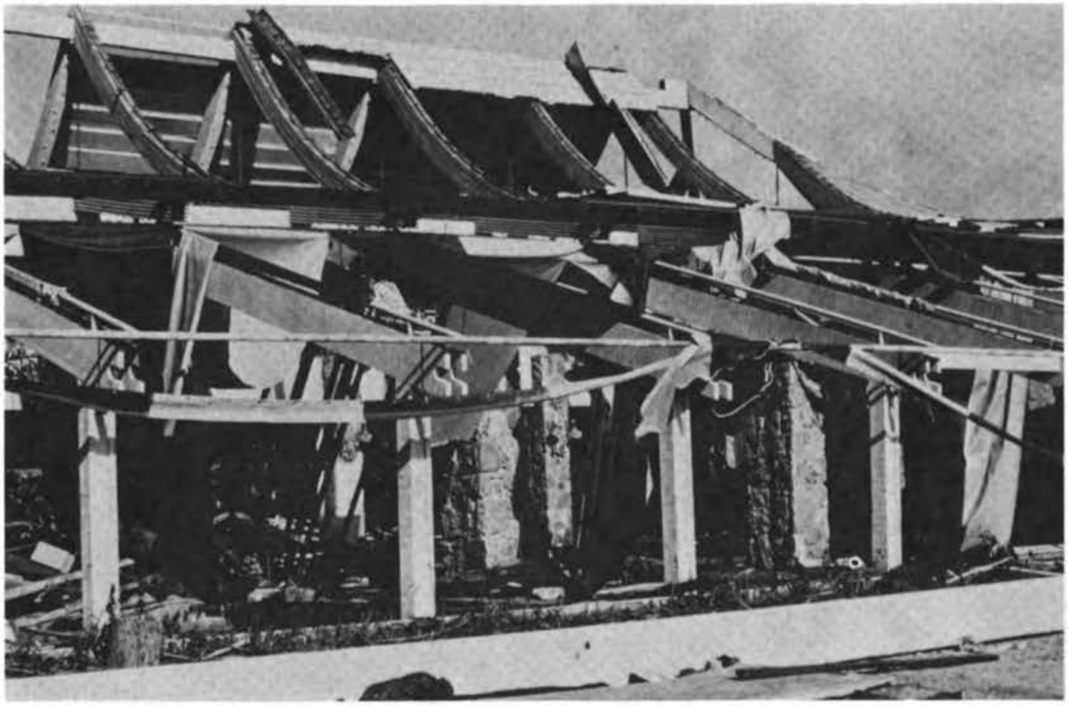

FIGURE 3.27 Flooding and wind-induced damage to Drum Lounge at Sheraton-Kauai.

FIGURE 3.28 Erosion of footings of three-story unit at Sheraton-Kauai.

FIGURE 3.29 Storm surge, wave, and flooding damage to interior of unit at Sheraton-Kauai.

although flooding of the ground-level portion of these structures occurred as far as 150 yd from the beach area.

The damage probably would have been worse to many buildings in this area were not many units founded on lava rock outcrops rather than beach sand with shear walls oriented parallel to the direction of wave approach. Rocks approximately 2 ft in diameter (local basalt) were moved inland up to 150 yd (Figure 3.30). Cars were overturned, piled up, and thrown into hotel ponds. The only watermark seen by the team in the entire postdamage survey was in a back unit of the newer section; it was approximately 3 ft above the first-floor elevation.

Approximately a half mile farther east along the coastline, the new $60 million Waiohai Resort was subjected to high storm surge and wave forces. This four-story structure has a floor plan in the shape of the letter W and affords an excellent example of modern reinforced concrete shear wall design. The shear walls in the "legs" of the W extend normal to the coastline. As the units were also situated near the beach (Figure 3.31), the entire ground level was gutted with waves. The structure was obviously subjected to massive wave forces, as many breakaway doors and exterior partitions failed. Although the ground-level units of this development experienced major water damage due to flooding and wave action, the team could find no indication of structural distress to the building. The hotel returned to service on January 15, 1983. Of interest is the fact that a basement kitchen was flooded and prevented an earlier opening of the hotel, since this kitchen was critical to the operations of the hotel. An unsubstantiated

FIGURE 3.30 Waterborne debris at Sheraton-Kauai.

FIGURE 3.31 Wave and flooding damage at Waiohai Hotel, Kauai.

water elevation mark at the Waiohai Hotel was 11 ft above mean sea level (Cox, 1983), which compares with 6 ft above mean sea level from Hurricane Dot in 1959 in the same general area.

Damage Due to Wind and Rainfall

Because the inspection was performed nine days after the hurricane, it was not possible to determine the extent of damage due to rainfall. The following discussions of various projects will center on the extensive wind-induced damage.

Kekaha to Poipu

As shown in Figures 1.2 and 2.1, the maximum sustained wind speeds for the coastline region extending from Kekaha to the Poipu Beach area were estimated to be 60 to 65 mph from the south to southeast. Inland from the coast, damage decreased. For example, at Koloa, which is approximately 1.5 miles inland from Poipu Beach, only very light damage to homes was observed, indicating sustained wind speeds in the range of 45 to 50 mph in the populated areas. Thus the maximum wind speeds in this region were very near (or below) values in the building code.

Wind-induced damage to timber-framed single-family dwellings was extensive for those homes immediately adjacent to the coastline. At Waimea High School a number of buildings sustained major damage, including the timber-framed library building and reinforced concrete industrial arts building. Both were constructed within the past six years, and both lost large portions of their roofs, which consisted of lightweight ship-lap wood sheeting.

At Port Allen a large number of older timber-framed warehouse-type structures clad with light-gage metal sheeting were destroyed or heavily damaged (Figure 3.32). Failure of the roof diaphragm system due to the loss of sheeting was unquestionably the mode of failure.

The roof of the relatively new Prince Kuhio Condominium was extensively damaged (Figure 3.33). Failure appeared to be due to the upward wind pressures on the large overhangs, the high localized wind-induced external pressures that probably existed at the geometric discontinuity of the roof, and the increases in internal pressure due to failure of the glass doors and windows.

Continuing in an easterly direction along Poipu Beach, it became difficult to always identify wind-induced damage and separate it from that inflicted by storm surge and wave action. This was particularly true for single-story structures on the beach, which in some cases were washed off their foundations and transported inland (Figure 3.13). Fairly extensive cladding damage to the roofs of multistory structures was observed in this area (Figures 3.34 and 3.35), again indicating a deficiency in the current building code requirements with respect to cladding design. Figure 3.36 is a photograph of the Monier-type roof tile used quite extensively on the newer buildings and homes in Hawaii. Note the single 8d nail used to fasten the tile to the roof.

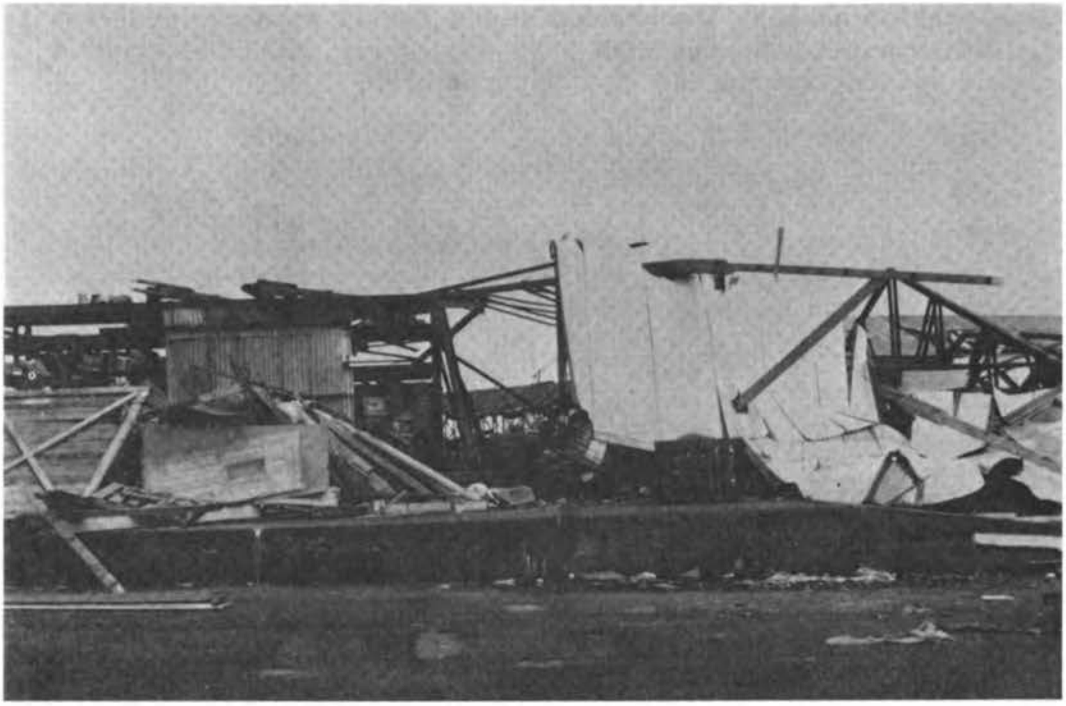

FIGURE 3.32 Wind damage to timber-framed warehouse structure at Port Allen, Kauai.

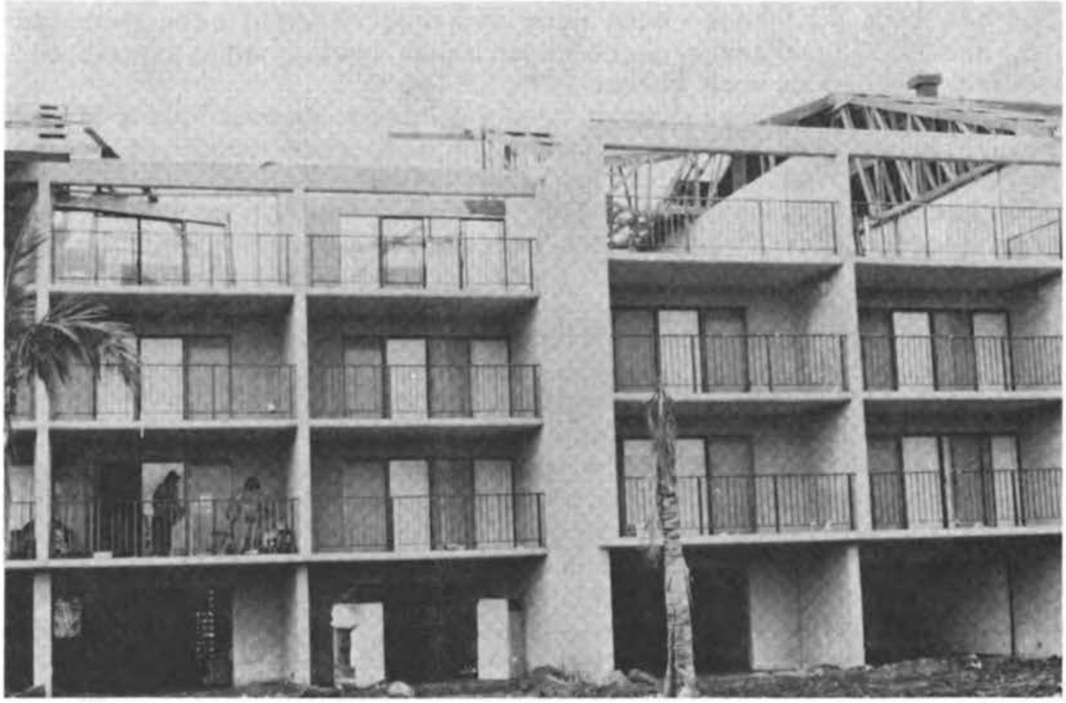

FIGURE 3.33 Wind damage to Prince Kuhio Condominium, Kauai (note geometric discontinuity in roof).

FIGURE 3.34 Roof damage to building inland from Poipu Beach, Kauai.

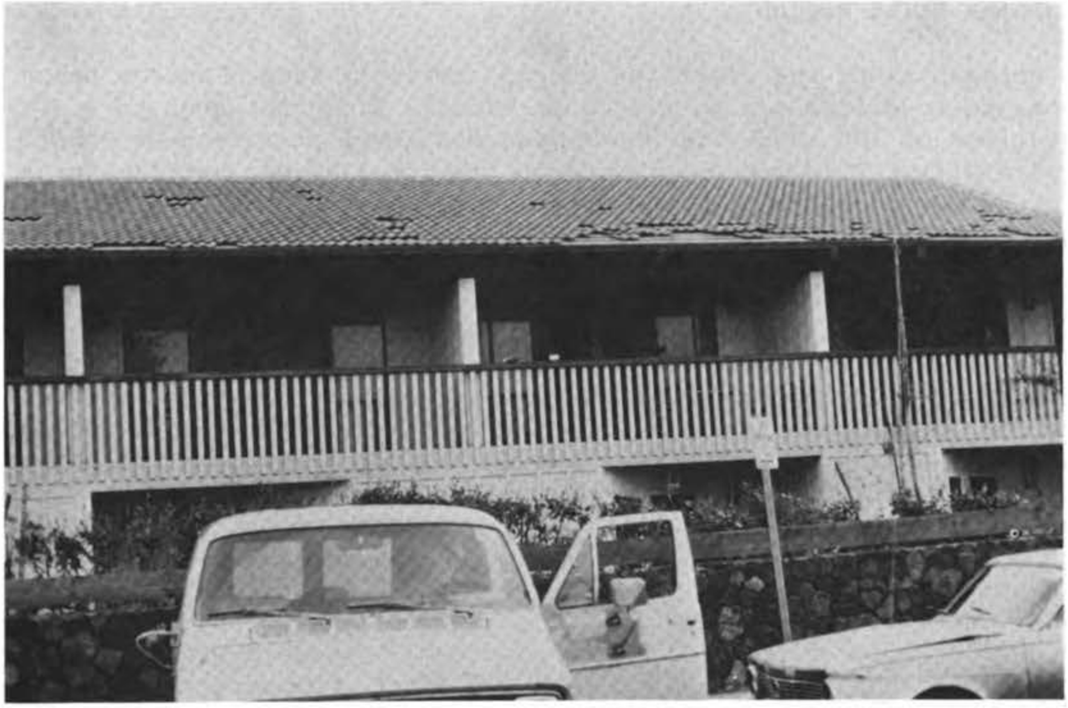

FIGURE 3.35 Cladding damage to building inland from Poipu Beach, Kauai.

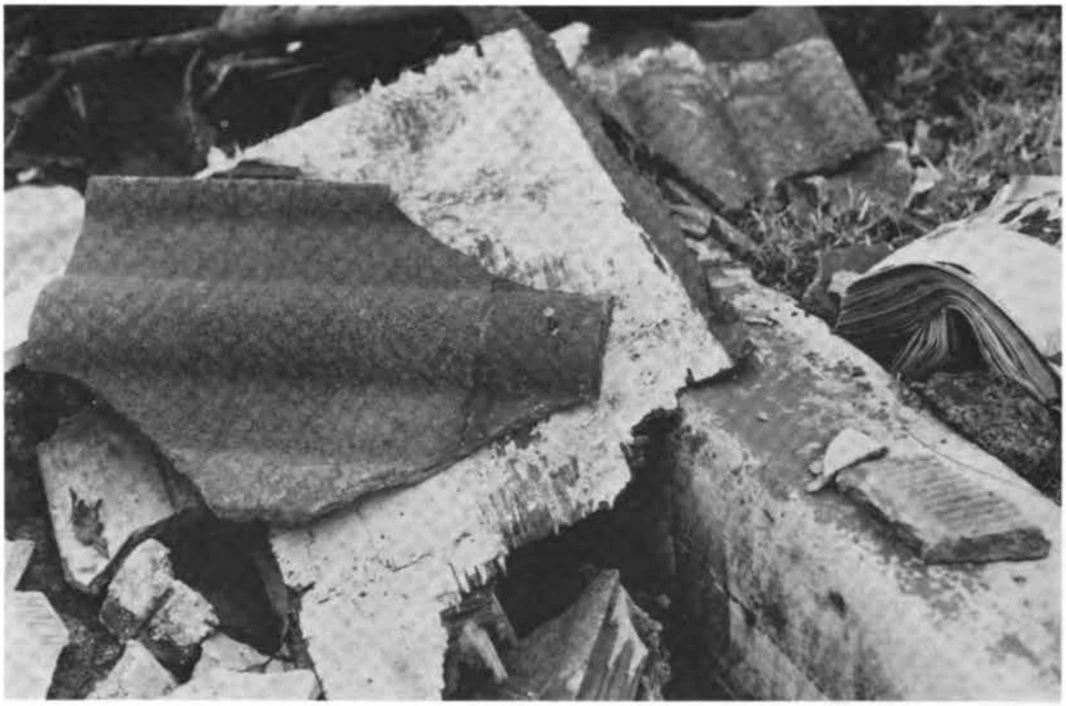

FIGURE 3.36 Monier-type roof tile (note single 8d nail fastener).

Makahuena Point Region

The terrain along the coastline changes abruptly from a narrow beach at Brennecke to cliffs rising nearly vertically from the water to elevations of 100 to 150 ft above mean sea level at Makahuena Point (Figure 2.1). This region provides a beautiful scenic setting for a large number of relatively new condominium developments and single-family dwellings. Unfortunately, the extent of damage observed by the team and the peak wind gust of 126 mph (71 mph sustained) recorded at this location (Table 2.1) indicate that winds striking the coastline from the south to southeast were sharply amplified. Major damage occurred to condominiums and homes located near the bluffs (Figures 3.37 and 3.38). Those well-designed buildings that apparently were capable of resisting the wind loadings were nevertheless inflicted with heavy damage by windborne shingles and other debris. The Poipu Shores Condominiums, a reinforced concrete shear wall structure having prestressed floor slabs (shown at the bottom and center of Figure 3.39), lost 45 percent of the glass windows in its 36 units due to impact by handsplit shakes that had been blown off the roofs of other buildings or homes upstream. Major water damage subsequently occurred to the contents of most of the units from rainfall. Damage decreased rapidly with increasing distance inland from the coastline and was soon limited to minor losses of shingles or roof tiles (Figures 3.40 and 3.41).

