2006 Kiholo Bay, Hawaii Earthquake

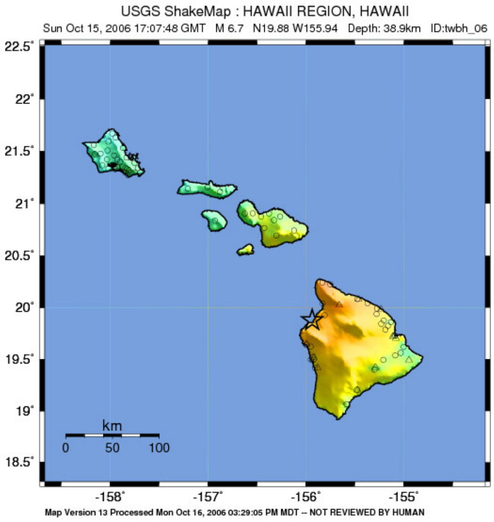
RMS Event Report

RMS™
Risk Management Solutions

INTRODUCTION

On Sunday, October 15, 2006 at 7:07:48 a.m. local time, a M_W 6.7 (moment magnitude) earthquake struck off the Kohala coast of the island of Hawaii, approximately 11 km (7 mi) north-northwest of Kalaoa, Hawaii. It was followed by over 50 aftershocks, including a M_W6.0 earthquake 7 minutes later. The depth of the earthquake was 29 km (18 mi), originating from bending stresses within the Pacific Plate caused by the weight of the overlying islands.

The event was felt throughout the Hawaiian Islands, with a maximum intensity of VII-VIII (very strong to severe) in the northwestern part of the island of Hawaii. The reported intensities were consistent with recorded ground motions incorporated into the USGS Instrumental Intensity maps (Figure 1). While there were localized reports of intensity VI on Maui, the strongest shaking and significant damage were clearly restricted to the island of Hawaii.



PERCEIVED SHAKING	Not felt	Weak	Light	Moderate	Strong	Very strong	Severe	Violent	Extreme
POTENTIAL DAMAGE Resistant Structures	none	none	none	V. Light	Light	Moderate	Moderate/Heavy	Heavy	V. Heavy
POTENTIAL DAMAGE Vulnerable Structures	none	none	none	Light	Moderate	Moderate/Heavy	Heavy	V. Heavy	V. Heavy
PEAK ACC.(%g)	<.17	.17-1.4	1.4-3.9	3.9-9.2	9.2-18	18-34	34-65	65-124	>124
PEAK VEL.(cm/s)	<0.1	0.1-1.1	1.1-3.4	3.4-8.1	8.1-16	16-31	31-60	60-116	>116
ESTIMATED INTENSITY	I	II-III	IV	V	VI	VII	VIII	IX	X+

Figure 1: USGS ShakeMap for the M_W6.7 October 15, 2006 Kiholo Bay Earthquake based on ShakeMap Instrumental Intensities as of October 25, 2006

The ground shaking was recorded by twelve instruments on the island of Hawaii, with locations and peak ground accelerations (PGAs) shown on Figure 2a. Despite its moderate depth, the earthquake generated high accelerations to the northeast of the epicenter. For example, the instrument at the Waimea fire station, measuring 0.88g as shown on Figure 2a, recorded a maximum horizontal component of 1.05g. Due to these high PGA values (i.e., the high-frequency content of the ground motion), the earthquake primarily affected acceleration-sensitive components, such as contents and nonstructural elements.

The ground motions at longer periods (e.g., periods over 1.0 second), however, did not follow this same trend. Figure 2b shows the USGS ShakeMap for spectral acceleration (Sa) at a period of 1.0 second. Due to the low Sa values (i.e., lack of low-frequency content in the ground motion), which is more strongly correlated to structural damage, the earthquake resulted in overall low levels of building damage.

