

Earthquakes in Hawai‘i—An Underappreciated but Serious Hazard

The State of Hawaii has a history of damaging earthquakes. Earthquakes in the State are primarily the result of active volcanism and related geologic processes. It is not a question of “if” a devastating quake will strike Hawai‘i but rather “when.” Tsunamis generated by both distant and local quakes are also an associated threat and have caused many deaths in the State. The U.S. Geological Survey (USGS) and its cooperators monitor seismic activity in the State and are providing crucial information needed to help better prepare emergency managers and residents of Hawai‘i for the quakes that are certain to strike in the future.



This photograph shows the historic Kalahikiola Congregational Church, Kapa‘au, North Kohala District, Island of Hawai‘i. The church, originally built in 1855, and its unreinforced mortared-stone facade were heavily damaged by two magnitude 6+ earthquakes that struck the northwest coast of the Island of Hawai‘i on October 15, 2006. Unreinforced masonry structures are particularly vulnerable to quake damage. (Copyrighted photo by Michael Darden/West Hawaii Today, used with permission.)

Each year, thousands of earthquakes occur in the State of Hawaii. As in other seismically active regions around the world, the vast majority of these are microearthquakes. Earthquakes in the State are detected by sensitive seismometers operated by the Hawai‘i Integrated Seismic Network. Sometimes the earthquakes are large enough to be felt by people. Less frequently, strong quakes occur like those that struck the northwest coast of the Island of Hawai‘i on the morning of October 15, 2006—a magnitude 6.7 quake at 7:07 a.m. and a magni-

tude 6.0 quake at 7:14 a.m. These earthquakes damaged roads and structures on Hawai‘i and Maui, the islands nearest the quakes’ epicenters.

Earthquakes and Volcanoes

Earthquakes in the Hawaiian Islands chain are closely linked to active volcanism. Most quakes occur closest to Kīlauea and Mauna Loa Volcanoes, along the southeastern coastline of the Island of Hawai‘i, extending inland beneath the flanks of these volcanoes. Earthquake activity is also evident at Lō‘ihi seamount, the State’s

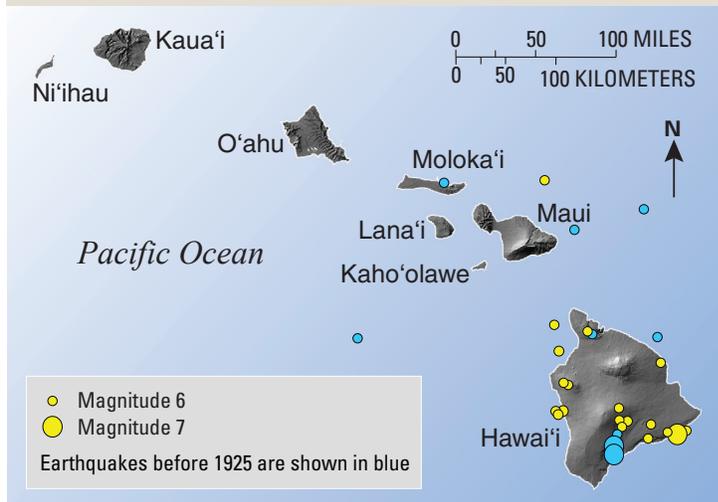
youngest volcano, about 22 miles (~35 km) southeast of the Island of Hawai‘i and still some 3,000 feet (1,000 m) beneath the surface of the Pacific Ocean. Rates of earthquake activity decrease progressively to the northwest, toward the older islands in the Hawaiian Islands chain.

Where an earthquake is located typically offers a basic understanding of its underlying cause. Earthquake patterns showing events closely spaced in time with points of origin, or “hypocenters,” clustered within the summit caldera and rift zone regions of Hawai‘i’s active volcanoes indicate magma (molten

rock) movement within the volcanoes. Away from active volcanic centers, on faults buried within and beneath the flanks of the volcanoes, quakes occur in response to stress changes resulting from magma movement and adjustments to the geologic structure of an island. In these regions, quakes occur on, and help delineate, active fault structures and geometries within volcanic edifices. On the Island of Hawai'i, one such prominent fault structure lies at a depth of roughly 6 miles (~9 km). This is thought to represent the interface between ancient oceanic crust and the overlying, much younger volcanic edifice. Most of the State's large and damaging historically recorded quakes are thought to have occurred along this interface.