FIGURE 3.37 Wind damage to single-family dwelling on bluff at Makahuena Point, Kauai.

FIGURE 3.38 Cladding damage to condominiums at Makahuena Point, Kauai.

FIGURE 3.39 Poipu Shores Condominiums (L-shaped building at bottom of photograph sustained extensive missile damage).

FIGURE 3.40 Minor cladding damage to homes inland from Makahuena Point, Kauai.

FIGURE 3.41 Minor cladding damage to sheltered condominiums sited in Poipu Crater at Makahuena Point, Kauai.

The Makahuena Condominium was constructed in 1980 immediately adjacent to the bluffs, as shown in the aerial photograph of Figure 3.42. Many of the units sustained major damage (Figure 3.43). These three-story timber-framed structures used a roof framing system consisting of multiple tongue-and-groove roof decking spanning between exposed interior beams; the maximum span noted was 15 ft. The unique roof decking consisted of five 1 x 8 planks (actual dimensions were 3/4 in. x 7-1/4 in.) laminated together, as shown in Figure 3.44. Attachment of the decking to the supporting beams and walls was with two 60d spikes having a penetration of approximately 2.0 in. and randomly spaced approximately 12 in. on center. Roof overhangs, end rakes, and a high percentage of glazed areas in the walls fronting on the ocean were used in the design. Failure was most probably initiated by loss of glass on the windward side, which created a high internal pressure that combined with the exterior suction on the roof surface to produce failure of large portions of many of the units' roof systems. For one of the units, a section of the roof decking approximately 30 ft x 80 ft was blown off as a unit into the wind. This struck another condominium upwind and inflicted extensive damage, clearly suggesting inadequate anchorage of the decking to the supporting structure.

In reviewing the damage to these units and others in the immediate vicinity, the team made the following observations. First, wind speeds in excess of 60 mph (the minimum prescribed value in the code) should have been anticipated for structures on the high bluffs overlooking the

FIGURE 3.42 Makahuena Point Condominiums sited immediately adjacent to bluff.

FIGURE 3.43 Wind damage to Makahuena Point Condominiums, Kauai.

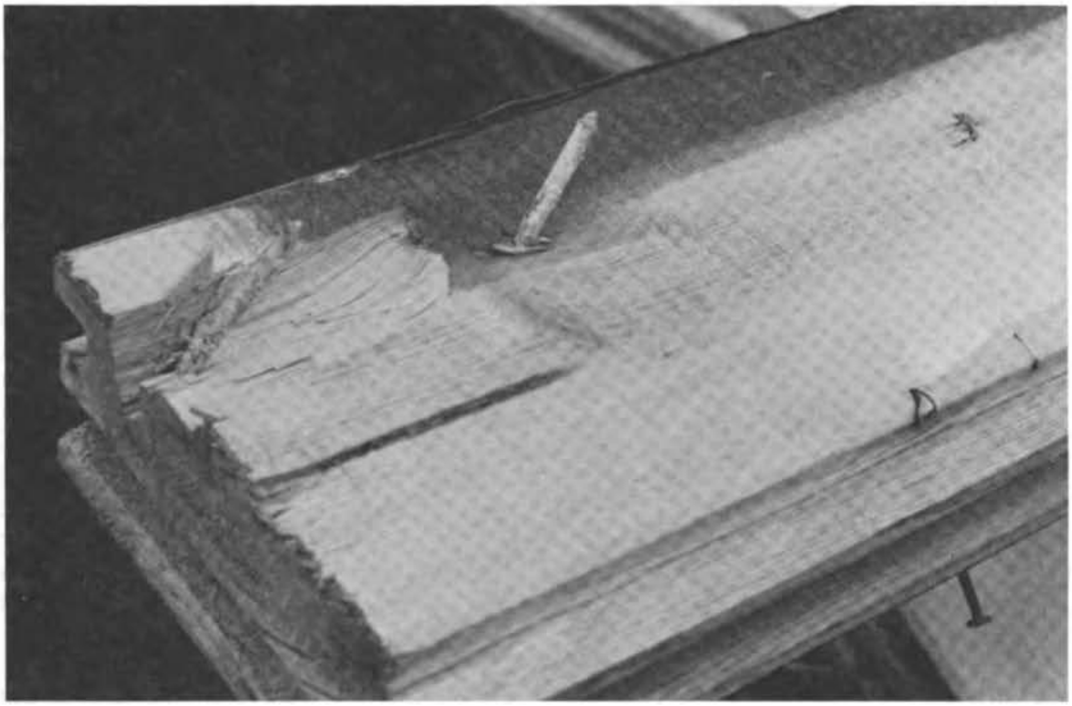

FIGURE 3.44 Roof deck fasteners (note penetration of 60d spikes is approximately 2 in.).

coastline. Second, the attachment of the roof decking to the supporting beams and walls should have consisted of wood screws or lag bolts (with adequate penetration) or perhaps even bolts and metal framing angles, considering the large spans involved. Finally, in view of the high percentage of glazed areas in the walls on the oceanfront side, the possibility of increased loading on the roof system due to a failure of a door or window should have been duely considered.

Nawiliwili Area

Maximum wind speeds in this area were probably close to that recorded at Lihue Airport, which Table 2.1 notes to be 73 mph (sustained), although some localized amplification in speeds may have occurred because of the Hoary Head Range (Figure 2.1). Damage to commercial structures was generally limited to older timber-framed structures clad with light-gage metal sheeting. Much of this damage can be attributed to inadequate nailing or in some cases to sheeting panels having rusted through at fastener locations or fasteners having been subjected to severe corrosion (Figures 3.45 and 3.46).

A preengineered metal warehouse building on the top of a bluff overlooking Nawiliwili Harbor sustained heavy damage at its south end adjacent to the cliff. This building was not visited by the team; for

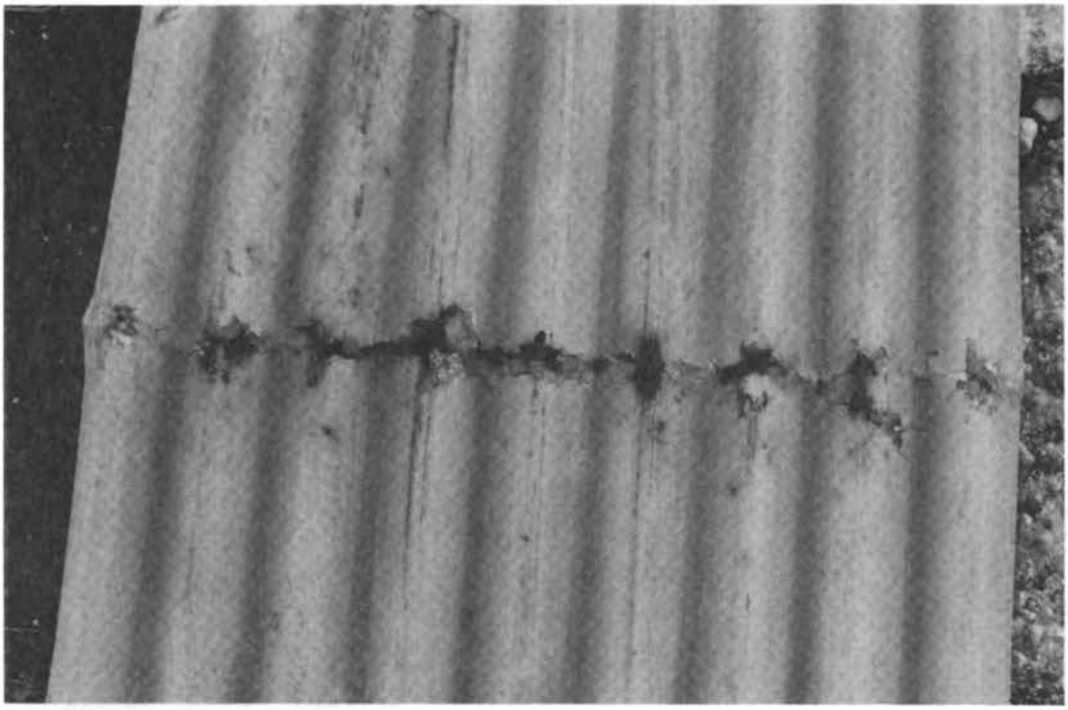

FIGURE 3.45 Light-gage corrugated metal sheeting (note sheeting has rusted through along fastener line).

FIGURE 3.46 Corrosion of metal fasteners used to attach light-gage metal sheeting.

further details refer to the report published by the Structural Engineers Association of Hawaii (1983).

Kauai High School, which is located north of Nawiliwili Harbor, experienced major damage to some of its buildings. The gymnasium building (which was used as a storm shelter) lost large portions of its roof covering, which consisted of lightweight ship-lap wood sheeting (Figure 3.47). A portable classroom building located on the slab shown in Figure 3.48 was completely demolished. Two other bungalow-type structures (an undamaged unit is shown in Figure 3.49) were heavily damaged. The structural integrity of these portable units was substantially reduced due to the lack of proper anchorage to the foundation.

The Kauai Surf Hotel north of Kalapaki Beach had one of its two 14-story units directly exposed to the maximum winds (Figure 3.50). While no structural damage to this reinforced concrete structure was noted, a large number of the sliding glass doors adjacent to the lanai porches on the windward side were blown off or sucked out of their tracks. Substantial water damage subsequently occurred to the contents and interior of the affected rooms.

Lihue Area

Maximum sustained wind speeds varied from 73 mph at the airport to an estimated 50 to 55 mph in downtown Lihue and in the residential areas. City, state, elementary school, and local small-business buildings in the downtown area performed satisfactorily for the most part, with minor damage to roof shingles and tiles (Figures 3.51 through 3.53). Newspaper accounts reported substantial damage to glass windows, apparently due to windborne debris.

The industrial area approximately one mile to the east of downtown Lihue provided the team with the opportunity to compare the performance of a large number of timber-framed warehouse buildings clad with light-gage metal sheeting with that of typical preengineered metal buildings. Substantial loss of sheeting occurred for many of the timber-framed buildings due to inadequate nailing (Figure 3.54). With the exception of those metal buildings cited earlier in which planned openings provided natural ventilation (Figures 3.11 and 3.12), the performance of the preengineered buildings was observed to be satisfactory (Figure 3.55).

Kapaa

In spite of the fact that the maximum sustained wind speeds were estimated to be in the range of 50 to 55 mph, superficial cladding damage to major damage of roof coverings was widespread. At Kapaa High School (which was used as a storm shelter), four classroom buildings suffered damage that involved the loss of portions of the light-gage metal sheeting used as roof coverings. At Kapaa Elementary School most of the classroom buildings lost substantial portions of the light-gage metal roofing that had been nailed over an existing shingle roof (Figure 3.56).

FIGURE 3.47 Wind damage to Kauai High School gymnasium.

FIGURE 3.48 Kauai High School (site of heavily damaged temporary building).

FIGURE 3.49 Undamaged bungalow unit at Kauai High School.

FIGURE 3.50 Kauai Surf Hotel.

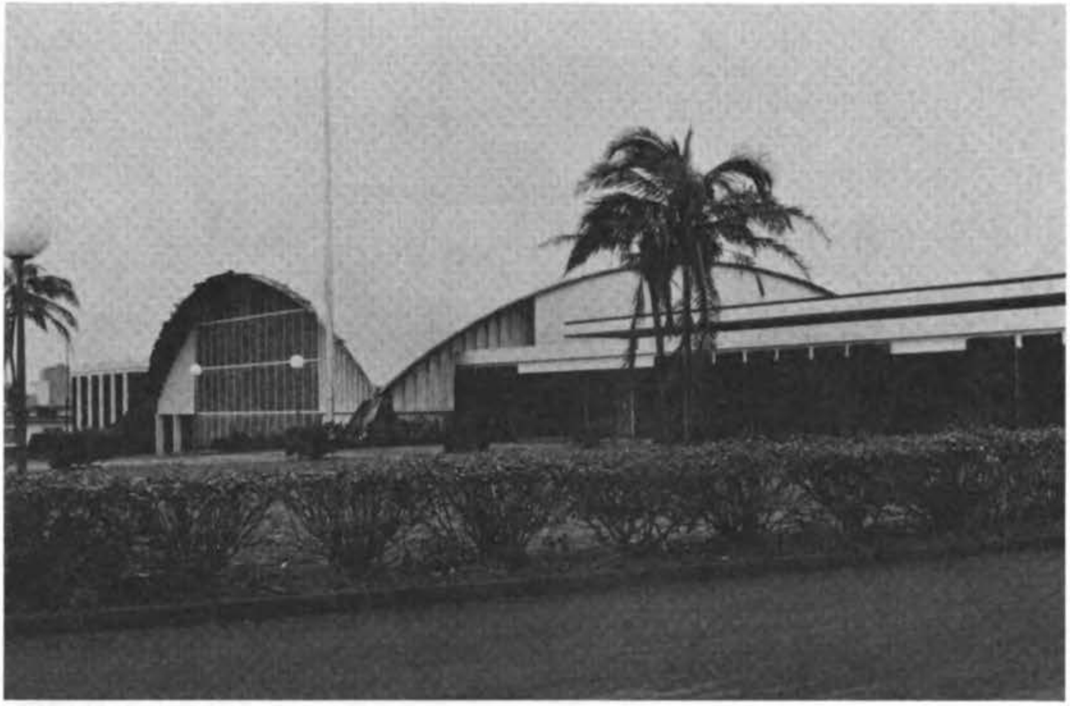

FIGURE 3.51 Convention Center at Lihue, Kauai (note minor damage to roof flashing at rake; some glass breakage occurred due to windborne debris).

FIGURE 3.52 Minor wind damage to city building at Lihue, Kauai.

FIGURE 3.53 Undamaged Wilcox Elementary School at Lihue, Kauai.

FIGURE 3.54 Damaged timber-framed warehouse building at Lihue, Kauai.

FIGURE 3.55 Undamaged preengineered metal building at Lihue, Kauai.

FIGURE 3.56 Damage to roof covering of Kapaa Elementary School (note light-gage corrugated metal sheeting nailed over existing roof).

The team inspected Kapaa Meadows, a new low-cost federally supported housing development. Of the 62 single-family dwellings, all but four units (which were in sheltered locations) sustained some degree of roof damage. The damage ranged from loss of some portions of the light-gage corrugated steel roof covering (Figures 3.57 and 3.58) to loss of entire sections of the roof system, which consisted of prefabricated wood trusses toe nailed to the top plates of the stud walls (Figure 3.59). A review of the construction plans for these dwellings indicated that no nailing schedule was provided for the sheeting, nor did the plans show any detail for anchorage of the roof trusses to the stud walls. Note the large roof overhangs and damage to the carport roofs. Virtually all of this damage could have been avoided by proper anchorage of the roof trusses to the stud walls, for instance through the use of metal clips, and by an adequate nailing schedule for the roofing material.

Princeville

The Princeville Realty Corporation resort development (Figures 1.6 and 3.60) proved of particular interest to the team for a number of reasons. First, 127 of the 180 new condominiums and townhouses were damaged; current market values of these units range from $120,000 to $400,000 per unit. Second, a variety of distinctly different modern designs were employed using a variety of construction materials. Third, some of the units sustained major damage to their roofs, walls, and glazed areas, whereas others exhibited no visible damage except an occasional missing shingle or roof tile. Fourth, although all of these units were located within a maximum distance of 1.5 miles, the team concluded that the wind environment was very different for some of the units because of topographic and terrain effects.

Although no reliable wind data are available for this region, eyewitness reports and examination of the extent and intensity of the damage suggest that strong winds approached the Princeville Center from at least two directions during the passage of the hurricane--namely, from the southwest, with speeds amplified as the wind was funneled through the valley lying between mountain ranges, and from the west, with winds flowing across Hanalei Bay (Figure 2.1). Based on the intensity and extent of damage, maximum sustained wind speeds were estimated to be in the range of 70 to 80 mph.

The general performance of six distinct units, of which Figure 3.60 depicts five, was investigated by the team. The units at Pali Ke Kua, the Hanalei Bay Villas, the condominiums at the Hanalei Bay Resort, and the Bali Hai Restaurant (located adjacent to the Hanalei Bay Resort units) all sustained wind damage ranging from superficial cladding damage to their roofs and sliding glass doors to the loss of major portions of their roofs and walls. The townhouses at Pu'u Po'a and Hale Moi, on the other hand, experienced no visible damage other than an occasional missing shingle or roof tile. The Sandpiper Village units (Figure 3.61) located east of the other developments and on flat open country terrain had no visible damage.

The aerial photograph of Figure 3.62 shows the topographical features immediately adjacent to four of the units inspected; the top of

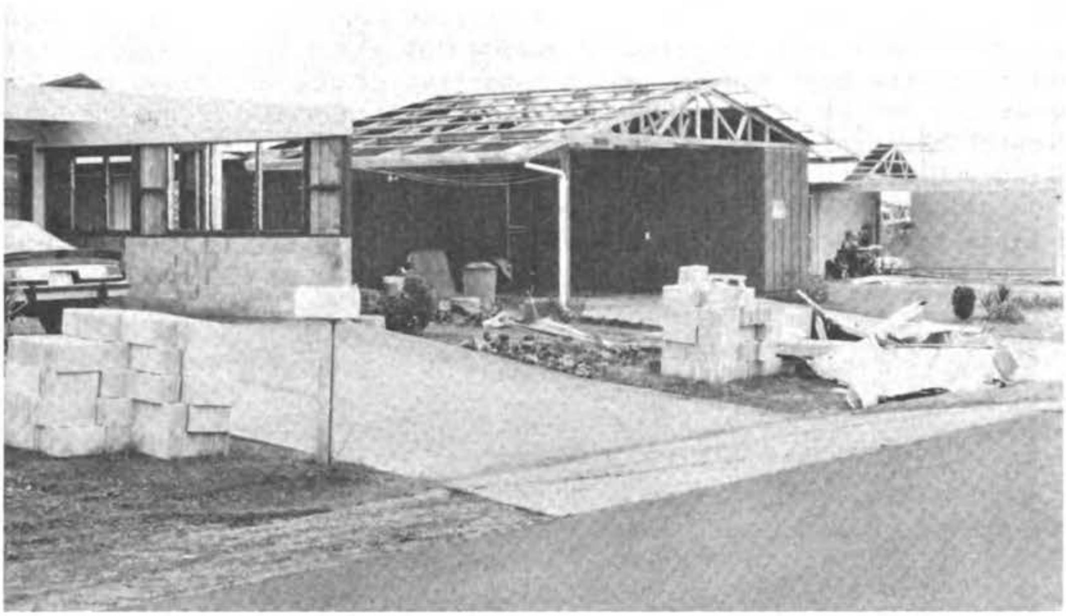

FIGURE 3.57 Damage to roof covering of single-family dwelling at Kapaa Meadows, Kauai.