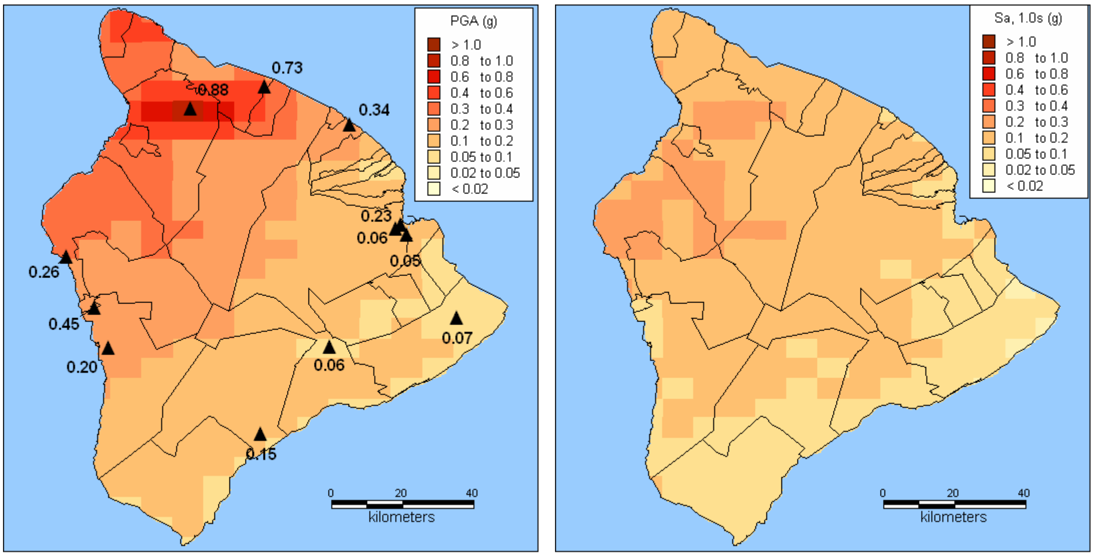


Figure 2: USGS ShakeMaps for (a) peak ground acceleration and (b) spectral acceleration at 1.0 second

RMS dispatched a reconnaissance team to the island of Hawaii within 48 hours of the main shock. The reconnaissance team surveyed damage in North Kohala, Waikoloa, Waimea, and Kailua Kona (See Figure 3 for location map). Their observations on commercial, residential, and public facility damage, as well as findings on insurance and economic impacts are presented in this report.

