

Earthquake Experience in Honolulu

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INTRODUCTION

The investigation on which this study is based was initiated to provide information to be used in appraising the adequacy of the seismic risk zone to which O'ahu is assigned in the building code of the City and County of Honolulu. The investigation involved not only the historical study, whose results are summarized in here, but a determination of the relationship between the intensities of earthquakes in Honolulu and the frequencies of their occurrence. Complete citations to the sources of information and methods of analysis used in the investigation have been or will be reported in a number of technical reports.¹ In this article, formal citations are limited mainly to those reports and those earlier summaries of earthquake experience of greatest use in the investigation. The results of the present historical study are limited to a summary of Honolulu's earthquake experience and to descriptions of the effects of the half-dozen quakes of highest intensity. Intensity-frequency relationships are discussed only as their determination bears on criteria employed in the historical study.

Some of the comments that will be made regarding the importance of historical research in relation to the evaluation of seismic risk, and regarding criteria that such research must meet if it is to be useful in this context, apply to the evaluation of natural hazards more generally. These comments are based, in part, on the earthquake investigation but also, in part, on past and continuing investigations relating to tsunami (tidal wave) hazards.

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EARTHQUAKE INTENSITIES AND MAGNITUDES

Distinction must be made between the intensities and the magnitudes of earthquakes. Magnitudes, such as those on the Richter scale, which will be used here, are measures of overall earthquake size. For any earthquake there can be but one Richter magnitude (although there may be a range of estimates of its value). Intensities are, by contrast, measures of the place-specific strengths of earthquakes, and any earthquake is likely to have a considerable range of intensities decreasing with distance from a maximum near the epicenter.

The values of intensity presented here are values on the Modified Mercalli (MM) scale. As originally defined in 1931,² the MM scale was comprised of 12 discrete-valued steps, each defined in terms of earthquake effects of kinds easily observed and generally reported. The definitions of the steps of the scale in Table 1 are drawn from an abridged 1956 version³ that discriminates better than the original the effects of earthquakes on masonry structures.

TABLE 1.

MODIFIED MERCALLI SCALE OF 1931, 1956 ABRIDGED VERSION FURTHER SIMPLIFIED

- I. Not felt.
- II. Felt by persons at rest or on upper floors.
- III. Felt indoors; duration may be estimated. Hanging objects swing. Vibration like passing of light trucks.
- IV. Hanging objects swing. Vibration like passage of heavy trucks or sensation of a jolt. Standing autos rock. Windows, dishes, doors, and crockery rattle. Wooden construction creaks in upper part of range.
- V. Felt outdoors; direction estimated. Sleepers wakened. Liquids disturbed, some spilled. Small unstable objects displaced or upset. Doors, shutters, pictures swing. Pendulum clocks stop.
- VI. Felt by all. Many frightened, run outdoors. Persons walk unsteadily. Windows, dishes, glassware broken. Knicknacks, books thrown off shelves, pictures off walls. Furniture moved, overturned. Weak plaster and masonry cracked. Small bells ring. Trees, bushes noticeably shaken.
- VII. Difficulty in standing. Noticed by drivers of autos. Hanging objects quiver. Furniture broken. Weak masonry damaged; weak chimneys broken at roof line. Fall of plaster, loose bricks, etc. Some cracks in ordinary masonry. Waves on ponds. Small slides on sand and gravel banks. Irrigation ditches damaged. Large bells ring.

- VIII. Steering of autos affected. Damage and partial collapse of ordinary masonry and some to good masonry not designed specifically to resist lateral forces. Twisting, fall of chimneys, monuments, towers, elevated tanks. Frame houses moved off foundations if not bolted down; loose panel walls thrown out. Branches broken from trees. Cracks in wet ground and on steep slopes.
- IX. General panic. Weak masonry destroyed; ordinary masonry heavily damaged with some collapse; good masonry seriously damaged. Frame structures shifted off foundations; frames racked. Serious damage to reservoirs. Underground pipes broken. Conspicuous ground cracks. Sand and mud ejected from alluvium.
- X. Most masonry and frame structures destroyed with their foundations. Some wooden bridges destroyed even if well built. Serious damage to dams, embankments, etc. Large landslides. Water thrown on banks of rivers, lakes, etc. Sand and mud shifted. Rails bent slightly.
- XI. Rails bent greatly. Underground pipelines completely out of service.
- XII. Damage nearly total. Large rock masses displaced. Lines of sight and level distorted. Objects thrown into the air.