FIGURE 3.58 Loss of carport roof at Kapaa Meadows, Kauai.

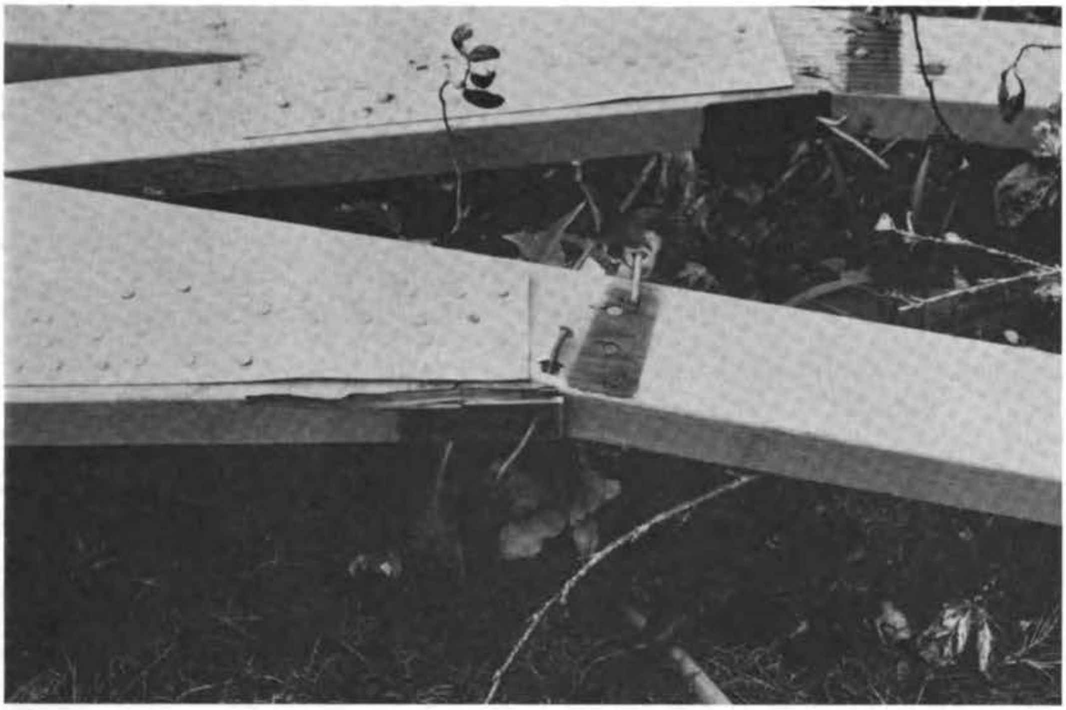

FIGURE 3.59 Toe nailing of prefabricated roof trusses to stud walls (note a single fastener is used for anchorage).

the photograph points toward the southeast (see Figure 3.60). The condominiums shown on the left edge of the photograph are a portion of the Pali Ke Kua units along the bluffs overlooking Hanalei Bay. In the center of the photograph are the Hanalei Bay Villas along the ridge line and bounded on the left by the Hale Moi townhouses (extreme upper left-hand corner) and the Pu'u Po'a units on the right (bottom right-hand corner).

The conventional timber-framed Hale Moi units sustained only very minor cladding damage to the roof coverings. The Pu'u Po'a condominiums (Figures 3.63) are of reinforced concrete shear wall construction, and no damage to these units was observed. However, the other two housing developments, Pali Ke Kua and Hanalei Bay Villas, sustained major damage to many of their units. In each case the location of the units appeared to be a factor.

The aerial photograph of Figure 3.64 provides a panoramic view of the damage sustained at Pali Ke Kua and the lack of damage to the Hale Moi units in the upper right-hand corner (see also Figures 3.60 and 3.62). The influence of terrain exposure is clearly seen, as those units near the cliffs along the oceanfront (Figure 3.65) were subjected to amplified speeds for winds flowing over the top of the bluffs from the southwest or west. The units at Pali Ke Kua were two-story multiple-family dwellings of conventional timber-framed construction. Note the high percentage of glazed areas on the windward faces.

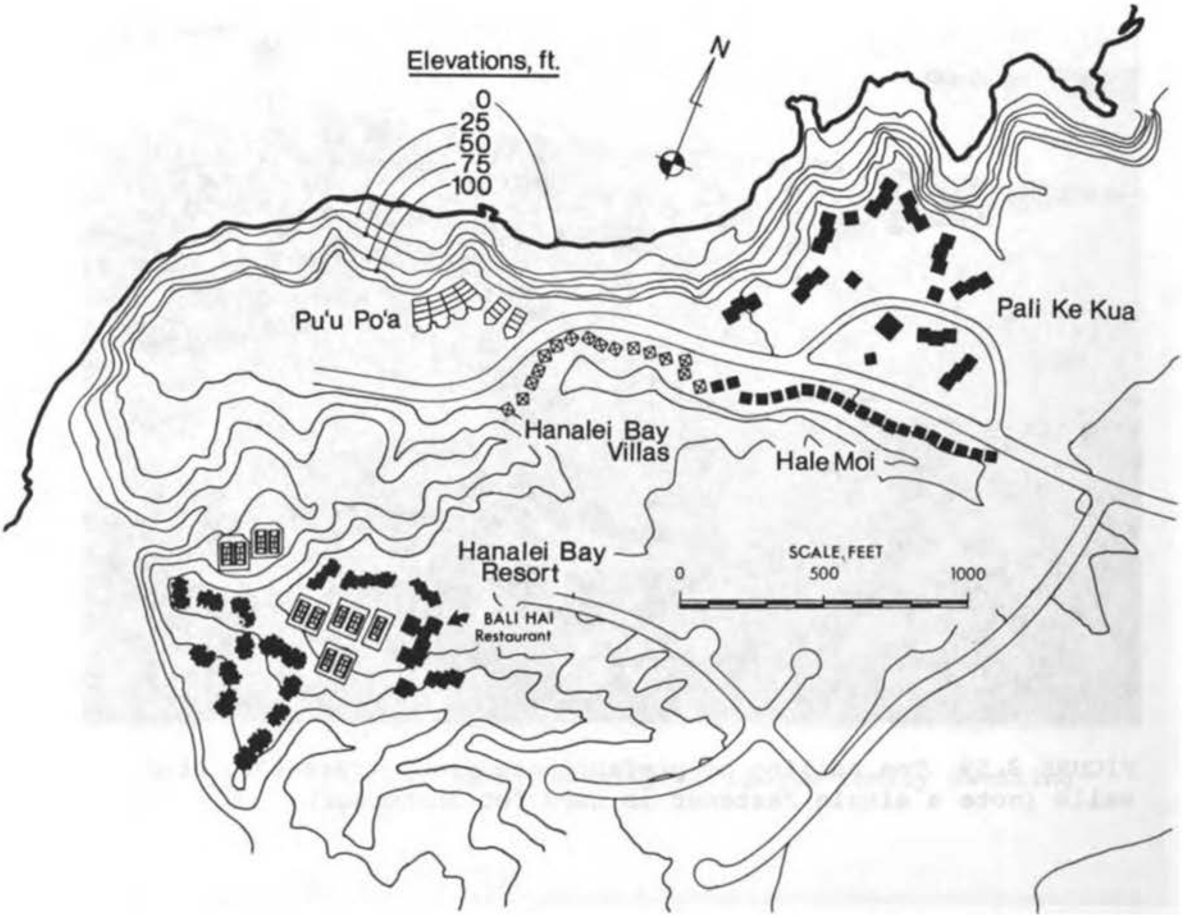

FIGURE 3.60 Topographical map of northwest portion of Princeville Realty Corporation resort development, Kauai.

Failures of the sliding glass doors or windows and the subsequent increase in internal pressure together with the external suction undoubtedly contributed to the losses of major portions of the roofs of these units.

The Hanalei Bay Villas are two- and three-story single-family dwellings that use the pole house design concept (Figures 3.66, 3.67, and 3.68); the floors and walls are of conventional wood joist and stud wall construction, respectively. Walls overlooking the golf course to the south were provided with a high percentage of glazed areas. Extensive wall damage was limited for the most part to these areas (Figure 3.68). The roof framing consists of four hip beams extending from the corners of the stud walls (which are arranged in a square floor plan) and converging at the center of the roof. The hip beams were toe nailed to each other at the apex of the roof, but apparently they were not fastened to the stud walls at the corners of the structure (Figure 3.69). Valley rafters at 90 degrees to the stud walls were toe nailed to the hip rafters and toe nailed (and blocked) to the top plate of the walls at the overhand.

FIGURE 3.61 Undamaged Sandpiper Village units, Kauai.

FIGURE 3.62 Aerial view of wind damage at Princeville, Kauai.

FIGURE 3.63 Undamaged Pu'u Po'a units, Princeville, Kauai.

FIGURE 3.64 Damage at Pali Ke Kua, Princeville, Kauai (note damage to units sited near bluffs).

FIGURE 3.65 Damage to townhouses at Pali Ke Kua, Princeville, Kauai (note high percentage of glazed areas in damaged walls).

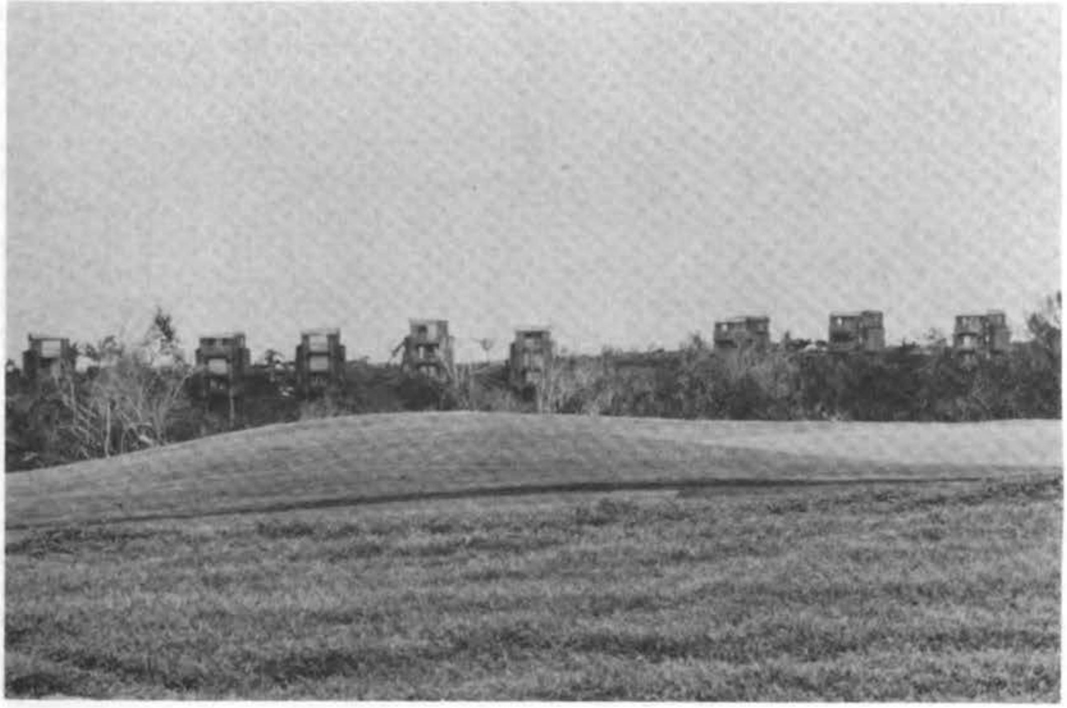

FIGURE 3.66 Wind damage to Hanalei Bay Villas, Princeville, Kauai (viewed from south).

FIGURE 3.67 Pole house type construction of Hanalei Bay Villas at Princeville, Kauai.

FIGURE 3.68 Damage to Hanalei Bay Villas on windward wall.

FIGURE 3.69 Fastener details of hip roof.

Almost all of these units sustained major damage to large portions of their roofs. This damage could have been eliminated or at least mitigated through the use of proper connections. At the very least, metal framing angles should have been provided to connect the hip beams to each other at the apex of the roof and to the top plate of the stud walls. Furthermore, experience has shown that the use of toe nailing for rafters that have large overhangs should be avoided where possible.

The Hanalei Bay Resort, shown in Figure 3.60, consists of clusters of two-story townhouse units, tennis courts, swimming pools, and the Bali Hai Restaurant. The development is located at the end of a ridge overlooking the ocean with deep ravines on either side. The general topography can be seen in Figure 3.70. The units are constructed of reinforced masonry load-bearing walls, reinforced concrete floor slabs, and lightweight timber-framed roofs. Most of the units sustained extensive roof damage (Figures 3.70 and 3.71). Because of time limitations, the team did not closely inspect these units, and the reader is referred to the report by the Structural Engineers Association of Hawaii (1983). This document attributes much of the observed damage to inadequate nailing of the tongue-and-groove wood decking to the timber supporting beams. Figure 3.70 shows that roof surfaces exposed to the winds from the south to west directions sustained the most damage. Again, the influence of topographic features on the wind environment appears to be a major contributing factor.

The Bali Hai Restaurant (Figure 3.72) is adjacent to the townhouse units at the northeast edge of the resort development. This two-story

FIGURE 3.70 Damage to Hanalei Bay Resort townhouses (viewed from southeasterly direction).

FIGURE 3.71 Hanalei Bay Resort townhouses (viewed from northeasterly direction).

FIGURE 3.72 Wind damage to roof of Bali Hai Restaurant, Princeville, Kauai.

structure sustained extensive damage to its roof covering and subsequent water damage. Eyewitness accounts indicate that a large number of the glass sliding doors enclosing the dance floor and bar area on the upper level were either sucked out or blown in during the passage of the hurricane. It is fortunate that no one was injured, as this structure was used as a storm shelter. Note again that topography was undoubtedly a factor in the extensive wind damage that occurred.

DAMAGE ON OAHU

Introduction

The intensity and extent of the damage inflicted on Oahu by Hurricane Iwa were considerably less than that encountered on Kauai. This was primarily due to the track of Iwa, as shown in Figure 1.1., which indicates that the center of the storm passed almost 110 miles to the west of Oahu. Damage due to storm surge, wave action, and flooding was primarily confined to the coasts from Makaha to Koko Head (Figure 1.3). Eyewitness accounts suggest that although high storm surge lasted for a protracted period of time, there was no continuous intensive wave activity along the coastal areas (Structural Engineers Association of Hawaii, 1983).

Maximum winds recorded throughout the island were substantially less than on Kauai (Table 2.1), with two exceptions: the Schofield Barracks area near Wahiawa, where winds were funneled through Kolekole Pass and south through the plains lying between the Waianae Mountains and Koolau Range, and Kaneohe, where heavy damage to residential construction occurred to the lee of the Koolau Mountains.

The figures that follow illustrate the type and intensity of damage documented by the team for four areas where the bulk of the damage occurred: the coastline from Makaha to Koko Head, the Honolulu airport area, the Wahiawa area, and Kaneohe.

Damage Due to Hydraulic Forces and Flooding

Harbor and Offshore Structures

This section describes damage in a general geographical order beginning at Haleiwa and continuing around the coastline in a counterclockwise direction. At Haleiwa an offshore breakwater built with federal funds for beach protection was severely damaged. Continuing down the coast, the Waianae small-boat harbor breakwater designed by the Corps of Engineers sustained very minor damage and appeared to have protected the boats in the harbor quite well. However, the Pokai Bay breakwater, a state-operated small-craft harbor of refuge less than two miles away, was breached in three places and rendered inadequate for boat protection (Figure 3.73). Large oil pipelines extending from a point 1.5 miles offshore to the two refineries at Barbers Point were damaged by wave- and wind-generated currents, although no major oil spillages occurred.

Kewalo Basin, a small-boat basin adjacent to Honolulu Harbor, experienced high storm surge and wave action, which destroyed one boat and caused minor damage to a revetment and catwalks. Ala Wai Harbor, another small-boat basin adjacent to Honolulu Harbor, suffered approximately $200,000 of damage to the breakwater and revetment. It was reported by Carl Keller, Pacific Ocean Division, Corps of Engineers, that 5- to 6-ft waves were overtopping the Ala Wai breakwater, which caused a backside stability problem on the breakwater. Many boats broke their moorings and collided in Honolulu Harbor, according to Coast Guard accounts.

It was reported by the Honolulu Star-Bulletin on November 24, 1982, that five crewmen were injured, one fatally, when the missile destroyer Goldsborough was hit by a 30-ft wave while leaving Pearl Harbor to ride out the storm.

(The Pacific Ocean Division of the Corps of Engineers in Honolulu, Hawaii, has prepared damage reports for the harbors on Oahu, but they were not available for review at the time this report was prepared.)

Beachfront Buildings and Structures

On Oahu the region that sustained the most damage from storm surge and wave action was the coastline area from Makaha to Nanakuli. This is a high-density residential area with some condominium developments and small businesses. Extensive damage ranging from total devastation to heavy flooding occurred throughout the residential neighborhood of Makaha (Figure 3.74).

FIGURE 3.73 Storm surge and wave damage to Pokai Bay breakwater, Oahu.