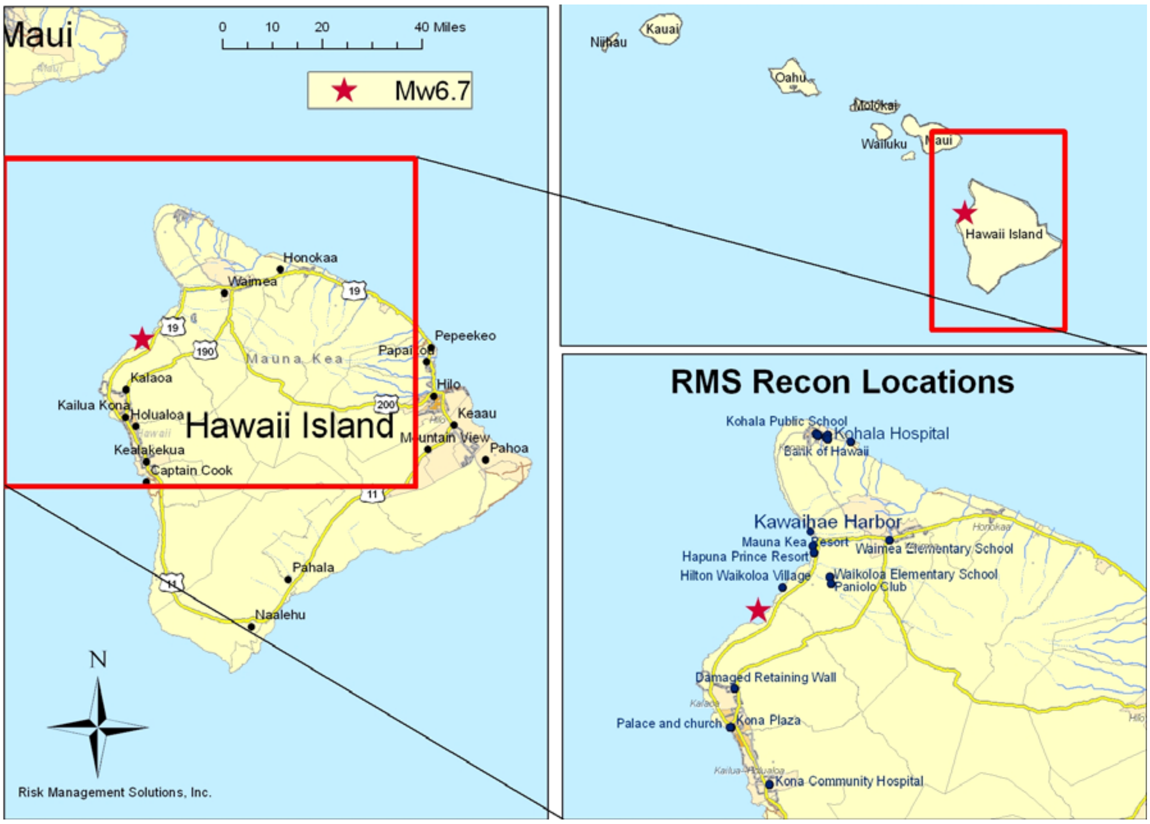


Figure 3: Map showing the locations visited by the RMS reconnaissance team on the island of Hawaii

Earthquake Hazard in Hawaii

Earthquakes are relatively common within the Hawaiian Islands, particularly on the island of Hawaii. The island of Hawaii is the youngest major island in this chain of volcanoes, and the high rate of seismicity is a consequence of the crustal stresses imparted by this volcanic activity. Numerous damaging earthquakes have affected Hawaii in the past 150 years. In Figure 4, intensity maps for eight significant events are compared. The largest of these events was the Great Kau Earthquake on April 2, 1868, which occurred along the southern coast and had an estimated magnitude of 7.9. Prior to the 2006 event, the last damaging event was the M_W6.1 Kalapana Earthquake of June 25, 1989, which damaged over 100 structures and caused $1 million in damage (1989 values).

Most of these historic events have been shallow events from 5 to 15 km (3 to 9 mi) in depth, but deeper earthquakes caused damage in 1973 and 1929. The earthquake of October 5, 1929, which also occurred beneath the western part of the island, has strong similarities to the 2006 event. The instrumental magnitude was M_S6.5, but several researchers have noted that there is significant uncertainty associated with this estimate and the isoseismal maps suggest a larger magnitude. The maximum intensity was VIII, with an isoseismal area similar to that experienced in 2006. The damage reports for 1929 include toppled block walls, multiple landslides in the epicentral region, and a few collapses of weak structures.

The high rate of earthquake occurrence, coupled with the potential for large events, places Hawaii among the areas of highest seismic hazard in the United States. According to the 2001 U.S. Geological Survey seismic hazard maps for Hawaii, the PGA with a 10% probability of exceedance in the next 50 years, equivalent to a 475-year return period, is in excess of 1.2g along the south coast. Only a few areas directly along the San Andreas fault in California have a higher hazard in terms of PGA.

Due to the high seismic hazard on the island, the building code for Hawaii contains relatively stringent design requirements. As Hawaii is also at risk from hurricanes, the wind load requirements may also have contributed to the relatively low levels of structural damage observed for well-built structures in the 2006 Kiholo Bay Earthquake.