More precise measures of the place-specific strengths of earthquakes are available in the form of the amplitudes, velocities, or accelerations of earthquake vibrations, but values of these parameters must be based on seismographic information. MM intensities have the advantage that they can be estimated from contemporary reports for quakes that occurred before there were seismographs and for places at which there are still no seismographs.

NATURE AND IMPLICATIONS OF INTENSITY-FREQUENCY RELATIONSHIPS

The relationship between the sizes of events of natural phenomena and the frequencies of their occurrence, referred to as the frequency distribution of the sizes, must be based on a historical record. The reliability of such a frequency distribution depends upon certain characteristics of the record on which it is based and the method of its analysis. Unless the occurrence of the events is strictly periodic, that is they occur at regular intervals (which is certainly not the case with earthquakes), it is average exceedence frequencies that must be estimated, and the record analyzed must be long with respect to the longest recurrence interval of interest. A ten-year record will not suffice if, for example, interest centers in the event size that is probably equalled or exceeded once in 100 years. Even

the results of analysis of a 100-year record may be subject to significant error; and the use of a 1000-year record would be preferable if one were available. In addition, the record must be both valid and complete—that is, all of the events in it must be of the sort whose frequencies are to be determined, the sizes of the events must be commensurate, and their values must be at least approximately correct. Furthermore, the record must contain all of the events that occurred during the period of record and, of course, none that did not actually occur.

NATURE OF STUDY

Scientific reports have been published on the occurrence of a considerable number of Hawaiian earthquakes. There are available, also, several lists of such earthquakes in which there are annotations as to places where some of the earthquakes were felt. However, previous experience in investigations of the history of tsunamis had indicated that significant discrepancies may be found between the contemporary descriptions of geophysical events and the descriptions in later reports. To some extent, contemporary reports may properly be subject to interpretation on the basis of technical knowledge not available to the reporters. However, it is obviously possible for later investigators or the publishers of their works to make mistakes. Therefore, to assure the reliability of a historic record of geophysical events, it is important at least to check the record against contemporary documentation of the events.

So that its results would provide as reliable as possible a base for the estimation of the frequency distribution of earthquake intensities in Honolulu, the historical study here reported involved the following phases:

- one, compilation of a list of events reported as if quakes felt on O'ahu during the entire period of written history prior to 1984, when the investigation was begun;

- two, search for contemporary reports of those events and revision of the list so that it included only those events that the contemporary reports indicated were natural quakes actually felt on O'ahu;

- three, compilation of the contemporary descriptions of the effects of those quakes in Honolulu and elsewhere on Oah'u;

- four, estimation of the O'ahu intensities of those quakes from the effects described (re-estimating as necessary in the case of those for which intensities had previously been reported).

The record of estimated intensities was, in addition, tested for validity and completeness before being subjected to frequency analysis.

Contemporary newspaper accounts form the greater part of the documentation used for most of the historic earthquakes. To have searched for earthquake reports in every issue of every newspaper published in Hawai'i would, of course, have been quite impractical. Fortunately, accounts of earthquakes that have just occurred frequently contain references to previous earthquakes. These references, indexes to issues of the two major Honolulu newspapers published in the last several decades, and the earthquake lists mentioned earlier were all used as guides to the search. The principal starting points were earthquake lists compiled by A. S. Furumoto, N. N. Nielson, *et al.*,⁴ and a set of manuscript notes on quakes of interest on O'ahu compiled about 1960 by the late Gordon A. Macdonald (then Senior Professor of Geology and Geophysics at the University of Hawai'i). These were supplemented by information drawn from the *Earthquake History of the United States* and annual summaries of *United States Earthquakes* published by the U. S. Coast and Geodetic Survey and successor agencies. Other sources include the *Volcano Letter*, published until 1955 by the Hawaiian Volcano Observatory, seismological notes in the *Bulletin of the Seismological Society of America*, and *Thrum's Hawaiian Almanac and Annual*. Supplementary information to earthquakes felt on O'ahu in 1861 was provided by Robert C. Schmitt, State Statistician, and to earthquakes occurring in 1982 and 1983 by the Tsunami Warning Center of the National Weather Service.