FIGURE 3.74 Damage to single-family dwelling at Makaha, Oahu.

A large portion of the ground-level floor of the Makaha Shores Condominium was gutted, with one resident reporting waveborne debris striking and breaking a glass door on the second floor of the building (Figure 3.75). A careful inspection of this reinforced concrete load-bearing-wall building indicated that it had sustained no apparent structural damage. The bearing wall in this case also functions as a shear wall. The building was constructed very near the water but was partially protected by a grouted unreinforced lava rock seawall (Figure 3.76). This wall experienced no damage and prevented extensive erosion around the footings of the structure, such as occurred at Kuhio Shores on Kauai (Figure 3.19). Note that the bearing walls of this building are roughly normal to the coastline.

Buildings and homes along the coastal (Farrington) highway on the ocean side of the road between Makaha and Nanakuli sustained extensive damage from storm surge and wave action. Most of the damage on the landward side of the highway appeared to be due to flooding and waterborne debris.

Extensive water damage was observed in the Waikiki area, which is highly developed with resort hotels adjacent to the beaches. In most oceanfront hotels on Waikiki, garages are below ground level and were flooded. Also, it was reported that the Royal Hawaiian Hotel's pool was submerged under 1 ft of water.

The inspection team of the Structural Engineers Association of Hawaii (1983) reported that a sidewalk on top of a seawall in the Waikiki area was damaged. They noted that failure was due to severe corrosion of the reinforcing steel, which severely reduced the stuctural capacity. Unreinforced concrete masonry unit walls were reported to fare far less well than reinforced concrete walls, as would be expected.

From the Honolulu area to Koko Head many coastal residences were flooded, and some extensive damage to single-family dwellings near the coastline was reported.

Damage Due to Wind

Makaha to Barbers Point

As shown in Figure 2.2, maximum sustained wind speeds for the coastline region of Oahu from Makaha to Barbers Point were estimated to be in the range of 55 to 60 mph and hence slightly less than values in the building code. Wind-induced damage in this region was observed to be light, being limited to minor losses of cladding (shingles, roof tiles, etc.).

Honolulu Airport Area

Perhaps the most reliable wind speed data available for Hurricane Iwa were recorded at the Honolulu International Airport (Table 2.1). Maximum sustained wind speeds were found to be 49 mph, with gusts to 84 mph. Modern engineered structures performed satisfactorily, with only

FIGURE 3.75 Water and wave damage to Makaha Shores Condominium, Oahu.

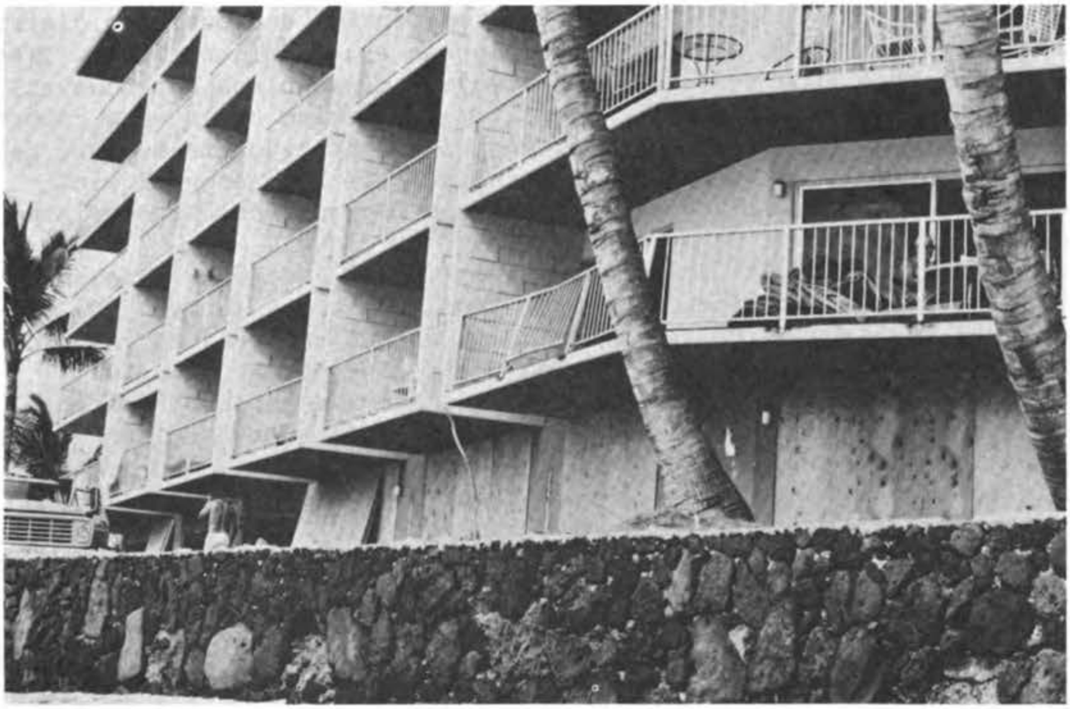

FIGURE 3.76 Seawall protecting Makaha Shores Condominium.

minor cladding damage (to roof coverings, glass windows, etc.) caused by windborne debris. A variety of modern preengineered metal buildings were located in the airport area. A number of these buildings were designed as hangars and were open on the side facing the storm (Figure 3.77). Other hangars for small aircraft were enclosed by large folding doors on the windward side (Figure 3.78). The team observed no indication of structural distress for any of the buildings. The team did note a bothersome item, however; the existence of a large number of old, metal- and timber-framed structures clad with light-gage corrugated metal sheeting (Figure 3.79). These structures, located in close proximity to newer buildings, posed a high hazard to life and property during the passage of the hurricane. A number of these buildings lost large portions of their roof and wall panels that were inadequately fastened to the purlins or had rusted through at the sites of fasteners.

Aircraft in this area fared less well. Newspaper accounts listed 25 light planes overturned, with 6 severely damaged. A DC-3 was blown across a runway at the height of the storm.

Wahiawa Area

Maximum sustained wind speeds in the Wahiawa area were estimated to be in the range of 60 to 65 mph for the open country and agricultural areas. Damage in the business and residential areas of Wahiawa was relatively light, being confined to minor cladding failures (loss of shingles, roof tiles, or glass). Most of this damage came from windborne objects, as shingles and foliage became windborne and struck structures and buildings. Part of the residential and business district is sheltered by a high density of eucalyptus trees (Figure 3.80). The presence of this type of foliage is always a mixed blessing, however, as some instances of windborne limbs and trees striking homes were reported (e.g., Figure 3.80). Nevertheless, the high density of trees must be considered overall as beneficial in dissipating the energy of wind. Undoubtedly, it partially accounted for the lack of more wind-related damage in this area.

The bulk of the estimate made by the Federal Emergency Management Agency (1982) for wind-induced damage from Iwa at U.S. Army installations is based on the severe damage that occurred to the old timber-framed warehouse buildings and their contents at Schofield Barracks (Figures 3.8, 3.9, and 3.81). Damage was extensive, with a large number of structures being completely destroyed. Failure of these buildings can be attributed to the loss of the light-gage corrugated metal sheeting panels nailed to timber purlins. The sheeting-purlin roof system was necessary to provide the roof diaphragm action, and loss of this system caused collapse of the buildings. Figure 3.82 shows the nailing schedule for most of these buildings. Failure occurred due to failure of the nail heads, withdrawal of the nails, or in some cases pulling of the panels through the nail heads.

One interesting structure is a modern preengineered building located in this general area on Kam Highway that endured maximum exposure to the wind (Figure 3.83). The structure is clad with light-gage sheeting, but

FIGURE 3.77 Undamaged preengineered metal hangar building at Honolulu International Airport (note building was open on windward face for Iwa).

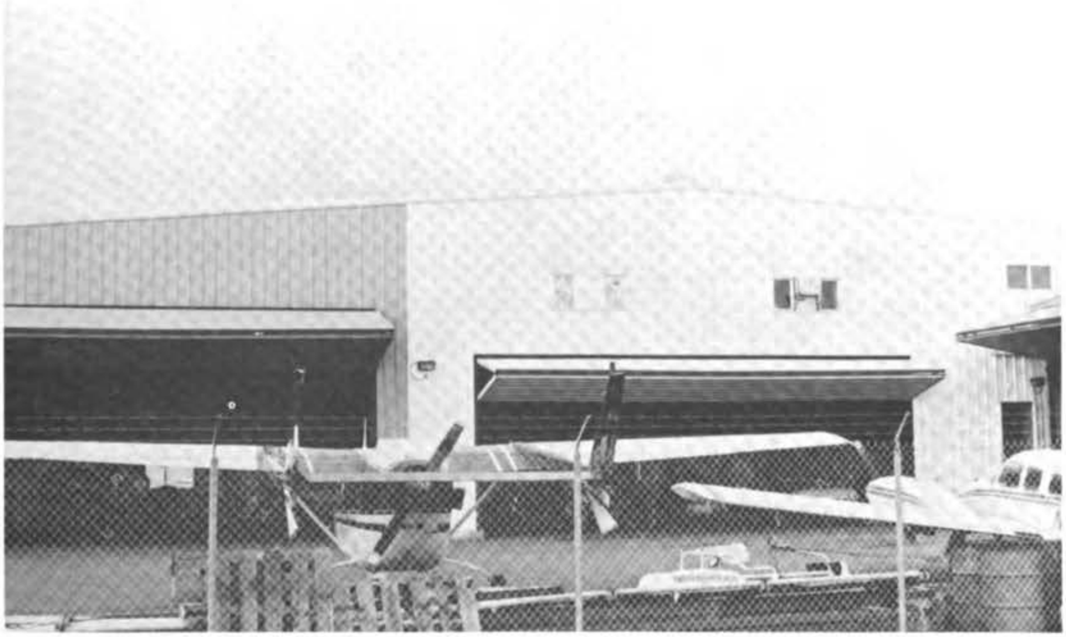

FIGURE 3.78 Undamaged preengineered metal hangar building at Honolulu International Airport (note large fold-up doors that escaped damage).

FIGURE 3.79 Old metal hangar building at Honolulu International Airport (note large portions of missing roof cladding).

FIGURE 3.80 Eucalyptus trees in residential area of Wahiawa, Oahu (note damage to residence from falling tree).

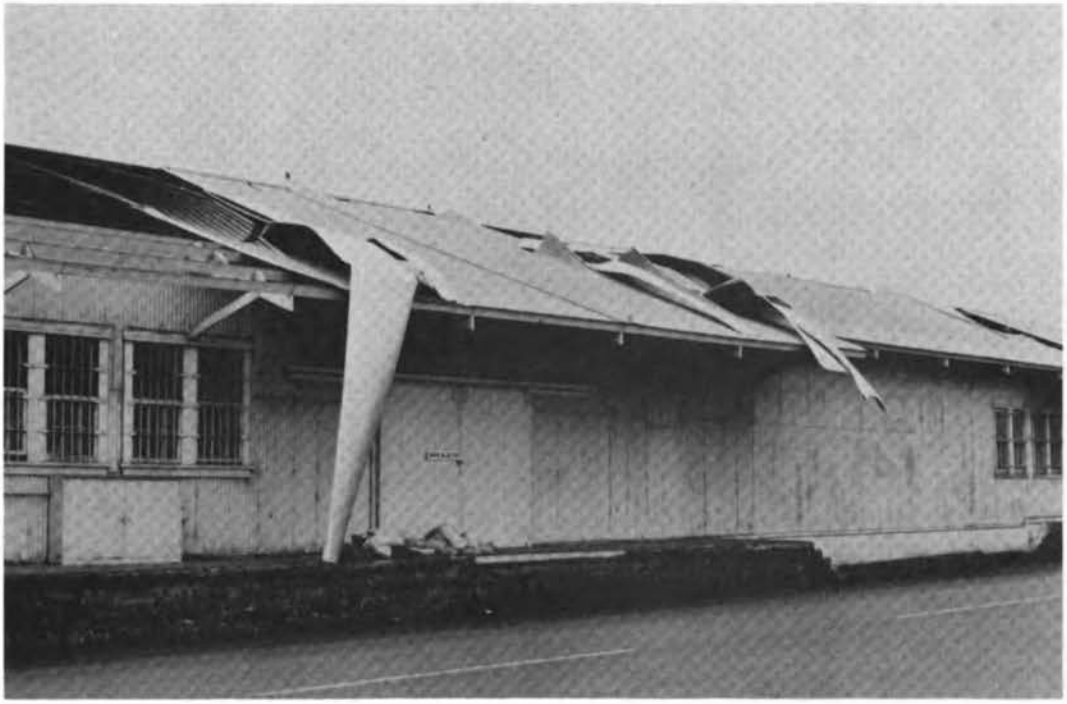

FIGURE 3.81 Cladding damage to warehouse buildings at Schofield Barracks, Oahu.

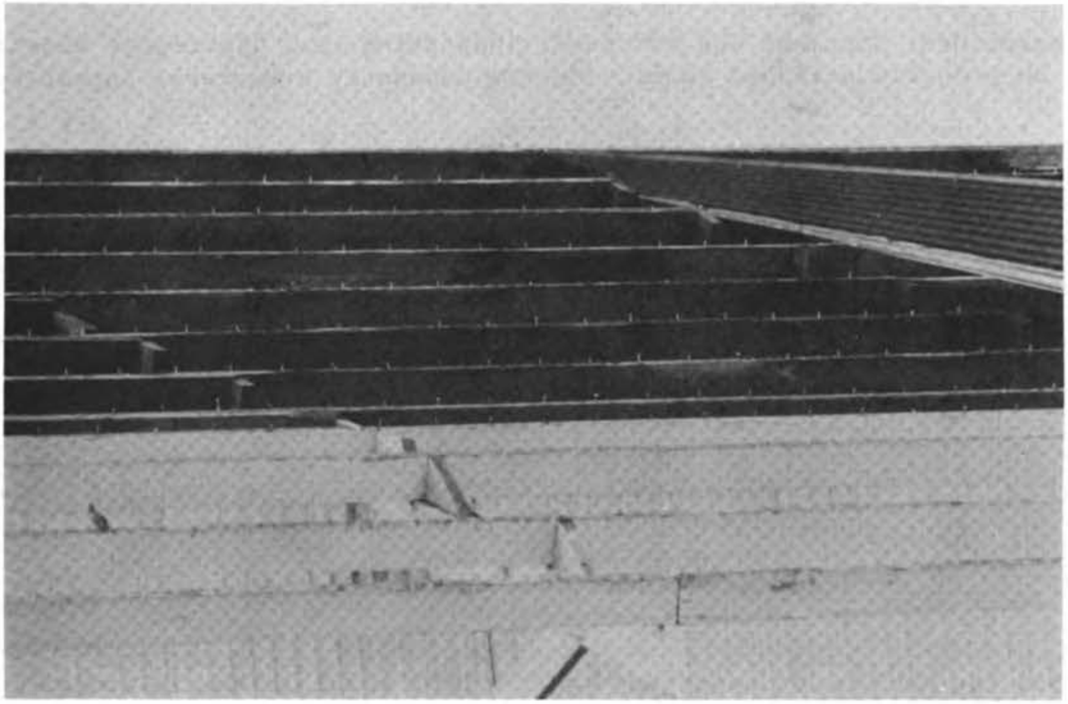

FIGURE 3.82 Nailing schedule for attachment of light-gage metal cladding to timber purlins.

FIGURE 3.83 Undamaged preengineered metal building located on Kamehameha Highway near Wahiawa, Oahu.

no structural distress was observed, indicating that light-gage sheeting can be properly attached to provide the necessary structural integrity.

Kaneohe

Sustained wind speeds in the Kaneohe area were estimated to be from 65 to 70 mph due to amplification of winds to the lee of the Koolau Range (Figure 3.84). Damage to residential construction and small-business buildings was widespread (Figures 3.85 and 3.86), but it was confined, for the most part, to minor losses of roof coverings and glass damage due to windborne debris (such as shingles and foliage). The team observed that, in general, the quality of construction of single- and multiple-family dwellings in Kaneohe was better than that noted on Kauai. This undoubtedly contributed to there being less damage observed in this area than in a comparable wind environment on Kauai.

DAMAGE ON NIIHAU

Across the Kaulahohe Channel of Kauai's west coast is the island of Niihau. At its closest point to land, Hurricane Iwa's center was less

FIGURE 3.84 Lee of Koolau Range, Kaneohe, Oahu.

FIGURE 3.85 Missile damage to roof of residence at Kaneohe, Oahu.

FIGURE 3.86 Roof damage to homes located along ridge line at Kaneohe, Oahu (there was little or no damage to homes not sited along the ridge in this area).

than 25 miles from the island. This island is privately owned by the Robinson family and was not visited by the team. It covers approximately 70 square miles and is only sparsely populated. Newspaper accounts indicate that Governor Ariyoshi, after flying over the island in a helicopter on an inspection tour, reported that a number of homes and farm buildings had been completely destroyed and that a large number of other homes and buildings had major roof damage.

4

LIFELINES

INTRODUCTION

Lifelines include power (energy), water, sewage, transportation, and communication systems. Most of the severe damage to lifelines was to electric pole-mounted (overhead) transmission and distribution lines and to telephone cables mounted on the same poles as the electric lines. The loss of transmission lines from generating stations caused the complete loss of electric power on the island of Kauai. On the island of Oahu, the loss of four circuits of transmission lines caused a 1-1/2 hour blackout in Honolulu and southeastern Oahu.

ELECTRIC POWER SYSTEMS

Almost all of the physical damage to electric power systems consisted of the failure of wood poles carrying transmission and distribution lines and the pulling out of guy anchors.

The City and County of Honolulu

Oahu has three generating stations: Kahe power plant (658 MW), Waiau power plant (531 MW), and Honolulu power plant (158 MW). These power plants furnish power through 138-kV tranmission lines to transmission stations at Wahiawa, the Campbell Estate Industrial Park (CEIP), Makalepa, Halawa, Koolau, and Pukele (Figure 4.1). A 46-kV subtransmission system connects the generating stations and the transmission substations to numerous local distribution stations, which distribute power to their respective service areas (Figure 4.1).