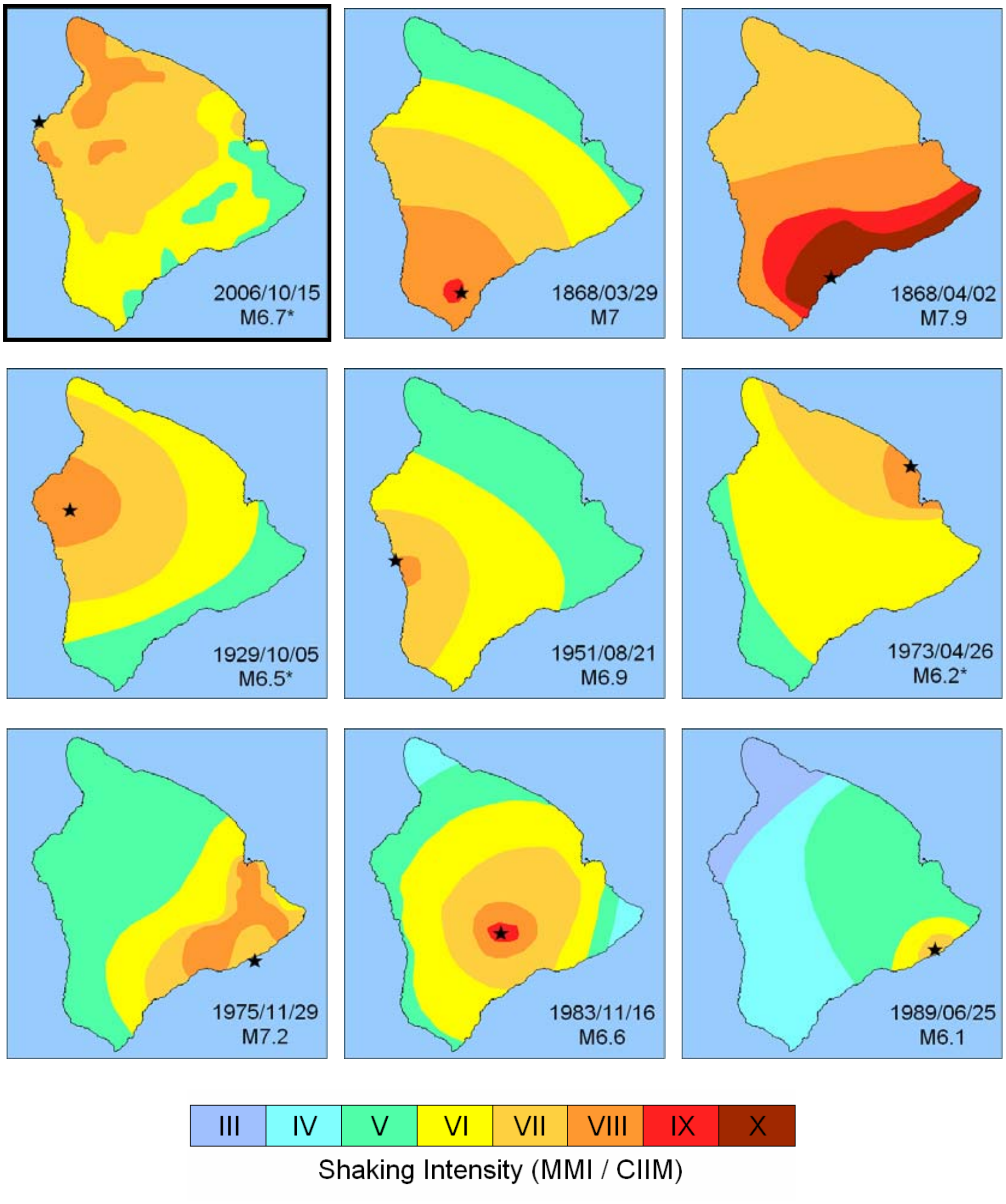


Figure 4: Comparison between simplified intensity map for the October 15, 2006 earthquake and eight major historical events on the island of Hawaii (Sources: USGS Community Internet Intensity Map and Shakemap downloads as of October 24, 2006; Wyss & Koyanagi, 1992)

COMMERCIAL BUILDING DAMAGE

According to the Department of Business, Economic Development and Tourism of the state of Hawaii, tourism accounts for over $10 billion in revenue of the $50 billion in gross state product (GSP) with over 10,000 hotel and condominium units on the island of Hawaii alone. The reconnaissance team visited various resorts, including the Mauna Kea Beach Resort, the Hapuna Beach Prince Hotel, the Mauni Lani Resort, the Fairmont Orchid, and the Hilton Waikoloa Village. While the majority of hotels sustained little or no damage and were back in business by Monday, October 16 when power and phone lines were restored, there were some resorts that suffered significant nonstructural and contents damage, including earthquake sprinkler leakage (EQSL) damage.

Of the resort complexes that the reconnaissance team visited, the Mauna Kea Beach Resort on the Kohala Coast sustained the worst damage, as illustrated in Figures 5a and 5b below. A few days following the event, the team was able to document several locations in various stages of clean up and repair. The worst areas were found in the corner rooms on the top floor, indicative of the high accelerations of the ground motion. Overall observations included destroyed ceiling panels, shattered windows and glass doors, exposed wall and ceiling framing, and water damage from sprinkler leakage. The most significant structural damage was caused by an elevator shaft and housing pulling away from the building (Figure 5a). Additionally, one area near an expansion joint, which allows for movement between adjoining parts of the concrete slab, had severe cracking and additional nonstructural finishing damage (Figure 5b). The damage to the ceiling and drywall was fairly major, involving significant repair costs.