Another type of earthquake reflects the flexing or bending of the Earth's crust and upper mantle, or "lithosphere," beneath the weight of the Hawaiian Islands. Lithospheric earthquakes occur deep beneath the Islands and are more common beneath Hawai'i and Maui, the geologically youngest islands. Some of these earthquakes, like the October 15, 2006, quakes, can be large and damaging. Such quakes are caused by the weight of the islands rather than by active

Large Earthquakes in Hawai'i, 1823–2010



The State of Hawaii has a history of damaging earthquakes. This map shows large earthquakes that struck Hawai'i between 1823 and 2010. Earthquakes in the State are primarily the result of active volcanism and related geologic processes.

volcanism. Similar powerful quakes could occur beneath older Hawaiian Islands and closer to the State's larger and more densely concentrated populations like those on O'ahu.

Measuring Earthquake Intensity

Most effects of earthquakes felt or observed by people are the result of shaking produced by seismic waves. In the United States, these effects or the "intensity" of a quake are compared using the Modified Mercalli Intensity (MMI) scale. The effects of a quake on the Earth's surface, humans, objects of nature, and manmade structures are ranked on a scale of I through XII; for example, I means not felt and XII means total destruction. Generally the values are higher closest to the quake's epicenter but will vary depending on local geology. Historically, the most

extreme earthquake effects in Hawai'i were recorded from the April 1868 Great Ka'u earthquake, but this quake predated instrumental seismic monitoring in the State. Using historical accounts of this earthquake, intensities of VII to XII were inferred to have occurred on the Island of Hawai'i, leading the USGS scientists to estimate the quake's magnitude at about 7.9. The earthquake produced tsunamis and landslides and caused stone buildings to collapse, killing a total of 77 people.

Earthquakes and Tsunamis

Hawaiians know that their islands have been struck by tsunamis produced by distant earthquakes, such as the 1960 magnitude 9.5 Chilean quake that generated a tsunami, which killed 61 people in Hilo, and the March 2011 magnitude 9.0 quake in Japan. However, many people are possibly unaware that large earthquakes in Hawai'i, like the 1868 Great Ka'u quake, have also produced tsunamis with devastating local impacts. The maximum height of the tsunami produced by the 1868 earthquake was approximately 45 feet (14 m) on the southeast coast of the Island of Hawai'i, and 46 people were killed by the waves. More recently, the 1975 magnitude 7.2 Kalapana earthquake, also along the southeast coast of the Island of Hawai'i, produced a tsunami with maximum height of roughly 45 feet (14 m), killing two people.

Because of the proximity of source zones for earthquakes to low-lying



The largest locally generated tsunami in Hawai'i in the past century was triggered by a magnitude 7.2 earthquake that struck the Island of Hawai'i in November 1975. Waves reached as high as 45 feet (14 m) above sea level near the quake's epicenter on the southeast coast of the island. The tsunami killed two people and caused property damage of about \$1.4 million (1975 dollars), including damage to this house in Punalu'u (top) and boat in Hilo (bottom). (House photo by David Shapiro and boat photo by Hugh Clark, courtesy Honolulu Star-Advertiser; used with permission.)

MODIFIED MERCALLI INTENSITIES FOR THE 1868 GREAT KA'U EARTHQUAKE

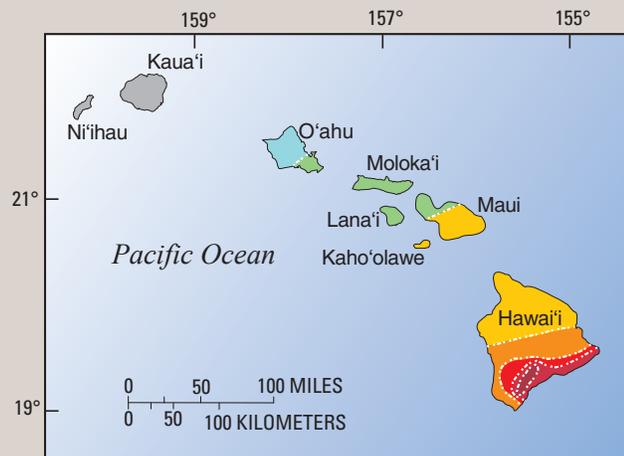
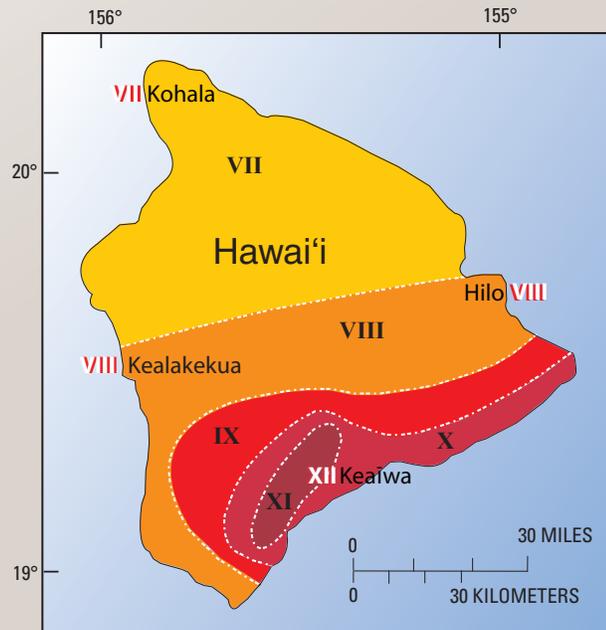
On April 2, 1868, Hawai'i was struck by a powerful earthquake estimated to have a magnitude of 7.9. This map shows Modified Mercalli Intensities (MMI) inferred from eyewitness accounts of the Great Ka'u earthquake. The earthquake produced tsunamis and landslides and caused stone buildings to collapse, killing 77 people. Original descriptions of the earthquake's effects are provided for the MMI values shown on the map in white:

Keaīwa, MMI XII: Frame building thrown off foundation, racked and strained. People thrown upon the earth, where they were tossed up and down like balls. Duration estimated at 2 minutes. . . . People found it impossible to stand, had to sit on ground bracing with hands and feet to keep from falling over. . . .

Hilo, MMI VIII: Shook down almost every stone wall in town (even the foundation stones were moved), cracked basement of church in several places, and knocked down most brick chimneys. . . . The few stone buildings were ruined. Furniture, clocks, mirrors, and crockery was thrown down and broken. . . .

Kealakekua, MMI VIII: Strong kukui trees were bent backward and forward, stone houses thrown down, large landslides. Walls fell in all directions. . . .

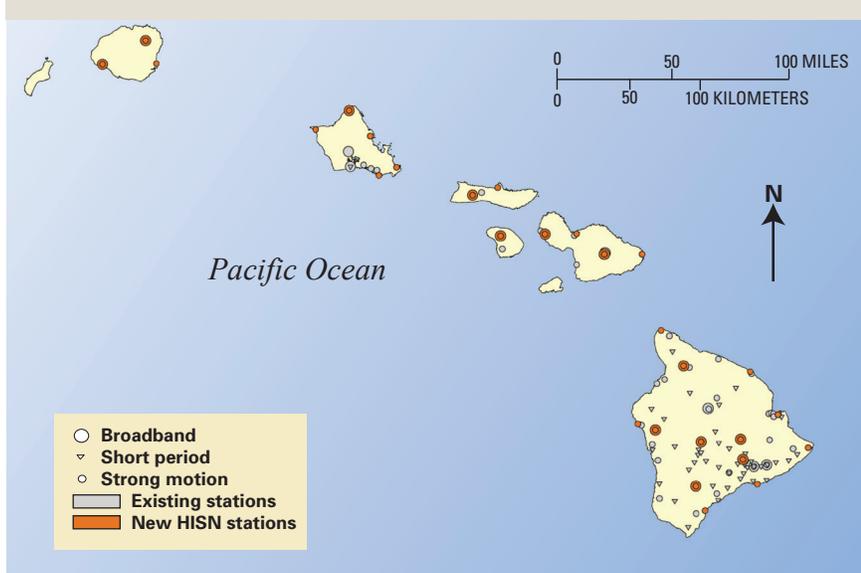
Kohala, MMI VII: Ground waves seen, hard to keep balance, all mill engines stopped, very little damage, tall chimney of sugar mill did not fall.



Naohulelua church was badly damaged by the 1868 Ka'u earthquake. The church, about 10 miles southwest of the quake's epicenter, was never used again. The quake and its effects killed 77 people in Hawai'i. (USGS photo by Paul Okubo.)