The single most important event affecting the Hawaiian Electric Company system on Oahu was the almost simultaneous loss at 6:32 p.m. on Tuesday, November 23, of four 138-kV transmission line circuits crossing the Waimalu Gulch 5-1/2 miles north-northwest of Honolulu International Airport. Two of these circuits were supported on wooden pole structures, and two others had aluminum frame structures. The conductor spans ranged from 2,000 to 3,000 ft. The cause of the failures appears to be the loss of embedment of the concrete block anchors for the guys

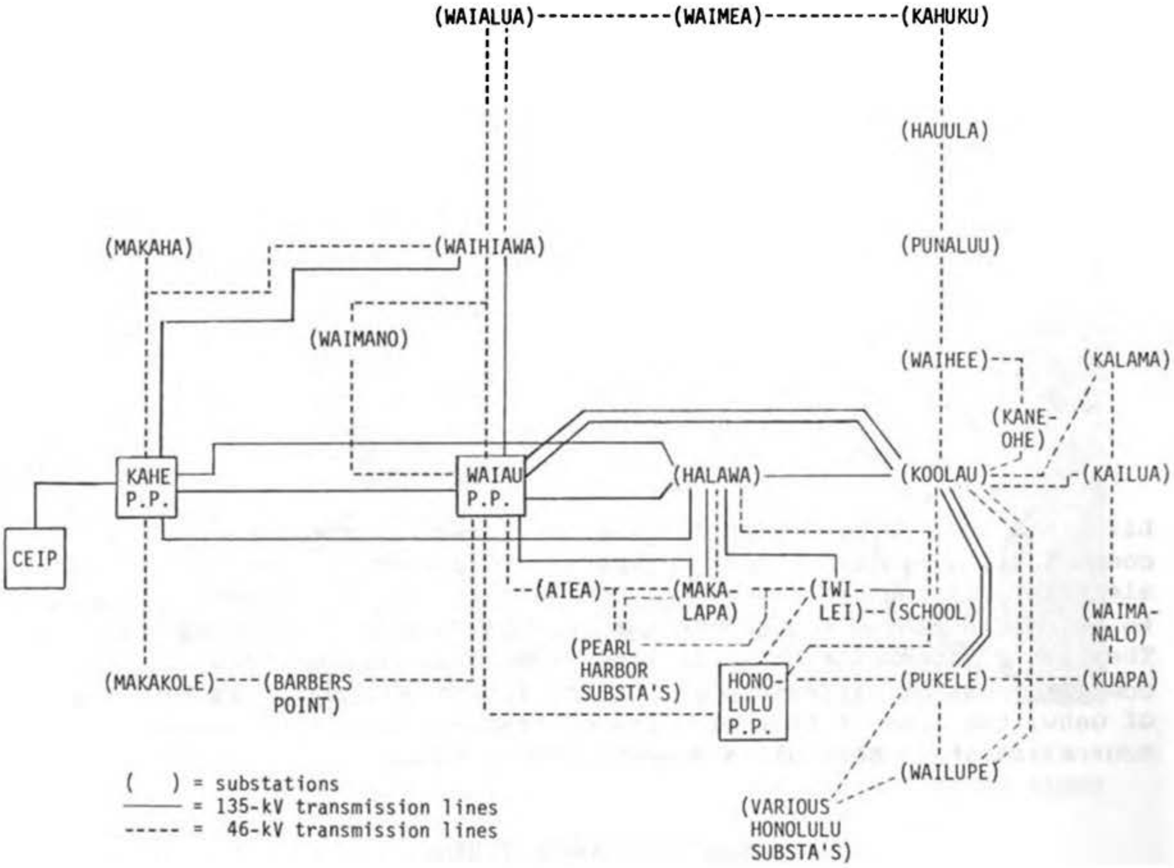

FIGURE 4.1 Hawaiian Electric Company power system (Oahu).

that furnish lateral support for the wooden pole structures and aluminum frame structures. The loss of these transmission lines and of other key subtransmission and distribution lines effectively blacked out the entire southeastern part of Oahu. The Honolulu power plant was thereby isolated and became overloaded immediately; the Honolulu voltage collapsed, which resulted in an "overload trip," and Honolulu was blacked out. The Kahe power plant was also isolated due to loss of the transmission lines. It was reported that except for an area of 4 miles radius from the Waiau power plant, located at the north shore of the West Lock of Pearl Harbor, all of Oahu was blacked out.

At the Honolulu International Airport almost all lighting was lost until power was restored. Emergency standby power was sufficient only for aircraft control and safety operations functions.

The computers of the Star-Bulletin newspaper were disabled due to the loss of power, which resulted in loss of communications and operations.

Power system engineers and operators quickly developed and implemented a switching plan in the electric system. Approximately 1-1/2 hours after it was lost they began restoring power to Honolulu and southeastern Oahu from the Waiau power plant, and later from the Honolulu power plant.

Also severely affected was the 46-kV subtransmission system for Oahu. Due mostly to the failure of wooden poles, 28 out of 60 46-kV circuits were lost, with multiple failures in several of them. Most of the Waianae coast (western Oahu) was without power for 1-1/2 days until portions of two damaged transmission lines were repaired. The Wahiawa-Mikilua and Kahe-Mikilua lines (Figure 4.1) failed due to overload on Tuesday, November 30. Power was then lost but was restored five hours later. One week later, 5 percent of the distribution lines still had to be restored, leaving small pockets of the island without electricity.

Out of 230,000 power subscribers, those without power were as follows:

November 25	50,000
December 1	12,000
December 3	5,000
December 5	900
December 6	500

There was no damage to transmission or distribution substations or their equipment. Generating stations (power plants) were not damaged. There was a report that the Kahe power plant (Figure 4.2) condenser cooling seawater intake system had ingested large quantities of sand. This phenomenon occasionally occurs during storms that stir up the sea bottom around the intake structures of power plants on exposed coastlines.

The only reported damage to electric equipment, other than conductors and their supports, was to transformers and switches mounted on poles that failed and to a transformer in the flooded basement of the Cinerama Reef Hotel.

The County of Kauai

Electric power on the island of Kauai is furnished by the Kauai Electric Company. Kauai Electric owns one generating station at Port Allen on the southern coastline. This station consists of two gas turbine units of 20 MW each, one oil-fueled unit of 10 MW, and five diesel units totaling 67.5 MW. In addition, Kauai Electric purchases up to 20 MW of power, of which 12 MW is firm power, from the Lihue Plantation Company. This power is generated using bagasse as fuel; bagasse is the residue of sugar cane after the juice has been extracted. Neither generating plant was damaged, but the Lihue Plantation Company plant shut down and could not be restarted until outside power became available.

The Kauai Electric Company has 600 miles of 57.1-kV transmission and 12.5-kV distribution lines, almost all of which are overhead lines supported on wooden poles. Two hundred miles of these lines were lost, mostly due to the failure of supporting poles because of high-velocity wind loads. The result was a total loss of power to the entire island.

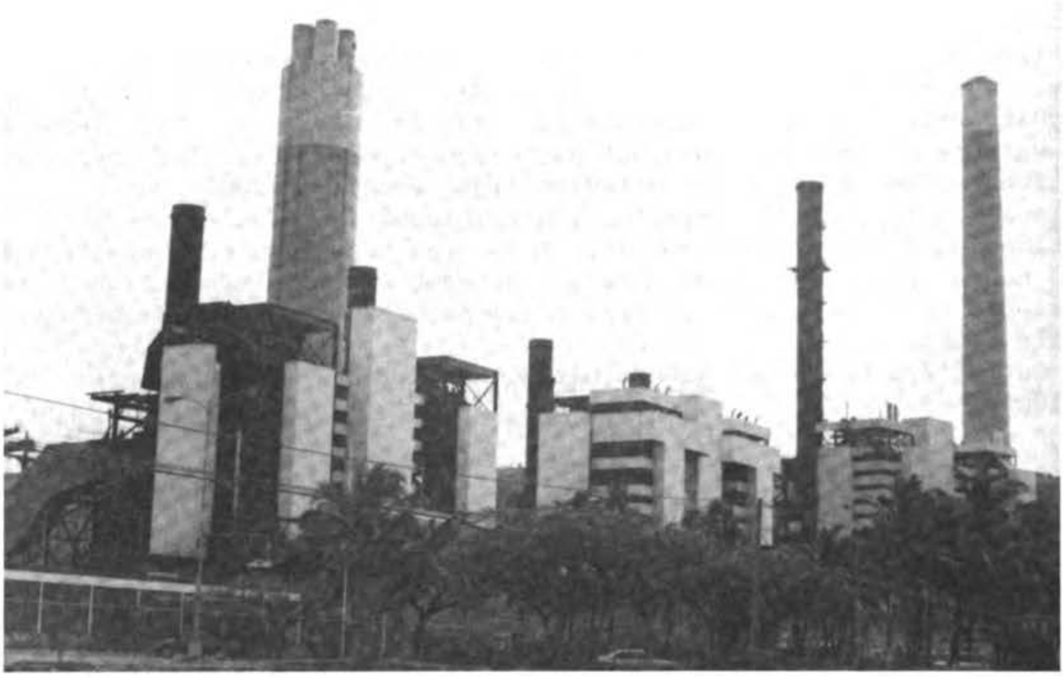

FIGURE 4.2 Undamaged Kahe power plant on the coast of Oahu 4-1/4 miles north of Barbers Point.

The loss of a third of the island's power transmission and distribution system had a severe impact on other lifelines, which will be covered later. The day after the hurricane, only 600 kW of electric power load could be picked up, less than one percent of the firm power available.

On November 23, when Hurricane Iwa struck Kauai, 39.7 MW of power was being delivered to consumers. That night all power deliveries ceased. Between November 23 and December 2, power deliveries increased from 0.6 MW to 24.7 MW, when 31.6 MW of firm power was available.

It was reported that most standby electric generators at essential facilities, such as the Office of Civil Defense and hospitals, started up and operated normally.

It was observed that many poles carrying power transmission and distribution lines fell over due to soil rupture caused by soft saturated soils, insufficient embedment of the pole, or both (Figure 4.3). Many poles failed by bending and shear failure at ground level (Figure 4.4); fewer failed at various heights above ground level (Figure 4.5). Several citizens stated that they had seen failures of poles weakened by termite infestation.

The only electric equipment, other than overhead power lines, known to have been damaged were transformers and circuit breakers installed on poles that failed (Figure 4.6). Several of these transformers burned.

FIGURE 4.3 Power and telephone pole at Poipu, Kauai, that toppled due to soil embedment failure.

FIGURE 4.4 Power pole at Poipu, Kauai, that failed due to pole rupture at ground level.

FIGURE 4.5 Power pole above Makahuena Point, Kauai, that failed at mid-pole height.

FIGURE 4.6 Pole-mounted transformers and circuit breakers damaged when wind-driven building debris knocked over a pole-supported customer substation near Kunia, Oahu.

In the Hanalei area on the northern coast, power from a small hydroelectric plant that furnishes electricity to the towns of Hanalei and Kilauea was lost due to a fallen transmission line tower. Portable generators were obtained to supply minimum lighting and to run refrigerators in an attempt to save perishable foods.

COMMUNICATION SYSTEMS

Telephone Systems

The Hawaiian Telephone Company systems on both Kauai and Oahu were affected by the loss of cables supported on poles owned jointly with the power companies (Figure 4.7). On Kauai, damage to cables mounted on overhead poles was severe (Figure 4.8).

The telephone company on Kauai has two microwave transmitting and receiving stations and nine switching centers. One microwave station was lost on Kalepa Ridge near Lihue due to wind damage and antenna misalignment. Although no switching centers were damaged, 80 percent of the trunk line cables interconnecting them were damaged.

The loss of electric power also affected the telephone systems, but most of the standby backup generators started and furnished sufficient power to surviving subscriber connections.

On Kauai approximately 35 to 40 percent of the 18,000 subscribers were without telephone service on November 24, the day after the hurricane struck. By December 3 approximately 3,000 subscribers were still without telephone service.

Restoration of the telephone systems required that new materials and equipment be imported; major repair of damaged equipment was not attempted. The highest priority was given to the repair of trunk lines between switching centers and the restoration of service to the Police Department, the Office of Civil Defense, the Wilcox Memorial Hospital in Lihue, and other emergency response organizations. The second highest priority was given to the restoration of the Kalepa Ridge microwave station, which is the primary telephone link between Kauai and Oahu. The third priority was given to the removal of fallen utility poles and cables from major highways, and the fourth priority was the maintenance of an emergency power generator at the Lihue Central Office of the Hawaiian Telephone Company.

Commercial Radio Stations

Commercial radio stations on Kauai and Oahu were inoperative on November 23 from 6:50 p.m. to 8:30 p.m. due to loss of electric power, problems with standby generators, and damaged antennas. Kauai's designated emergency broadcast station (KIPO) lost its antenna and 90 percent of its power at 5:12 p.m. on November 23. It went off the air until 6:01 p.m., when it resumed broadcasting at 30 percent of normal power with a temporary antenna. Kauai's Civil Defense Agency headquarters lost its National Warning System (NAWAS, the National Civil Defense Warning Network) and teletype links after 5 p.m. but switched to emergency generators. Battery-powered radios in Honolulu and elsewhere could

FIGURE 4.7 Damaged power transmission lines and telephone cables on jointly owned wood pole at Poipu, Kauai.

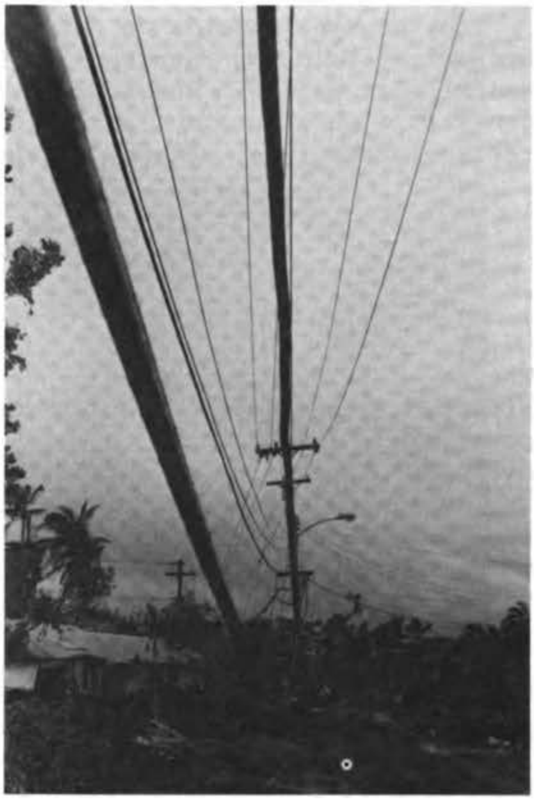

FIGURE 4.8 Telephone cables that toppled due to failure of supporting wood poles south of Kapaa, Kauai.

receive only commercial stations on Maui. Listeners reported that Maui appeared to be unaware of what was occurring on Oahu and Kauai, and no radio instructions or guidance was transmitted. When power was restored to Honolulu 1-1/2 hours after it was lost, radio stations were again operative and broadcast news as it became available.

Other Communication Systems

Military, Civil Defense, and other government communication systems with independent and backup or standby power systems continued to function. It was reported that the submarine cable 10 miles offshore from Makaha, Oahu, was apparently damaged, reducing service to the mainland and to Asia.

TRANSPORTATION

Roads

On Oahu the most severe impact to road transportation was caused by trees and electric power poles and lines falling onto roads and streets. On the Waianae coast (in western Oahu), ocean waves surged inland, depositing large quantities of sand on several stretches of the coastal highway. The Honolulu Police Department station at Waianae had only one four-wheel drive sedan in their fleet that was capable of negotiating the roads covered with wet sand and debris. There were also reports that parts of roads were washed out at Maili Point, near Waianae, and that the road was undermined at Makua. At Nanakuli the Honolulu police blocked the coastal highway because water was surging over the highway.

On Kauai, damage to roads was more severe. Besides fallen trees and power lines, several stretches of coastal road in the Poipu area (Figures 3.16 and 4.9) and in Kekaha were undermined and washed out by surging ocean waves. In the Kekaha-Oomana Point area, road pavement debris was carried 50 yd inland. Continuing damage to roads, particularly in Kauai, is occurring due to increased usage by heavy construction equipment during the restoration of lifelines and cleanup work.

Bridges

The only reported damage to bridges was in the Haena area of Kauai. Several small narrow bridges were reported to be damaged by surging of ocean waves.

Fatalities

Two road fatalities were reported in Honolulu when two vehicles entered an intersection and collided where the traffic signal was inoperative due to the loss of electricity.

FIGURE 4.9 Severely damaged coastline road at Hoai Bay in the Poipu area of Kauai.

Public Transportation

No significant problems were encountered in public transportation systems.

Airports

Commercial airports on Kauai were closed during the height of the storm, apparently due to a combination of circumstances, including gale force winds and the loss of communications and air control equipment because of the interruption of electric power. During the height of the storm at 8:20 p.m., a Boeing 747 landed in Honolulu; another 747 was reportedly diverted to Hilo.

Neither the Honolulu International Airport nor the Lihue Airport on Kauai suffered any significant physical damage. It was reported that a plate glass window at Gate 18 of the Honolulu International Airport was shattered, showering people with glass shards; several people were treated for minor cuts. Airports on Kauai were in service within 12 hours, although the Lihue Airport was restricted to daylight use for several days.

Princeville Airport on Kauai suffered roof damage to buildings due to high winds. A collapsed hangar roof damaged two helicopters, one severely (Figure 4.10).

FIGURE 4.10 Partially destroyed aircraft hangar at Princeville Airport at Hanalei, Kauai.

WATER SUPPLY

Water supply on Oahu was affected in those parts of the systems requiring pumping when the electric power is interrupted. In some locations standby generators were used; at other locations mobile generators were furnished by the U.S. Army and the Marine Corps.