(a) (b)

Figure 5: Damage at the Mauna Kea Beach Resort: (a) structural damage at an elevator shaft and (b) severe cracking at expansion joint

(a)

(b)

Figure 6: Clean up from earthquake sprinkler leakage (a) in the main ballroom of the Fairmont Orchid and (b) in the ballroom of the Hapuna Beach Prince Resort

At the resorts visited by the reconnaissance team, the most significant form of nonstructural and contents damage was due to EQSL, particularly noticeable in the Fairmont Orchid where the ballroom's ceiling was damaged and the floor was soaked (Figure 6a shows the clean up efforts). Additionally, the contents in a number of the rooms on the sixth floor of the south tower were damaged, as 10 to 15% of the rooms had sprinklers go off. At the Hapuna Beach Prince Resort, the head engineer also confirmed that the most serious problem had been sprinkler leakage. He reported that 40 of 48 sprinklers in the main ballroom were sheared off by the shaking ceiling panels and leaked for about ten minutes before the water supply was shut off (Figure 6b shows the clean up efforts). Interestingly, the engineer also reported that the resort has seismic shut-off values for the propane system, which performed properly.

Other observed damage to commercial buildings beyond hotels and resorts included nonstructural and contents damage due to dropped ceiling panels at a hardware store (Figure 7a) and broken windows at an Airgas distribution store (Figure 7b) near Waimea. In North Kohala, a small concrete block building that housed the local Bank of Hawaii office was completely shut down. There were major cracks in the structures façade and one front window had shattered.

(a) (b)

Figure 7: Nonstructural damage to commercial properties in the form of (a) dropped ceiling panels and (b) broken windows

Several multi-family dwellings also experienced damage with patterns similar to those seen in other commercial structures. In particular, minor crushing at expansion joints, nonstructural damage to ceilings and partition walls, and damage to contents were commonly observed. A four-story apartment complex in Kona had damage at the balcony/breezeway joints on all levels in both wings. There was minor crushing and spalling of the concrete at the joints as well as residual gaps especially at the upper floors (Figures 8a and 8b). The facilities manager listed additional problems relating to piping, including minor sprinkler leakage limited to the underground garage, and ruptured hydraulic lines in the elevator system.

(a) (b)

Figure 8: Damage to an apartment complex in Kailua Kona, showing (a) moderate pounding damage at breezeway joint and (b) a close-up of crushing of concrete slab and residual separation at the third and fourth levels

Residential Building Damage

The RMS reconnaissance team investigated residential homes in Kailua Kona, Kaoloa, North Kohala, Waikoloa Village, and Waimea. Overall, structural damage to single-family residential homes due to ground shaking was minimal with the exception of a few homes in the Kohala area. Ground shaking damage was primarily of the form of nonstructural and contents damage. It was estimated that 1,800 homes were impacted by the event. Most of these residential structures were on the island of Hawaii, where over 60 have been red-tagged as unusable as of October 26, 2006 (Robertson and others, 2006).

The typical Hawaiian home is wood frame construction as shown in Figure 9a, which withstood the ground motions from the Kona Earthquake fairly well. Interestingly, many of the unreinforced lava rock and rubble stone walls in front of residential homes collapsed as shown in Figure 9b, illustrating the importance of reinforcement in masonry and stone building construction.

(a) (b)

Figure 9: (a) Typical house with no damage in Waimea and (b) collapse of a rubble stone wall in front of a home in North Kohala

The typical nonstructural and contents damage from this event included tile roof damage, water damage due to broken pipes, drywall cracks, and the 'breakage' of contents. The reconnaissance team spoke to homeowners in and around Waimea and over 75% of them had the piping on their water heater break and cause water damage. For the most part, the damage was relatively minor as people caught it shortly after the event. However, there was at least one case where the water ran for probably an hour or more, causing flooding throughout the house.

As for other contents damage, many homeowners reported 'breakage' of their personal belongings, including dishes, pictures, televisions, stereos, etc. One exception to the typical damage seen in residential properties was a house in Waimea, which was completely destroyed due to fire following earthquake (FFEQ) as shown in Figure 10. A gas leak triggered the fire.