INTENSITY	II-III	IV	V	VII	VIII	IX	X+
SHAKING	Weak	Light	Moderate	Very strong	Severe	Violent	Extreme
DAMAGE	None	None	Very light	Moderate	Moderate/Heavy	Heavy	Very Heavy

Hawai'i Integrated Seismic Network Stations



Earthquakes in Hawai'i are monitored by sensitive seismometers operated by the Hawai'i Integrated Seismic Network (HISN). This map shows the distribution of previously existing and new or planned HISN seismic stations. The HISN is operated by the U.S. Geological Survey and the Pacific Tsunami Warning Center of the National Oceanic and Atmosphere Administration, in cooperation with State of Hawaii Civil Defense and other organizations.

coastal regions in Hawai'i, there is little time to react and respond to such earthquakes and their associated tsunamis. The tsunami generated by the 1975 quake reached populated areas along that coastline in seconds and Hilo Harbor in less than 20 minutes. Emergency managers in the State are concerned about tsunamis generated by quakes along the western coast of the Island of Hawai'i. It has been estimated that a tsunami from such a quake would reach Honolulu in 35 minutes.

Seismic Monitoring in Hawai'i

There are three principal groups that monitor earthquakes in the State of Hawaii—the U.S. Geological Survey (USGS) Hawaiian Volcano Observatory, the USGS National Strong Motion Project, and the Pacific Tsunami Warning Center (PTWC) of the National Oceanic and Atmospheric Administration (NOAA). Although each group has specific seismic monitoring objectives, improvements and upgrades to seismic instruments and data transmission technologies are presenting new opportunities for

cooperatively operating seismic monitoring stations and integrating and coordinating data sharing, data handling, and earthquake reporting among these three groups. To meet the State's seismic monitoring needs, the USGS and PTWC, in cooperation with the State of Hawaii Civil Defense and other organizations, have formed the Hawai'i Integrated Seismic Network (HISN).

Using seismic data streams from the HISN and other sources, the USGS automatically generates and posts on the Internet the time, location, and magni-

tude of quakes in Hawai'i. The USGS also automatically posts enhanced earthquake information products, including near real-time earthquake analysis and post-earthquake decision-making tools. The data and related products are shared among USGS and NOAA partners for enhanced hazard warning capabilities. The information products are intended to assist with effective post-earthquake response and recovery efforts. Through online questionnaires, the USGS also collects reports of earthquake effects and earthquake damage from the general public. As quickly after a significant earthquake as possible, these are automatically compiled and posted to the Web in the form of maps that reflect the intensity and extent of a quake's impact.

The Earthquake Hazard in Hawai'i

Because of Hawai'i's history of damaging earthquakes and its active volcanism, it is not a question of "if" another devastating quake will strike but rather "when." Hawai'i's recorded history of damaging quakes provides helpful clues about the impact of future large earthquakes.

Probabilistic seismic hazard maps quantify the shaking hazard posed by future earthquakes. The USGS has produced a new generation of seismic hazard maps, recently developing and applying a consistent methodology across the entire United States. Important input and participation in arriving at the final products came from local expertise and experience. The National Seismic Hazard Maps are intended to reflect the

best available science in earthquake hazards estimation. As of 2000, the USGS seismic hazards maps have been incorporated into all U.S. model building codes.

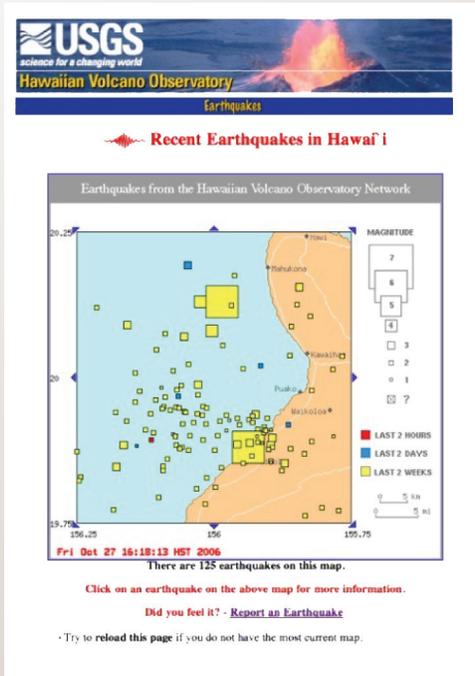
Seismic hazards maps show levels of



This road in Hawai'i Volcanoes National Park, on the Island of Hawai'i, was severely damaged by a magnitude 6.7 earthquake in November 1983. (USGS photo by T.J. Takahashi.)