On Kauai, water shortages were reported at Waialua, Hanalei, and Kapaa because of loss of power to pumps. Several deep well pumps were also inoperative due to loss of electric power. Mobile generators furnished by the armed forces and other government agencies were barged in from Oahu. Tanker trucks furnished by the fire department, the water department, and the National Guard supplied water for essential uses at various community centers.

Damage to water supply systems was minimal, and the situation was manageable.

SEWERAGE

There was no damage reported to wastewater treatment plants on Oahu or Kauai. Loss of power caused only minor interruptions, as standby power operated as expected. Many areas have individual cesspools that suffered little, if any, damage.

5

RESPONSE AND RECOVERY

EMERGENCY PREPAREDNESS IN HAWAII

Previous Natural Disasters

From a standpoint of human impact, Iwa was an event without precedent in modern Hawaii. It came from an unexpected direction and caused losses many times greater than any previous storm. Hurricanes and tropical storms sometimes travel west through adjacent waters within 100 miles of the islands, generating damaging surf along exposed coasts, but only one recorded hurricane has struck a populated island and inflicted significant losses. During August 1959, Hurricane Dot brought peak gusts of over 100 mph and caused $5.65 million worth of damages, mostly to agricultural crops on Kauai. Although Iwa was a storm of similar magnitude, it caused much greater losses than Dot because large-scale development had taken place in coastal areas during the intervening years. On most scales of comparison--the numbers of people accommodated in shelters, total buildings damaged or destroyed, the variety of affected activities, the geographic spread of impacts, or the scale of economic losses--Iwa dwarfed previous storms. In terms of economic losses, Iwa may also rank as the largest natural disaster, of any kind, to strike Hawaii during this century. Although three tsunamis have caused a total of 222 deaths, only the tsunami of 1946 inflicted remotely comparable economic losses (Table 5.1).

Hurricane Preparedness

Hawaii's emergency preparedness agencies are primarily geared to protect residents against tsunamis, volcanic eruptions, earthquakes, and nuclear warfare. They have traditionally devoted little effort to the special problems posed by hurricanes. Beginning in 1979 the National Weather Service and the Hawaii Department of Civil Defense sponsored a series of hurricane awareness workshops designed to remedy this deficiency (Sorensen, 1980). These workshops stressed that the most disabling natural disaster that Hawaii could experience would be a direct hit by a major hurricane. Among the problems identified by safety analysts were (1) housing that cannot withstand hurricane-force winds, (2)

TABLE 5.1 Major Natural Disasters in Hawaii

Date	Type	Deaths	Damages (millions of dollars, unadjusted)
1946	Tsunami	159	26.0[a]
1952	Tsunami	0	1.0
1955	Volcanic eruption (Kilauea)	0	2.6
1957	Tsunami	0	5.0
1959	Hurricane Dot	0	5.6
1960	Tsunami	61	23.0
1960	Volcanic eruption (Kilauea)	0	6.0
1973	Earthquake (Hilo)	0	6.0
1974	Flash floods (Oahu and Kauai)	6	3.9
1975	Tsunami	2	1.5
1979	Winter storm (Feb.) (Hawaii)	0	6.4
1979	Winter storm (Nov.) (Hawaii)	1	4.2
1980	Winter storm (Jan.)	0	42.0
1980	Winter storm (Mar.) (Hawaii)	2	3.8
1982	Hurricane Iwa	1	203.0 to 234.0+

[a] Using a generous 5 percent average annual inflation rate for the period 1946-82, this equals approximately $150 million in 1982 dollars.

Sources: Ayre, 1975; Haraguchi, 1980; Schroeder, 1977, 1981; U.S. Office of Coastal Zone Management, 1978; Warrick, 1975.

insufficient shelters for the total number of people at risk, (3) mismatches between shelter locations and population distributions, (4) shelters that are themselves subject to damage from floods, landslides, or other hazards, and (5) the inherent vulnerability of infrastructure on small mountainous islands (Honolulu Advertiser, September 21, 1979). Moreover, in the opinion of several of the workshops' organizers, hazard managers were often skeptical that hurricanes could affect the islands and they placed undue confidence in the smooth operation of warning and evacuation systems (Murton, 1982). Recent surveys of public knowledge about hurricane risks reveal that anticipated behavior in the face of a Hawaiian hurricane is likely to be complex and difficult to predict (Sorensen, 1980). Although a start had been made in identifying safe shelters on Oahu, most of the foregoing problems remained unresolved when Iwa struck.

Judging by the very low death toll (one person) during the storm and the small number of generally minor injuries, it can be inferred that emergency warning and response systems performed relatively well. However, Iwa was a hurricane of modest size and intensity. Much larger storms have come close to Hawaii (e.g., Hurricane Nina in 1957). Given the lack of precedent, it is not surprising that many individuals and some public agencies were not fully prepared for the disaster or the issues of recovery and redevelopment that it raised.

IMMEDIATE RESPONSES TO IWA

Prewarning Phase

The existence of tropical storm Iwa was officially noted by National Weather Service personnel at Honolulu several days before it arrived over the islands. Little attention was paid to these reports until 5 p.m. on November 22, when Iwa achieved hurricane status. At that time the storm was drifting slowly north from a point approximately 600 miles southwest of Honolulu. Evening radio and television broadcasts in Hawaii and on the mainland later carried this news. Just after 10 p.m. on November 22, state and county Civil Defense officials were notified via the National Warning System (NAWAS) and telephone that a hurricane watch was to become effective at 11 p.m. for Oahu, Kauai, Niihau, and the eastern leeward islands.* In view of the lack of a precedent, it was assumed that news media and the public would be skeptical about a threatened hurricane. Hence National Weather Service personnel wanted to ensure that the information reached as many people as possible before they went to bed. By this time the storm was about 500 miles southwest of Honolulu and beginning to accelerate. It is unlikely that many citizens were aware of this turn of events. Although Civil Defense officials monitored developments, there is no evidence that the public undertook significant storm preparations during the night of November 22.

The next morning at 8 a.m. the National Weather Service upgraded the hurricane watch to a hurricane warning for Kauai and Niihau and posted storm warnings for the Kauai Channel. A hurricane watch remained in effect for Oahu and continued throughout the duration of the storm. Public agencies and utility companies began to activate emergency operations procedures and plans.

Postwarning Phase

Kauai

Tuesday, November 23: Morning On Kauai the Civil Defense Administrator received a telephone call from the National Weather Service at 8:08 a.m. informing him directly about the island's warning status (Figure 5.1).

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*A hurricane watch serves notice that there is a 50 percent probability of a direct hurricane strike in the targeted area within 36 hours. It is designed to alert residents to the potential need for evacuation and other actions. A hurricane warning alerts threatened residents to immediate danger and urges immediate protective actions.

November 22	
2300 hr	Hurricane watch established
November 23	
0800 hr	Hurricane warning issued
0808 hr	Kauai Civil Defense notified of warning
1030 hr	Mayor makes public broadcast
1200 hr	Elementary schools closed
1215 hr	Warning sirens sounded; shelters begin opening
1230 hr	Secondary schools closed
1300 hr	Warning sirens sounded
1400 hr	Warning sirens sounded; police order cars off roads
1413 hr	KUAI radio transmission antenna toppled
1425 hr	Lihue Airport closed
1430 hr	Police ordered to shelters
1712 hr	KIPO radio emergency broadcast station off the air
1900 hr	Looting reported
2000 hr	Civil Defense search and rescue/damage assessment teams dispatched
2130 hr	National Guard begins patrols
2300 hr	Hurricane warning/watch canceled

FIGURE 5.1 Timetable of major events on Kauai.

He requested postponement of the announcement until 9 a.m. to permit sufficient time for the establishment of shelters. However, public radio stations had already begun to broadcast warning information shortly after 8 a.m. In consultation with county government leaders, the Civil Defense Administrator set a target of 1:15 p.m. for sounding Kauai's 32 sirens. These are primarily designed to give warning of impending tsunami and are located near known tsunami run-up zones. Approximately 80 percent of the island's population lives within earshot of the sirens.

In the meantime, Kauai Civil Defense personnel began the process of contacting Red Cross representatives and of opening shelters throughout the island. Eleven neighborhood centers and schools were selected for this purpose but it was recognized that none of Kauai's large public buildings guaranteed effective protection against hurricane-force winds.* The accuracy of this evaluation was subsequently borne out by

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*Shelters included the Koloa Neighborhood Center, Koloa Elementary School, the Lihue War Memorial Convention Hall, the Wilcox School cafeteria, the Kapaa School cafeteria, the Kaumakani Neighborhood Center, the Kalaheo Neighborhood Center, the Kilauea Neighborhood Center, the Waimea High School music building, and the Eleele School cafeteria.

extensive roof damage at the Kilauea Neighborhood Center, the Kapaa School, and Waimea High School, as well as the loss of plate glass windows in the Lihue War Memorial Convention Hall. Civil Defense officials advised residents of flood hazard areas to prepare to evacuate their homes. Those who were unsure whether they lived in such areas were advised to consult tsunami risk zone maps contained in the Kauai telephone directory.

During the morning, radio stations asked residents of Kauai and Niihau to secure windows, store food and water, and keep extra batteries, flashlights, and battery-powered radios on hand. This triggered an immediate rush of customers to local supermarkets and hardware stores, most of which remained open until after 2 p.m., when damaging tides had already arrived. Aircraft based at the Pacific Missile Range were sent to Oahu, interisland barge service to Kauai was canceled, and containers at Nawiliwili Harbor were unstacked to reduce the likelihood of wind damage. At 10:30 a.m. the mayor of Kauai broadcast an announcement that he was closing county offices and sending home all but emergency personnel. This was followed by a directive from the superintendent of schools closing elementary schools at noon and secondary schools at 12:30 p.m.

Tuesday, November 23: Afternoon and Evening Just before noon it was reported that north coast communities were being flooded. Although this was probably due to an offshore low-pressure area unrelated to Iwa, the news caused warning sirens to be sounded earlier than anticipated (between 12:15 p.m. and 12:18 p.m.). Evacuees began to arrive at shelters, which opened their doors shortly thereafter. Kauai's sirens were again sounded at 1 p.m. and 2 p.m. By then Lihue Airport was recording gusts to 39 knots, electric power outages were being reported, coastal flooding was already serious, emergency workers had been advised to seek shelter, and police had ordered cars off the roads. Kauai lost a major radio station (KUAI) at 2:13 p.m. when its transmission tower was toppled by high winds. A few minutes later at 2:25 p.m., Lihue Airport was closed and large numbers of tourists awaiting departure were transferred to a shelter at the Lihue War Memorial Convention Hall. Unexpectedly large numbers of visitors and residents sought shelter in designated public facilities. At the overcrowded memorial hall, a Red Cross representative requested that those who could safely do so should travel to Koloa, where shelters were less heavily used. Tourists among the evacuees at a number of shelters later criticized the lateness of the warnings they received, the shortages of food and bedding, and the disorganization of the shelter administration. Eventually, approximately 5,645 people were accommodated in public shelters.

By 2:30 p.m. conditions had deteriorated to the point where Civil Defense officials ordered police to seek shelter. From then until 8 p.m. most people rode out the storm where they were, while winds built up to gusts in excess of 100 mph. Between 5 p.m. and 10 p.m. tourists at Poipu walked and rode buses to shelter 3-1/2 miles inland at Koloa. Most tourists remained on upper floors of landward units at resort hotels and condominiums. Peak winds occurred at different times on different parts of Kauai, but the height of the storm generally fell between 4 p.m. and 6 p.m. At that time there was a total loss of electric power throughout the island. Roads were blocked by fallen trees and utility poles. Communications media also ceased to be effective as telephone poles and radio antennas toppled. For example, Kauai's designated emergency broadcast station (KIPO) lost 90 percent of its power at 5:12 p.m. when an antenna blew over. It went off the air until 6:01 p.m., when a temporary antenna was rigged that permitted broadcasts at 30 percent of normal power. The Civil Defense headquarters lost its NAWAS and teletype links after 5 p.m. but switched to emergency generators.

As darkness fell around 7 p.m., there were reports of looting at Nawiliwili and Poipu. Governor Ariyoshi authorized use of the National Guard at 8:40 p.m. and by 9:30 p.m. units were patrolling the streets of Lihue and blocking access by road to Poipu. At 8 p.m. the Kauai Fire Department was ordered to conduct a search and rescue operation, and damage assessment teams were dispatched from Civil Defense centers. A few hours later at 11 p.m., the National Weather Service canceled the hurricane warning and watch as Iwa moved swiftly away toward the northeast.

Oahu

Damaging winds arrived 30 minutes to 1 hour later on Oahu than on Kauai, thus giving emergency organizations and threatened populations some additional time to take safety precautions. Coastal flooding on Oahu did not become severe until between 7 p.m. and 9 p.m.

Tuesday, November 23: Morning Civil Defense and other emergency services monitored Iwa's progress throughout the night of November 22, and mass media issued safety instructions during the following morning. Around 10 a.m. some Oahu radio stations began advising people in low-lying areas to use caution or leave for safer locations (Figure 5.2). Traffic jams and long checkout lines at stores were reported throughout the morning and early afternoon. Some stores in Waikiki did not close until 5 p.m. At 11 a.m. the National Weather Service extended gale warnings to cover all Hawaiian waters. Shortly thereafter at 11:30 a.m., Governor Ariyoshi announced the closure of public schools. Some bureaucratic confusion ensued because school district officials were not informed of this action before it was released to the news media. Further jurisdictional problems arose between some principals and Red Cross officials when Oahu schools were used as disaster shelters.

No warning sirens were sounded on Oahu during the storm. The County Civil Defense Administrator made this decision because the National Weather Service did not issue a hurricane warning covering the island. He instead relied on police and Civil Defense personnel to directly inform residents in exposed areas about developing local problems. Specific sirens within the Oahu warning network cannot be sounded independently of the entire system.

November 22	
2300 hr	Hurricane watch established
November 23	
1000 hr	Oahu radio stations advise public in low-lying areas
1100 hr	Gale warnings issued for state waters
1130 hr	Governor makes public broadcast
1445 hr	First shelter opens (Nanakuli)
1612 hr	Mass media links to National Weather Service severed
1750 hr	Erroneous radio message announces evacuation
1753 hr	Selective evacuation ordered by County Civil Defense
1850 hr	All major radio and TV stations off the air
1914 hr	Farrington Highway (on Waianae coast) blocked
1945 hr	Looting reported
2040 hr	National Guard Activated
2300 hr	Hurricane watch canceled
November 24	
0138 hr	Farrington Highway reopened
0600 hr	Civil Defense damage assessment teams dispatched

FIGURE 5.2 Timetable of major events on Oahu.

Tuesday, November 23: Afternoon and Evening As winds rose on the Waianae coast, a shelter was opened at Nanakuli High School (at 2:45 p.m.). The County Civil Defense Administrator sought assurance from National Weather Service officials at 3 p.m. that a high-wind warning would be issued for Oahu. No formal evacuation was anticipated at this time. The opening of additional shelters was authorized at Kaelepulu Elementary School in Enchanted Lakes at 3:30 p.m., Wahiawa Elementary School at 4 p.m., Kahuku High School at 6 p.m., and elsewhere. After a local television station mistakenly reported the opening of shelters on the Waianae coast as an "evacuation" at 5:50 p.m., Oahu's Civil Defense Administrator declared a formal evacuation for that area at 5:53 p.m. By 6 p.m. approximately 40 people had taken refuge in Nanakuli High School, though Red Cross representatives had not yet reached the Waianae coast schools and adequate emergency supplies were not available there (at 6:20 p.m.). Eventually, close to 1,500 people entered eight public shelters on Oahu, with perhaps 500 to 600 people remaining overnight, mostly at Nanakuli. At least one unused shelter was closed by midnight on November 23.

Widespread loss of electric power began by midafternoon (e.g., 3:44 p.m. at Wahiawa) and continued until approximately 8 p.m. in Honolulu and much later in other locations. At the height of the storm around 7:30 p.m., when wind gusts exceeded 90 mph, 93 percent of the customers of the Hawaii Electric Company on Oahu lacked power. At 4:12 p.m. connections among the National Weather Service, wire service organizations, and the mass media were lost. All major radio and television stations remained off the air between 6:50 p.m. and 8:03 p.m. Only KAIM, a music station, continued to operate. KGU in Honolulu, the designated official Civil Defense broadcast station for Oahu and Kauai, lost power intermittently despite the use of emergency generators. When it did operate, the station lacked timely news to disseminate because telephone links to reporters and officials did not function properly.

The Waianae coast posed various special problems for Civil Defense officials. Farrington Highway, the principal access road, was blocked at several places by sand, downed utility poles, and debris between 7:14 p.m. on November 23 and 1:38 a.m. on November 24. This isolated several areas from public shelters. Many residents reported that they were alerted about potential hazards by neighbors rather than public emergency personnel. Looting was observed in Waianae and near Makaha at 7:45 p.m. Between 8:18 p.m. and 8:25 p.m. the Oahu Civil Defense Administrator, the Honolulu Police Chief, and National Guard leaders conducted telephone discussions about possible activation of National Guard units. Guard detachments were committed by Governor Ariyoshi at 8:40 p.m. but did not arrive on the leeward coast for approximately 1-1/2 hours. Local residents criticized the action as being "unnecessarily late." Elsewhere, local problems such as evening flooding in Waikiki from 8 p.m. to 9 p.m. and the closure of Kamehameha Highway on the windward coast at 12:07 a.m., November 24, did not constitute significant emergencies. Damage assessment teams were dispatched by Civil Defense officials at daybreak (6 a.m. on November 24) throughout the island.

THE AFTERMATH OF IWA

Stages of Postdisaster Recovery

It is customary to divide the postdisaster period into four overlapping stages: (1) an emergency period dominated by search and rescue operations, mass feeding and housing, and clearance of debris; (2) a restoration period characterized by repair of damaged facilities, return of displaced populations, and the beginning of normal community functions; (3) a reconstruction period marked by rebuilding of destroyed structures and achievement of predisaster levels of economic activity; and (4) a betterment period during which the disaster is memorialized and new development projects are begun (Haas et al., 1977). For most residents of the impacted islands, the emergency period was drawing to a close two weeks after the hurricane, and the restoration period was already well under way. Some of the issues that will affect reconstruction and betterment were already apparent.