Figure 10: House destroyed by fire following earthquake in Waimea

Another exception to typical damage was seen in the Kohala area, where several single-family residences with pier-and-post foundations had been structurally damaged. A pier-and-post foundation behaves similarly to a cripple wall (as seen in California construction), offering little lateral resistance to earthquake loading. This type of construction is found in some older, wood frame homes sometimes referred to as Hawaiian 'plantation' style. While these types of homes are highly damageable, they do not represent a significant portion of the building stock. One example is shown in Figure 11, where the wood frame house shifted off its foundation.

Figure 11: Damage to a residential structure in North Kohala, where the wood frame home shifted off its foundation

PUBLIC FACILITIES DAMAGE

The reconnaissance team surveyed a number of schools on the island of Hawaii with significant nonstructural damage. Elementary school campuses typically consist of multiple buildings with varying construction types, most commonly concrete block masonry and wood frame. In general, the older, concrete block structures exhibited minor structural and nonstructural damage in the form of cracking; additional nonstructural and contents damage was found across all types of buildings.

Several of the island's public school facilities temporarily closed parts of their campuses due to the ground shaking damage. In the case of Waimea Elementary School, multiple classrooms had ceiling panels along the perimeter of the room that were cracked or had completely fallen out as shown in Figure 12a. The metal hanging system for the ceiling panels were bent and had pulled the anchors out of the wall. With repairs and clean up underway in many of the classrooms, the school hoped to fully re-open within six days of the event. Similarly, Waikoloa Elementary School sustained heavy damage to the hanging ceiling system in all of its 32 classrooms as shown in Figure 12b. There was no structural damage, however; the damage estimate is approximately $2 million for the ceiling and light fixtures. The school was expected to remain closed for a week following the event.

(a) (b)

Figure 12: Nonstructural damage in schools, showing (a) dropped ceiling panels in a classroom at Waimea Elementary School and (b) hanging ceiling system damage in a classroom at Waikoloa Elementary School

In North Kohala, the complex of buildings for the local public elementary, middle, and high school contained one structure that was still closed four days after the earthquake. This two-story concrete block masonry building had significant cracking in the area around the elevator. The thin, wood-panel soffit under the roof overhang had buckled near the elevator core. According to a teacher, the whole campus was closed for two days following the earthquake. Re-opening of the damaged building was on hold until inspection by a state engineer.

Beyond damage to public schools, there was widespread damage to old historic buildings. In particular, Kalahikiola Church in Kapaau was completely destroyed as shown in Figure 13. The Landmark Baptist church in North Kohala was also marked as unsafe and displayed major cracks in the façade.

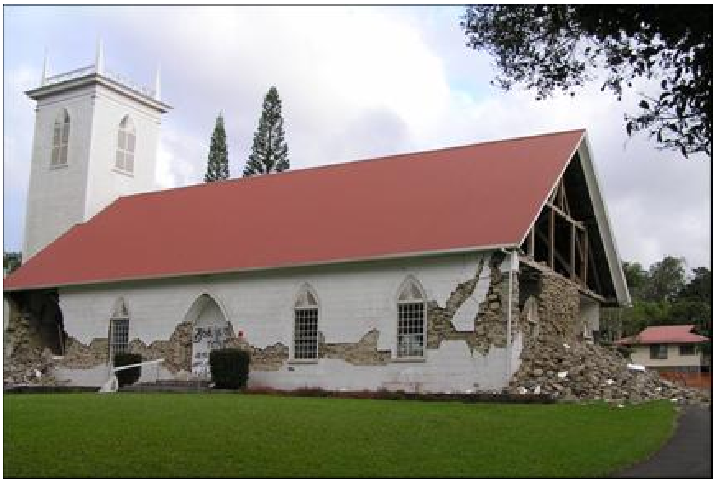


Figure 13: Severe damage experienced at Kalahikiola Church in Kapaau

Two historic buildings in the Kailua Kona community also had significant damage and were red-tagged as unusable by officials. Although the nearly 200-year old Mokuaikaua Congregational church was visually in good shape, engineers were still in the process of assessing the stability of its lava rock and mortar construction walls less than one week following the earthquake. Just across the street, the Hulihe'e Palace suffered major external cracks on multiple walls (Figure 14). Local newspapers report that repairs are expected to cost more than $1 million.