EARTHQUAKE INFORMATION PRODUCTS RAPIDLY AVAILABLE ON THE INTERNET FROM THE USGS

HVO Recent Earthquakes Web Page



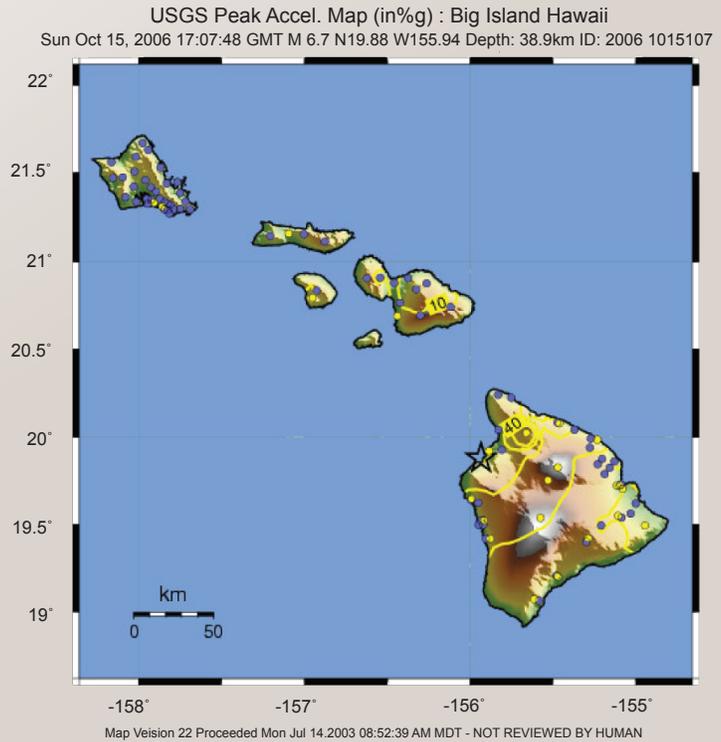
Since the early 1990s, the magnitude and location of an earthquake have been available within minutes on the Internet, as a result of work by the U.S. Geological Survey (USGS) in cooperation with various regional seismic networks. Internet maps for recent and past quakes in Hawai'i can be found through either the USGS Hawaiian Volcano Observatory (HVO) earthquakes Web page (<http://hvo.wr.usgs.gov/earthquakes/>) or the USGS Earthquake Hazards Web site (<http://earthquake.usgs.gov/>).

The maps of Hawai'i shown here were posted online following a magnitude 6.7 earthquake on October 15, 2006. The map above shows the location of the quake, along with the locations of aftershocks from the following 12 days, including one of magnitude 6.0 that occurred 7 minutes after the main shock.

The "ShakeMap" is an automatically generated computer map of the intensity of ground shaking in percent of g (g is the acceleration due to gravity or 980 cm/sec/sec). Immediately following a quake, emergency managers can use this kind of map to quickly make response decisions. The quick, accurate, and important information provided in such ShakeMaps can aid in making the most effective use of emergency response resources.

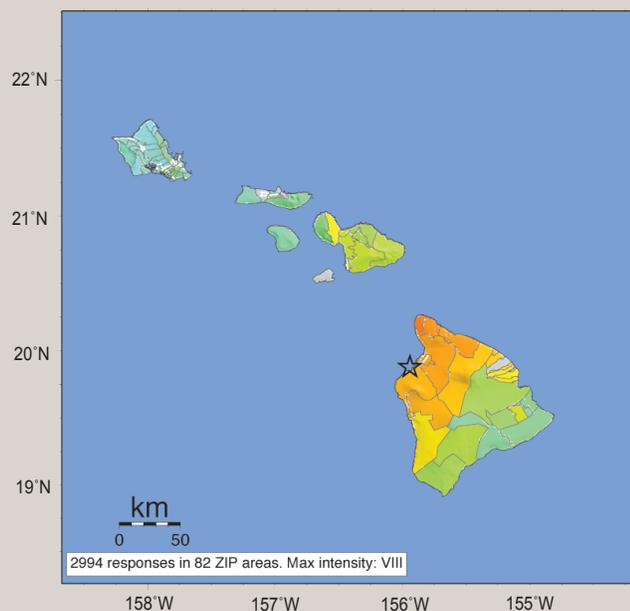
The "Community Internet Intensity Map" was automatically created using information provided through an online questionnaire by 2,994 responders who experienced the earthquake. This shared information was then used to help create a map of shaking intensities and damage. Such maps contribute greatly in quickly assessing the scope of an earthquake emergency, even in areas lacking seismic instruments. In the United States, the "intensity" or effects of a quake are described using the Modified Mercalli Intensity (MMI) scale. The effects of a quake on the Earth's surface, humans, objects of nature, and manmade structures are ranked on a scale of I through XII for the amount of shaking and the degree of damage; for example, I is not felt and XII is total destruction.