In the days immediately following Iwa, individuals affected by the storm gave priority to basic survival needs, and public agencies busied themselves with meeting those needs, assessing damage, and laying the groundwork for longer-term recovery.

Damage Assessment

Damage assessment was a high priority for private individuals and public organizations. On the morning after the storm, many residents who had assessed their own losses set out to view the damage that others had suffered. This prompted police and Civil Defense officials to broadcast public appeals for gasoline conservation and maintenance of open highways. Long lines formed at gasoline stations and stores, but shortages do not appear to have been severe, nor was highway congestion particularly serious.

Many organizations carried out damage assessments. Chief among these were the Red Cross, private insurance adjustors, and government officials. Inasmuch as these groups used different procedures to classify and analyze different types of loss, and because they carried out assessments at different times, it is not surprising that results do not always agree. For example, the mayor of Kauai first estimated total losses at $15 million to $20 million (on November 24) and then revised the figure upward to $106.6 million (on November 25). Over a four-day period from November 26 to 29, state Civil Defense officials adjusted estimated total damages from $160 million to $137 million and, finally, to $143 million. Likewise, an insurance industry spokesman suggested on November 26 that losses to insured private property on Kauai would exceed $500 million. A week later another insurance expert claimed that $62 million was nearer the mark for Kauai and $32 million for Oahu. Somewhat later the insurance industry's figure for total insured losses on both islands was $137 million. Red Cross analysts initially estimated that 6,391 houses, 21 hotels, and 2 condominium apartment buildings had been destroyed throughout the state, but subsequently they reduced these figures to 5,106 single-family homes, 869 apartments, and 105 small businesses. Federal Emergency Management Agency (FEMA) personnel stated on December 5 that housing losses totaled 3,177. Despite these considerable inconsistencies, within two weeks of the storm a figure of $200 million was becoming accepted as a "reasonable" estimate of total damages (see Table 1.2). By late January this had been replaced by a revised figure of $234 million, with the possibility of additional losses in tourism and agriculture.

Costs of Damage

Damage to private homes was the single largest category of losses. On Oahu virtually all geographically assignable damages were related to housing. On Kauai, although one out of every eight single-family homes received some damage, losses were also incurred by a wide range of public, commercial, and agricultural facilities (Table 5.2). Initial Red Cross data suggest that losses were most widespread and severe in the communities of Poipu, Lihue, Wailua Homestead, Kalaheo, Kekaha, and Princeville. On January 6, 1983, an updated FEMA damage estimate concluded that losses on Kauai totaled $190.6 million (all public property--$23 million; private housing--$84 million; business and agriculture--$83.6 million).

TABLE 5.2 Geographically Assignable Losses (millions of dollars)

	Kauai	Oahu	Total
Public property	11.2	1.1	12.3
Housing	41.0	27.0	68.0
Business	51.0	0.5	51.5
Total	103.2	28.6	131.8

Note: Does not include damages to schools, highways, agriculture, and state or federal facilities (totaling $71.1 million).

Source: Federal Emergency Management Agency (1982).

Business losses were mainly confined to Kauai (Table 5.3) and generally include only the immediate direct costs of physical damage. Half a dozen large resort hotels and condominium apartment complexes along the island's south coast accounted for the bulk of the losses. Approximately 60 percent of the island's 5,207 tourist accommodation units sustained at least some damage. Unemployment costs among hotel employees have not been calculated, but by January 10 at least 1,350 claims for unemployment compensation had been approved for Kauai, compared with 125 on Oahu. Some rental car agencies suffered severe losses. One firm reported damage to 149 of its 550 vehicles. Port Allen's small commercial fishing industry lost its entire fleet.

Agricultural losses were initially estimated at $21.5 million (later revised to $17 million). They include destruction of sugar cane plants and irrigation systems, a nearly total loss of Kauai's papaya plantations, damage to commercially owned experimental seed plots, and more than half a million dollars in losses to the University of Hawaii's research facilities. In addition, the State Land Board estimated that 2,100 acres of eucalyptus trees, containing 10.5 million board feet of timber, were knocked down.

Disaster Declarations

While local public works and emergency personnel carried out ground-based assessments, the Governor and State Civil Defense Director made an aerial survey of the three islands on November 24. This formed a basis for the state's Disaster Declaration and the subsequent request that a Presidential Disaster Declaration be issued. By November 26 a

TABLE 5.3 Business Losses

Location	Scale of Damage	Number of Businesses	Losses (millions of dollars)
Kauai	Major	176	40
	Minor	537	11
Oahu	Major	8	0.25
	Minor	32	0.25
Statewide		753	51.50

Source: Federal Emergency Management Agency (1982).

five-person survey team from FEMA arrived, together with representatives from the U.S. Small Business Administration, the Red Cross, the Corps of Engineers, the Federal Highways Administration, and other federal agencies. The following day President Reagan named the islands a disaster area, thus paving the way for an integrated federal disaster assistance program. The state Disaster Declaration had previously released $750,000 in state repair funds and $450,000 in low-interest loans.

Debris Clearance and Restoration of Communications

For at least one day after the storm, many roads were blocked and there were no reliable radio, television, telephone, or newspaper services on Kauai. During Iwa, and on November 24, amateur radio operators played a key role in the dissemination of official messages and the transmission of requests for assistance from isolated areas. Within four days virtually all roads were open, broadcasting stations had resumed operations, the island's newspaper was being distributed, 80 percent of subscriber's telephones were working, and portable generators had restarted Kauai Electric's main power generator, thus restoring electricity to about half of the utility's customers. In contrast to the rapid restoration of most public services, most of the island's schools did not reopen until the week of December 6. Some areas continued to lack good access because roads had been washed away. Scattered looting was reported in Poipu for several days, but no looters were apprehended.

Although periodic electricity failures continued to plague the Waianae coast for several days after the storm, and although approximately 1,000 telephone subscribers there were still without service by December 7, most public services were quickly restored on Oahu. All public schools were open by November 30.

Emergency Medical and Food Services

Since there were almost no serious injuries, hospitals and Red Cross nurses received relatively few requests for assistance. For example, between 8 a.m. and 1:30 p.m. on November 24 only 36 people were treated at Wilcox Hospital in Lihue. Red Cross nurses treated and released 194 victims, leaving only 12 cases still open on December 1.

Emergency feeding programs were much more active, particularly on Kauai. This occurred because even residents whose homes were undamaged found themselves without electricity and, therefore, unable to store perishable foods or cook meals. In some places (e.g., Haena), water was also in short supply because well pumps lacked power. By December 7 Salvation Army workers had served 31,329 meals in Kauai, mostly from facilities at the Lihue War Memorial Hall and the Hanapepe Salvation Army building. Approximately half of these were C-rations distributed at Hanapepe. During the same period the Red Cross had served 82,000 meals. Beginning on November 27, hot meals were available from three mass feeding centers at Wilcox Elementary School, Kilauea Elementary School, and Koloa Elementary School. At the height of both programs, as many as 21,384 meals were served on a single day (December 1). This represents total daily sustenance for about 7,500 people, or 24 percent of Kauai's population. By December 7 around 3,000 meals per day were being provided, and Red Cross officials planned to end mass feeding on December 8 for all areas except those that still lacked electric power.

Much less is known about emergency feeding services on Oahu. The Salvation Army served about one third as many meals there as on Kauai (11,218 between November 23 and December 7). By December 5 the Red Cross had processed requests for food, clothing, and emergency repairs from 1,427 families on Oahu and 1,065 families on Kauai.

Temporary Housing

Low-cost housing is normally scarce on Kauai and Oahu. With the destruction or damage of an estimated 12 percent of the housing units on Kauai, shelter became an immediate problem. Many displaced residents with modest incomes found room with relatives or friends, and the stock of undamaged condominium resort apartments provided additional space for those who could afford higher-cost accommodations on Kauai. Most tourists there had vacated hotels on November 23 or November 24. Prospective visitors generally changed their plans and diverted to Maui or Hawaii during the following two weeks. Nonetheless, two weeks after the storm 350 temporary housing units were still being sought on Kauai and 200 to 300 on Oahu. FEMA officials issued appeals for assistance in locating additional accommodations, and Red Cross leaders contemplated reopening shelters to alleviate possible hardship. By late January 1983, 560 individuals and families had been given temporary housing, and federal officials had authorized $200,000 worth of home repairs.

Disaster Assistance Centers

Shortly after a Presidential Disaster Declaration is issued, FEMA establishes Disaster Assistance Centers (DACs) at accessible locations in impacted areas. These centers are designed to speed the recovery process by coordinating and centralizing federal, state, and local aid to individuals, families, and small businesses. Typically, a DAC includes representatives from a wide range of agencies. Centers are staffed by a combination of emergency agency personnel, locally hired people, students, and volunteers. Often, three or more months may elapse before an application for assistance is approved.

Three DACs were opened on Kauai on December 2 at facilities in Lihue, Koloa, and Kilauea. Between then and December 5, 1,622 people registered for assistance (Table 5.4). Approximately equal numbers of people attended the centers, but considerably more applications for aid were issued at Koloa (e.g., food, clothing, emergency repairs, temporary housing, unemployment payments, federal tax reimbursements) (Table 5.5). This probably reflects the severity of damage along Kauai's south shore. Koloa also recorded the largest number of return registrants, perhaps indicating greater dissatisfaction with the level or type of assistance offered.

Three DACs were also opened on Oahu at Wahiawa, Waianae, and Kailua on December 2. Despite the fact that Kauai bore the brunt of the storm and accounted for perhaps three quarters of the losses included in FEMA's damage assessments, more people registered for DAC aid on Oahu. By December 5, 1,855 people had sought aid (Table 5.6). Moreover, most of the Oahu registrants attended the Waianae center. The bulk of Temporary Housing and Individual Family Grant applications were processed there, together with the smallest proportion of Small Business Administration loans (Table 5.7). It was, by far, the most heavily used of the six DACs. Long lines of waiting people and extended hours of operation were also characteristic. Furthermore, Waianae was beset by unusual and complex issues that did not occur elsewhere. For example, squatters who resided in flimsy homes near the ocean applied for assistance. This raised issues of precedence, legality, and public responsibility that remained largely unresolved for want of clear policy guidelines. At Makua Beach betwen 100 and 150 squatters' homes were subsequently removed by state government personnel. FEMA staff also experienced difficulties in confirming map locations of claimants' addresses while determining eligibility for flood hazard insurance benefits. This was, to some extent, a product of language barriers and residents' unfamiliarity with maps, but it also involved differing cultural conceptions of spatial relations.

Red Cross personnel and FEMA administrators believed that many local residents were reluctant to use relief and assistance centers on Kauai. Some observed that levels of attendance were low by the standards of areas stricken by disaster on the mainland. This was said to reflect general local unwillingness to seek help outside home communities and the association of relief with "welfare"--an attribute of stigmatized "transient" immigrants from the mainland during the 1960s. Certainly, attendance at DACs was much greater in the low-income communities of the

TABLE 5.4 Disaster Assistance Center Interviews in Kauai

	Lihue		Koloa		Kilauea		Total	
Program	N	%	N	%	N	%	N	%
Small Business Administration loans	326	37	324	36	242	27	892	100
Temporary Housing	194	35	218	39	143	26	555	100
Individual Family Grants	172	18	548	59	211	23	931	100
Unemployment Assistance	61	21	131	44	103	35	295	100

Source: Based on unpublished daily DAC summary reports compiled by FEMA (December 2-5).

TABLE 5.5 Disaster Assistance Center Applications in Kauai

	Lihue		Koloa		Kilauea		Total	
Program	N	%	N	%	N	%	N	%
Small Business Administration loans	188	36	194	37	144	27	526	100
Temporary Housing	157	41	154	41	69	18	380	100
Individual Family Grants	165	30	216	40	163	30	544	100
Unemployment Assistance	38	18	105	50	69	33	212	100

Source: Based on unpublished daily DAC summary reports compiled by FEMA (December 2-5).

Waianae coast, where many residents already receive public assistance (Table 5.8). In any event, the social mosaic of Kauai was not initially well known to incoming relief workers. Few appeared aware of the diversity of client groups. After several days of using English as the medium of communication, Red Cross workers sought the advice of a local radio personality to improve the targeting of posters carrying disaster services information and to make broadcasts aimed at vernacular and non-English-speaking islanders. Four days after opening the DACs, FEMA officials also recognized the need to improve communications with Kauai's diverse social, ethnic, and linguistic groups. A meeting with

TABLE 5.6 Disaster Assistance Center Interviews in Oahu

Program	Wahiawa N	Wahiawa %	Waianae N	Waianae %	Kailua N	Kailua %	Total N	Total %
Small Business Administration loans	175	22	419	52	205	26	799	100
Temporary Housing	56	14	262	65	87	21	405	100
Individual Family Grants	107	16	399	60	156	24	662	100
Unemployment Assistance	21	26	41	50	20	24	82	100

Source: Based on unpublished daily DAC summary reports compiled by FEMA (December 2-5).

TABLE 5.7 Disaster Assistance Center Applications in Oahu

Program	Wahiawa N	Wahiawa %	Waianae N	Waianae %	Kailua N	Kailua %	Total N	Total %
Small Business Administration loans	96	33	86	30	108	37	290	100
Temporary Housing	41	16	149	60	60	24	250	100
Individual Family Grants	107	20	392	74	130	24	532	100
Unemployment Assistance	0	0	1	14	6	86	7	100

Source: Based on unpublished daily DAC summary reports compiled by FEMA (December 2-5).

local church leaders on December 5 was arranged to help achieve that goal.

The DACs closed on December 16, 1982, but residents continued to file applications for assistance at other federal offices (Waimea and Lihue on Kauai, Honolulu on Oahu). By January 6, 8,202 applications had been received. Officials again commented on the low numbers of requests for assistance. The Federal Coordinator noted on January 5 that applications for Small Business Administration loans were so few that a media publicity campaign was planned. Nonetheless, only 300 more

TABLE 5.8 Attendance at Disaster Assistance Centers

Date	Wahiawa	Waianae	Kailua	Lihue	Koloa	Kilauea	Total
Dec. 2, 1982, Thursday	78	74	80	92	120	75	519
Dec. 3, 1982, Friday	120	365	79	123	111	128	926
Dec. 4, 1982, Saturday	115	192	64	163	109	120	763
Dec. 5, 1982, Sunday		217			198		415
Dec. 6, 1982, Monday		471			383		854
Total							3,477

Note: Total at Kauai DACs: 1,622 (47 percent). Total at Oahu DACs: 1,855 (53 percent).

applications were received by the January 26 deadline for submission of claims. The Small Business Administration interviewed a total of 6,143 people, received 692 loan applications, and approved 264 loans totaling $2.4 million. Hawaii's Department of Social Services and Housing awarded $79,118. The American Red Cross interviewed 7,396 people and provided postdisaster assistance valued at $1,625,000. The Salvation Army interviewed 5,887 people and spent $65,000. Emergency food stamps valued at $248,766 were distributed to 2,994 people on Kauai, and 1,558 Kauai residents registered for disaster unemployment assistance.

Hindsight Analysis

Although several public agencies have performed internal analyses of their performance during Iwa, only one public review of the hurricane experience is known to have taken place. The Honolulu City Council held a series of public hearings on January 18 in Waianae, on January 19 in Leilehua, on January 20 in Castle Hill, and on January 26 in Honolulu. These produced strong criticisms of emergency preparedness programs from Waianae coast residents. It was alleged that (1) Civil Defense agencies were understaffed, underequipped, and underfunded, (2) warnings were issued too late, and (3) there was a lack of safe alternative evacuation routes. Many witnesses requested the development of a detailed local disaster plan. Others complained of price gouging, inadequate security against looting, lack of privacy from sightseers, and difficulties in securing reimbursement from insurance for damaged property.

Insurance

For private property owners, insurance reimbursements are usually a major source of funds to recover from a disaster. Hurricanes pose special problems for insurance because they involve three separate loss processes that are rarely covered by a single insurance policy: wind, rain, and flood. Homeowners insurance offers protection against wind damage and those rainfall losses that stem directly from wind action (e.g., rain damage to the contents of a roofless home). Losses caused by coastal flooding are not included in homeowners policies. Instead, individuals may purchase federally supported flood insurance if they live in communities that participate in the National Flood Insurance Program (NFIP).

Soon after Iwa's departure, evidence of serious inadequacies in insurance protection began to appear. Two potential problems were revealed: (1) a possible lack of sufficient homeowners insurance and (2) misleading designations of coastal high hazard area boundaries, which are the basis for Kauai's flood hazard insurance program. In addition, some property owners sought to attribute losses to high winds, even where wave action or surge damage was readily apparent. Only the broad outlines of these problems can be identified because insurance officials are reluctant to divulge details of damages and claims.

The Hawaiian Insurers Council has estimated that total losses to insured property were $137 million while uninsured losses were $50 million (Hogan, 1983). These figures are based on projections from data supplied by First Insurance Company, the largest policy holder. This company received approximately 5,000 claims, each of which averaged $5,000 in Kauai. Claims on Oahu averaged $2,000. Most claims were for unambiguous wind damage, but in 25 cases the cause of damage--wind or flood--was in dispute. Information about flood damage claims made on NFIP policies is not included in this assessment. Eighty percent of the claims were for residential property, but these probably accounted for a minority of the dollar losses. Many of the low-value properties on the Waianae coast of Oahu would not normally be considered good insurance risks but were underwritten anyway as a social service provided by the insurance companies. Despite this, many Waianae coast residents reported problems in receiving reimbursements.