Figure 14: Damage to Hulihe'e Palace

Kona Community Hospital, a 94-bed full-service acute and long term care facility, was severely impacted by nonstructural damage to ceilings and equipment (Figure 15). A major challenge was the evacuation of the hospital's long-term care patients, who were housed in a nearby hotel with their caretakers for five days. Their return to the hospital and the completion of significant repairs marked the achievement of 35% operating capacity, up from nearly 0%. The regional chief operation officer for the hospital estimated that business interruption (BI) costs are $150,000 per day while not fully operational and that physical damage costs are around $5 million. The hospital was expected to be 100% operational by October 27, less than two weeks after the event.

Figure 15: Non-structural damage to equipment and ceiling grids at Kona Community Hospital

There were also reports of significant damage at the port in Kawaihae Harbor, near the Mauna Kea Resort (see location map in Figure 3), including some liquefaction and lateral spreading. Port authorities did not permit photographs or a walk through by the RMS reconnaissance team. An official claimed that the overall functionality of the port was at 25% capacity two days after the event. On Wednesday, October 18 it was reported that the cargo shipping center reopened to shipping after the U.S. Coast Guard determined the main cargo pier was safe. And while some port buildings were damaged, operations were at 100% capacity within two weeks of the event due to expedited loading and unloading and extended operating hours.

Overall Insurance and economic Impacts

The RMS reconnaissance team saw no surprises in the damage patterns to Hawaii as a result of the October 15, 2006 earthquake event. The damage to the commercial structures in the form of earthquake sprinkler leakage and other nonstructural and contents damage was typical, as was the contents damage in residential structures. In particular, unsecured contents suffered considerable damage and partial collapse of unreinforced volcanic rock walls (appurtenant structures) was common in the area of shaking intensity VII-VIII.

Overall, the RMS team found a picture of widespread low level damage to nonstructural elements and contents throughout the area traversed by the reconnaissance team, all of which was of within 65 km (40 mi) surrounding the earthquake epicenter. There was localized structural damage, most notably pier-and-post residential structures that shifted off their foundations and older, historic buildings with little or no consideration of seismic design. Ground failures, primarily localized landslides and rockfalls, were common near the epicenter, but relatively few structures were impacted.

Over 1,800 residences were damaged to some degree, with 62 red-tagged (declared unusable until major repairs are made) and 151 yellow-tagged (partially unusable until major repairs are made). Most of these losses will be borne by homeowners, as few policy owners purchase earthquake coverage in Hawaii. Within two weeks of the event, the State of Hawaii Insurance Division issued a memorandum reiterating that earthquake is not included in homeowners' policies; they indicate that some coverage may be available, such as ensuing glass breakage, theft, fire, and food spoilage.

As of October 21, total reported damage is approximately $100 million, excluding costs to repair or rebuild private homes. On October 18, 2006 RMS released a preliminary modeled loss estimate, which indicated that the total property insurance losses would be on the order of $40 to $60 million. Almost all of this loss will be to commercial lines and government facilities, with minimal insured residential loss. RMS estimates that nearly all of this loss will occur on the island of Hawaii with very limited losses possible for Maui.

References

Klein FW, Frankel AD, Mueller CS, Wesson RL, and Okubo PG (2001). Seismic hazard in Hawaii: high rate of large earthquakes and probabilistic ground motion maps. Bulletin of the Seismological Society of America 91: 479-498.

Robertson IN, Nicholson PG, and Brandes HG (2006). Reconnaissance Following the October 15th, 2006 Earthquakes on the Island of Hawai'i. University of Hawaii Dept. Civil and Environmental Eng. Research Report UHM/CEE/06-07. http://www.cee.hawaii.edu/

U.S. Geological Survey Community Internet Intensity Map (2006). http://pasadena.wr.usgs.gov/shake/STORE/Xtwbh_06/ciim_display.html

U.S. Geological Survey ShakeMaps (2006). http://earthquake.usgs.gov/eqcenter/shakemap/global/shake/twbh_06/

Wyss M and Koyanagi R (1992). *Isoseismal Maps, Macroseismic Epicenters, and Estimated Magnitudes of Historical Earthquakes in the Hawaiian Islands*. U.S. Geological Survey Bulletin 2006, 93pp.