Shakemap



Community Internet Intensity Map

USGS Community Internet Intensity Map (10 miles of Kailua Kona, Hawaii, Hawaii)
ID:twbh_06 07:07:48 HST OCT 15 2006 Mag=6.7 Latitude=19.88 Longitude=W155.94



INTENSITY	I	II-III	IV	V	VI	VII	VIII	IX	X+
SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
DAMAGE	none	none	none	Very light	Light	Moderate	Moderate/Heavy	Heavy	Very Heavy

earthquake ground motions computed for specified probability levels of exceedance, within specified timeframes. Often, these are stated as 10% probabilities that calculated levels of ground motion will be exceeded in a 50-year period. This is roughly equivalent to saying that these ground motions have a 1-in-475 chance of being exceeded in any given year.

Hawai'i seismic hazard maps, along with hazards maps for other regions, are available online at <http://earthquake.usgs.gov/hazards/>. The online Hawai'i maps show both 2% and 10% exceedance probabilities for a 50-year time interval. There is general agreement between the hazard maps and historical earthquake experience in Hawai'i. It is also worth noting that the entire southeast coast of the Island of Hawai'i is associated with 50-year-exceedance probabilities for ground motions of 100% g (g is the acceleration due to gravity or 980 cm/sec/sec), comparable to those associated with the maximum Modified Mercalli Intensity (MMI) values recorded from the 1868 Ka'u earthquake. As incorporated in updated seismic provisions of building codes, the hazards maps will help

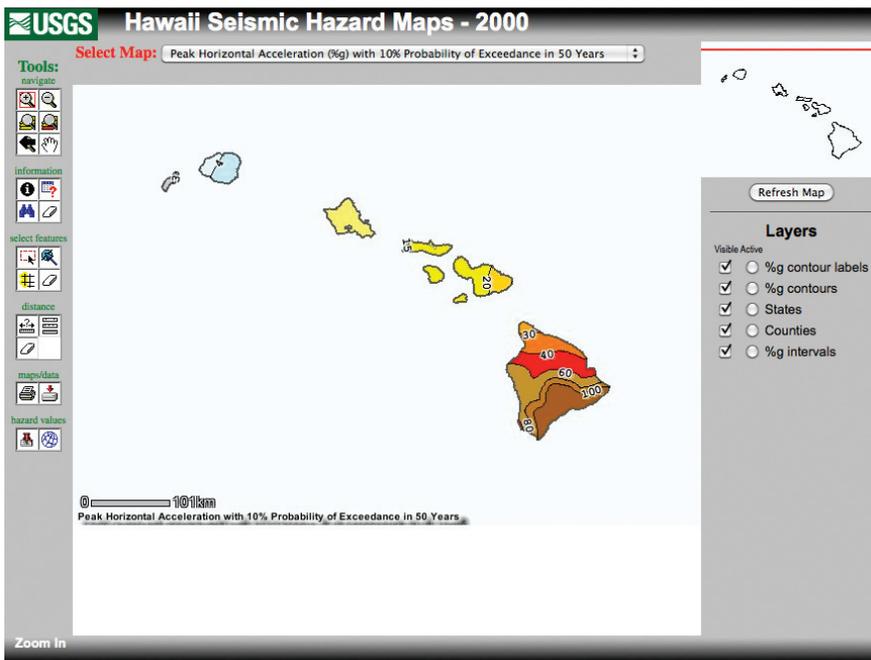


This home in Kalapana collapsed as a result of a magnitude 6.1 earthquake that struck the Island of Hawai'i in June 1989. (USGS photo by J.D. Griggs.)

mitigate against future earthquake losses as Hawai'i's built environment expands and evolves. Hawai'i seismic hazards maps are expected to be updated, taking advantage of additional data from Hawai'i's damaging earthquakes of October 2006, as well as data derived from the HISSN.

The work of the USGS and its co-operators to monitor seismic activity in

the State of Hawaii is providing crucial information needed to help better prepare emergency managers and residents of Hawai'i for the quakes that are certain to strike in the future. This effort is only part of the USGS hazards programs' ongoing efforts to protect people's lives and property, including in all of the volcanic regions of the United States.



Seismic hazard maps for the State of Hawaii are available on the Web at <http://gldims.cr.usgs.gov/website/hishmp/viewer.htm>. This map shows estimated peak horizontal ground acceleration with a 10% probability of exceedance in a 50-year interval. Ground acceleration values shown are expressed as a percentage of g (g is the acceleration due to gravity or 980 cm/sec/sec).

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