These data suggest that most of the property owners who suffered losses during Iwa are eligible for insurance reimbursements, but there is some evidence that not all victims possessed insurance. Red Cross estimates from November 28 suggest that only 30 percent of 3,310 householders who had sought assistance owned homes covered by insurance. It is also unlikely that any residents of Niihau owned insured homes. The mayor of Honolulu established a special low-interest loan fund for victims who did not qualify for insurance payments and who lacked the financial ability to secure other loans. This fund provides loans up to $10,000 per person at 3 percent interest, repayable over periods up to 20 years. The fund is expected to be drawn on by at least 300 people. Given that $5,000 is the maximum available federal disaster relief grant, and in light of the relatively low numbers of Small

Business Administration loans, long-term recovery may be a slow and costly process for uninsured low- and moderate-income families that suffered wind damage.

FEMA representatives have estimated that before Iwa struck there were 300 to 500 active flood insurance policies on Kauai. Most of these were held by individual homeowners whose property lay within or close to coastal high hazard areas, but some resorts also carried federal flood insurance because it provides a means of recouping losses smaller than the deductibles on their commercial policies. By December 3, 29 flood damage insurance claims had been filed; it was not anticipated that many more would be initiated. This is an unexpectedly small number in view of the heavy damage sustained by coastal properties along a 5-mile stretch of Kauai's south shore that is more or less totally developed. In contrast, 35 of Oahu's 3,500 to 4,000 NFIP policy holders reported losses.

To some extent, the small number of claims on Kauai is explained by incentives for property owners to argue that hurricane losses were inflicted by high winds rather than floods. This makes claimants eligible for reimbursement of homeowners insurance policies that have lower deductibles, higher rates of coverage, and quicker paybacks than do flood insurance policies. Many oceanfront residents also lack flood insurance coverage. It is known that a substantial number of the residents of tsunami zones in Hawaii are unaware of the vulnerability of these locations and thus do not purchase insurance (Sorensen, 1980; Havighurst, 1967). In fact, many coastal residents who consulted existing insurance maps found that their properties were located outside designated flood hazard zones. Unfortunately, such maps proved to be poor indicators of risk from Hurricane Iwa's floods. On the day after the storm, aerial damage assessment teams detected evidence of flood damage 200 to 300 ft beyond the inland boundaries of hazard areas shown on current flood insurance maps of Poipu and adjacent communities. In the report issued by the U.S. Interagency Flood Hazard Mitigation Team (1982) on December 12, FEMA analysts recognized this problem but recommended only that the Corps of Engineers make preliminary studies to assess the need for modifying existing flood insurance rate maps. Kauai County land use planners have mapped the location of waterborne debris lines associated with Iwa.

If Kauai's flood insurance maps are modified because of Hurricane Iwa, all of Hawaii's flood maps may require similar changes. As the state's Coastal Zone Management document indicates, existing maps are based on tsunami inundation zones that may systematically underestimate flood risks for certain areas (U.S. Office of Coastal Zone Management, 1978). This is not an entirely new experience for Hawaii's flood insurance program because flood maps have already been modified as improved data about previous tsunamis have become available (Cox, 1982). Modified and enlarged flood hazard zones might encourage increased purchase of flood insurance, thereby providing improved protection to property owners at risk. Changes in designated flood hazard zones may also influence the positioning of Civil Defense warning sirens and may increase the numbers of evacuees requiring emergency transportation and shelter during future coastal storms.

Plans for Long-Term Redevelopment

No postdisaster redevelopment plan existed prior to Hurricane Iwa. Nor is there evidence that federal, state, or local agencies intend to develop such a plan for use in this or future Hawaiian coastal disasters. On the contrary, public officials and private property owners seek to encourage early and rapid redevelopment within the context of existing codes and regulations.

Some advocate temporary suspension of those provisions. The mayor of Kauai proposed on December 2 speeding up rebuilding by easing the permit approval process. On December 9 the Kauai County Council enacted a new ordinance waiving permits for emergency repairs and allowing retroactive approval of permits for work completed between November 23, 1982, and January 31, 1983 (County of Kauai, 1982). Permits continued to be required for nonconforming structures and buildings in existing Special Flood Hazard Areas, but public hearings were waived until March 31, 1983, for most reconstruction activities.

The U.S. Interagency Flood Hazard Mitigation Team has suggested (1982) that substantially damaged or destroyed buildings also be exempt from the proposed ordinance. This includes many flood-damaged buildings located outside Special Flood Hazard Areas. Such action is judged necessary to ensure implementation of flood mitigation measures and compliance with county codes and regulations. Otherwise, investments and populations at risk to events like Iwa may be reestablished or expanded. Nonetheless, the interagency team argued against a general moratorium on reconstruction in flood hazard areas because new flood insurance maps could not be prepared without lengthy delays and because properly designed and constructed buildings were held to be capable of surviving floods similar to those experienced during Iwa. Nor are there promising prospects for the reduction of coastal flood hazards by requiring increased setback of oceanfront buildings or by otherwise tightening land use controls. Intensive development is confined to strictly delimited urban lands under the control of the county government. Resorts and housing development may not readily encroach on surrounding agricultural, rural, or conservation districts controlled by the state government. County regulations lack legal provisions for controlling the siting of buildings on lots, developments, or subdivisions. There is also substantial public opposition toward increased tourism-related development. Some islanders opposed construction of the original 170-room Sheraton-Kauai Hotel in Poipu in the early 1970s, ostensibly because they feared loss of access to the shoreline, increased traffic, and overburdened local facilities. Though unsuccessful in attempts to halt that development, in 1980 local residents voted against construction of a 350-room hotel at Nukolii. A recent Hawaii Supreme Court decision has upheld the results of this referendum. So far as is known, no attempts have been made to devise comprehensive redevelopment guidelines for wind-damaged areas.

CONCLUSION

1. Like occupants of most small mountainous oceanic islands, the people of Hawaii are especially vulnerable to tropical storms and hurricanes because:

a. Their linear circumferential infrastructure systems are easily disrupted.
b. Few locations are safely beyond the potential influence of storms.
c. Threatened populations cannot easily be removed from the islands.
d. Assistance from elsewhere cannot readily reach impacted island populations.

2. In Hawaii, Civil Defense and other emergency organizations responded relatively well to the hurricane, but a number of problems seriously hampered their effectiveness. These included:

a. A brief period between initial detection of Iwa and warning of threatened populations of its imminent arrival.
b. A mismatch between hazard warning assessments made by the National Weather Service, Kauai Civil Defense, and Oahu Civil Defense and actual threats perceived or experienced by local populations on both Kauai and Oahu.
c. Difficulties in communicating warning messages to targeted populations to alert them to the need for selective evacuation (on Oahu).
d. Incomplete coverage of the siren warning network (on Kauai).
e. Insufficient available Civil Defense staff and trained volunteers (on Oahu).
f. Insufficient safe and adequately provisioned and staffed emergency shelters in accessible locations.
g. Inadequate or absent storm shelter and evacuation plans for hotels and resorts (on Kauai).
h. Isolation of the public from sources of emergency information during and after the storm.
i. Lack of safe alternative evacuation routes (on Oahu).

3. Public and private agencies responsible for postdisaster recovery also faced major problems, including:

a. Variability of damage assessments.
b. Protracted needs for mass feeding (on Kauai).
c. Lack of knowledge among disaster assistance personnel from the mainland of the complex socioeconomic character of populations in the disaster area.

d. Public reticence to use federal aid programs (on Kauai).
e. Disproportionate dependence of poor minority populations on federal disaster aid funds rather than insurance or other means (on Oahu).
f. Lack of temporary housing.
g. Complex and lengthy procedures for distinguishing wind and water damage for purposes of insurance reimbursement.
h. Lack of flood insurance coverage for many flood-damaged structures.
i. Minimal attention to mitigation of future hazards in redevelopment plans.
j. Lack of guidelines for emergency response on privately owned Niihau.

6

CONCLUSION

Hurricane Iwa brought to the fore many issues that should receive priority attention by those associated with safeguarding life and property in Hawaii. Because of its location in the middle of the Pacific, Hawaii is especially isolated when hit by a hurricane. It is important to note that Iwa was not a strong hurricane. For land stations with comparable data, Iwa failed to produce winds in excess of previous records in Hawaii, even though the records cover as much as 30 years. Hence the extent of the damage caused by Iwa becomes all the more disconcerting. Based on its observations, the team offers the following summarized comments for consideration in mitigating damage from future similar events.

METEOROLOGY

1. The National Weather Service should modify its remote stations so that either radio or satellite telemetry can be used.
2. The ocean data buoy network should be expanded to permit adequate documentation of both hurricane winds and seas.
3. A weather radar station should be established in Hawaii.
4. Transmission of weather satellite imagery to Honolulu should use the satellite's communication capability.
5. Anemometer heights should be standardized.
6. Research should be undertaken to determine the spatial variation of vertical shear of horizontal winds.

BUILDINGS AND STRUCTURES

1. Evaluation of the performance of the large number of buildings and structures affected by Iwa indicated that the current wind load provisions in effect in Hawaii--those of the 1955-79 versions of the Uniform Building Code (International Council of Building Officials, 1979)--may not be adequate. The major shortcomings are related to the fact that the appropriate wind loads to be used in the design of components and cladding are not specifically addressed. The 1982 version of this code (currently under consideration for adoption in

Hawaii) appears to resolve this question, but the following caveats are offered with respect to the provisions of this document:

a. An investigation should be conducted to determine the probability distribution of hurricane wind speeds for Hawaii to establish the appropriate basic design wind speed.
b. The unique topographical features common to all of the islands of Hawaii and the data collected and analyzed by the team for Kauai and Oahu suggest that topographical and terrain effects warrant special consideration. It is recommended that special wind regions be delineated reflecting the possibility of higher wind speeds for local areas adjacent to mountainous terrain, gorges, and ocean promontories.
c. Due to the widespread practice in Hawaii of providing natural ventilation in industrial structures by incorporating planned openings in the walls or roofs, and the use of a high percentage of glazed areas in walls fronting beachfront areas, the internal pressure provisions built into the 1982 version of the Uniform Building Code may not be adequate. Specifically, the code incorporates different internal pressure coefficients for enclosed structures as compared with unenclosed structures (Perry, 1981). The problem is that an unenclosed structure is defined as a structure with an opening of more than 30 percent of any one side. This definition may lead to unconservative design loads for some buildings having smaller planned openings. It is suggested that specific design provisions include the possibility of the failure of a window or door and the corresponding increase in internal pressures.

2. The existence of older timber-framed buildings clad with light-gage metal sheeting and of residential construction with lightweight roof coverings not adequately fastened to the purlins or beams poses a continuing high hazard to life and property in Hawaii. It is important to note that damage to cladding fasteners tends to be cumulative in nature, and additional failures for some structures affected by Iwa may occur in the future under relatively light winds.

3. In the light of the above observation, attention should be directed toward the development of appropriate criteria to mitigate future damage due to windborne debris. Storm shutters, movable window louvers, and other safeguards might be used to good advantage for at least essential facilities (e.g., hospitals, storm shelters, fire stations, and state and local government offices) and school buildings.

4. The development of appropriate design criteria for the attachment of windows, sliding glass doors, and roll-up overhead doors to the parent structure should be considered to ensure that these components will not fail during high winds. Such failures, in addition to increasing the risk to human safety, may increase the wind loading on the main wind-force resisting systems of the buildings as well as on components and cladding.

5. In general, it was observed that most of the wind damage to timber-framed buildings and wood-framed single- and multiple-family

dwellings could be traced to inadequate fastening of the roof covering, poor anchorage of the roof systems to the walls, and weak connections of the stud walls to their foundations. Carport roofs and roofs having large overhangs were observed to be particularly vulnerable. Specific construction practices that would substantially eliminate or at least mitigate such damage in the future include:

a. Adequate nailing schedules for the attachment of all types of roof coverings and siding to wood framing.
b. Use of metal framing anchors, bolts, or other positive means for attaching roof systems to stud walls.
c. Anchorage of stud walls to concrete slabs or foundations with anchor bolts or metal straps rather than through "power nailing" (e.g., ramset).

6. It is recommended that structural tie-downs anchoring the floor system to the foundation or "over the roof" ties be required for all temporary homes or buildings erected on piers or concrete slabs.

7. For coastal buildings and structures directly exposed to salt air or salt water, provisions should be developed to deal with the problem of corrosion of reinforcing steel in masonry and reinforced concrete, metal fasteners, and other metal structural components such as light-weight corrugated metal sheeting. Epoxy coatings, corrosion-resistant metals, and periodic inspection and maintenance programs should be considered.

8. The identification of specific buildings throughout Hawaii that are resistant to hurricanes and can be used for storm shelters should be given top priority by state and local officials. For some of the islands, an adequate number of publicly owned structures may not be available for this purpose and contingency plans should be formulated for the use of privately owned buildings if necessary.

9. In principle any type of construction material (e.g., wood, masonry, reinforced concrete, steel, etc.) can be properly designed to withstand the high winds and hydraulic forces generated by hurricanes. The structural damage observed by the team indicates, however, that the performance of timber-framed structures close to the water and subjected to storm surge and wave action was far less satisfactory than that of reinforced concrete and masonry shear wall structures. The team recommends, therefore, that new timber-framed structures sited near the beachfront be of "pole or stilt house" construction if located in the high hazard flood zone.

10. Given the present value of beachfront property and the importance of tourism in Hawaii, it is unrealistic to assume that commercial property owners will consider a radical retreat from oceanfront sites. Specific design and construction practices such as the following would mitigate damage from future hurricanes:

a. Scouring protection should be incorporated into the foundation design to protect footings from erosion.
b. Where possible, main structural footings and exterior retaining walls should be founded on and keyed into lava rock formations rather than being founded on sand.

c. Shear walls should be oriented normal to the beachline.

d. "Breakaway" interior partitions or other nonstructural walls should be used to dissipate or relieve the hydraulic forces generated by storm surge, wave action, and hydrostatic forces.

FLOODING

1. Present flood levels established by the Federal Emergency Management Agency (FEMA) for the coastal zone of Hawaii do not incorporate the effects of possible extratropical or hurricane-generated storm surge and wave action. In view of the extensive wave damage and flooding on Kauai and Oahu, and the wide transgression of the presently established 100-year flood limits on the south coast of Kauai, the FEMA flood levels need to be reestablished to consider the effects of both tsunamis and tropical and extratropical storm surge with wave action.

2. Due to the importance of localized bathymetric controls (e.g., reefs, island sheltering, irregular coasts), coastal flood studies for Pacific islands should be conducted with more detail in areas of high population density than is now the case for studies of mainland areas.

3. FEMA should encourage research that seeks to establish a standardized methodology to predict coastal flooding for Pacific islands. FEMA has established a standardized methodology for the Atlantic and Gulf Coast regions of the United States in response to a recommendation by the National Academy of Sciences (Federal Emergency Management Agency, 1981). A similar attempt needs to be made to establish acceptable engineering approaches for determining flood levels for Pacific islands.

4. FEMA or some other government agency should be given the responsibility of collecting water level data after extreme events such as Hurricane Iwa. Such surveys would have to be accomplished immediately after the storm while water level marks inside buildings are still fresh and apparent (U.S. Army Corps of Engineers, 1981). This would provide a data base for:

a. Evaluating the adequacy of existing coastal flood insurance maps where extreme floods have occurred (after the original establishment of Federal Insurance Rate Maps).

b. Calibrating numerical and analytical models used to establish coastal flood levels.

LIFELINES

1. An investigation should be made of the design of wood power poles, including their embedment into the ground, to determine the cause of their numerous failures.

2. Pole-top equipment, such as transformers, circuit breakers, and Civil Defense or emergency sirens, should be anchored securely to platforms that are designed to withstand extremely high velocity winds.

3. Essential facilities requiring commercial electric power for

their operation should have independent backup or standby generators. These generators should be properly maintained and serviced on a strictly monitored schedule (for example, they should be periodically started).

4. Total reliance should not be placed on telephone systems for emergency communications. In fact, communication plans should anticipate the total loss of telephone service, and alternate means of short- and long-distance communications should be available to police, fire, and utility departments.

5. Coastal roads subject to destruction from high seas during hurricanes and other extreme natural phenomena (such as tsunamis) should have backup alternate paved roads on higher ground, if it is possible to construct them.

6. Facilities and procedures should be available to promptly test domestic water for contamination after a natural disaster. Sources of water that are not likely to become contaminated during a natural disaster should be found and cataloged.

RESPONSE AND RECOVERY

1. Federal agencies and research funding organizations should increase their support to develop broadly applicable strategies for identifying, measuring, and reducing vulnerability to storms on oceanic islands. An early step in this direction should be an analysis of storm disaster assistance programs for oceanic islands mounted by FEMA, the U.S. Agency for International Development, and other bodies.

2. A comprehensive storm shelter and evacuation plan covering the entire Hawaiian population and expected visitors should be developed by state and county Civil Defense agencies. As part of this task, public and private buildings that can function as potential hurricane shelters should be inventoried, and their hurricane-resistant characteristics and risks should be assessed. Procedures for initiating and implementing limited warnings and evacuations in local districts should be clearly specified. The possibility of providing alternate evacuation routes from areas that now depend on single access routes should also be investigated and documented.

3. Local government preparedness agencies should investigate the feasibility of using hurricane-resistant hotel and resort buildings outside flood hazard areas as public storm shelters.

4. Major hotel and resort developments should be required to develop or update and test comprehensive emergency preparedness and evacuation plans for use in future coastal storms and tsunamis.

5. Alternatives to the present system of unselective and incomplete warning sirens should be examined.

6. FEMA should investigate and encourage the development of improved or new methods for relieving the disproportionate burdens borne by poor and uninsured or underinsured populations after disasters.

7. Special guidelines and training exercises for the delivery of disaster relief and assistance programs to local multiethnic and multilingual communities should be developed by FEMA, Red Cross, and other national disaster agencies.

8. County and state governments in Hawaii should be encouraged to prohibit further development or redevelopment of nearshore zones, landward of existing Special Flood Hazard Areas, pending the completion of revised studies of coastal flood hazards and insurance rates.

9. County governments in Hawaii should prepare and adopt postdisaster redevelopment policies, plans, and procedures designed to reduce the potential for future loss.

10. Public responsibilities toward the inhabitants of Niihau during threatened or actual disasters should be formally clarified by federal, state, and local emergency preparedness and disaster response agencies.

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