In the search for information, every citation referring to each event in every later report was checked, and not merely newspaper accounts. The newspapers searched included every English language paper published in Honolulu during a period immediately after the event, from about a month for events occurring when the newspapers were weekly and news traveled slowly, to less than a week for the events of the last few decades. For the earthquake whose Honolulu intensity seemed likely to be the highest experienced, translations by Esther Mookini of accounts in Hawaiian language newspapers, that she made for Furumoto, were also consulted.⁵

The list eventually compiled included contemporary documentation of 139 events occurring prior to 1984. As accounts of an event were found, the descriptions of the event and its O'ahu effects were copied or abstracted. In the case of 26 of the events on the overall

list, no credible evidence could be found that natural earthquakes were actually felt on O'ahu at the times reported. Some of the events were earthquakes felt on other islands, recorded by seismographs, or both. Some were identified soon after their occurrence as definitely or probably artificial blasts or sonic booms. Some were non-event entries resulting from date or time errors in the reporting of actual earthquakes. There were, however, evidences of the actual non-instrumental observation on O'ahu of 113 earthquakes, the earliest occurring in 1859.

On the basis of the reported effects of each of these 113 earthquakes, an estimate was made of its probable average MM intensity in Honolulu and, where possible, similar estimates for other places on O'ahu, and to each estimate was attached a range of uncertainty. In general, reference hereafter is simply to the average Honolulu intensities of the quakes.

HAWAIIAN EARTHQUAKES OF LARGEST MAGNITUDE

Neither of the two earthquakes of largest magnitude in Hawaiian history had a very high intensity in Honolulu. These two quakes were remarkably similar. From the distribution of the effects of the first, which occurred in April 1868, Furumoto has estimated a magnitude between $7\text{-}1/4$ and $7\text{-}3/4$.⁶ The magnitude of the second, which occurred in November 1975, was determined from seismographic information as 7.2. The epicenters of both quakes were on the Ka'u-south Puna coast of the island of Hawai'i. Both were accompanied by subsidence of that coast and by tsunamis whose maximum runup heights were on that coast and whose runup patterns generally were very similar. The 1868 quake triggered eruptions of Kilauea and Mauna Loa volcanoes, and the 1975 one triggered a Kilauea eruption.

The low intensities of these quakes on O'ahu are attributable to the distance of their epicenters from this island. The estimates made herein of their Honolulu intensities are only IV or V for the 1868 quake and only IV for the 1975 quake. Hence, the 1975 quake is not included in the list in Table 2, which is limited to those historic earthquakes that had Honolulu intensities of V or greater.

EARLY EARTHQUAKES

The first of the earthquakes in the O'ahu historic record occurred

TABLE 2.
HISTORIC EARTHQUAKES WITH HONOLULU INTENSITIES OF V OR GREATER

| <i>Date</i> | <i>Epicentral location</i> | <i>Magnitude</i> | <i>Honolulu intensity*</i> |
|-------------|----------------------------|------------------|----------------------------|
| 1861 Dec 5 | Moloka'i-Lāna'i vic. (?) | ? | Mid V |
| 1861 Dec 15 | Moloka'i-Lāna'i vic. (?) | ? | Lower V – mid V |
| 1868 Apr 2 | SE coast of Hawai'i | 7.5 | Upper IV – lower V |
| 1868 Apr 4 | Maui group vicinity (?) | ? | Lower V |
| 1871 Feb 19 | S coast of Lāna'i | 7.0 | Upper VI – lower VII |
| 1895 Dec 8 | O'ahu vicinity (?) | ? | Mid V |
| 1926 Mar 19 | N of Kohala, Hawai'i | ? | Upper IV – lower V |
| 1929 Oct 5 | W of Kona, Hawai'i | 6.5 | Lower V |
| 1938 Jan 22 | N of Maui | 6.8 | Upper V – lower VI |
| 1948 Jun 28 | S coast of O'ahu | 4.8 | Mid VI |
| 1964 Oct 11 | Ka Lae, Hawai'i | 5.5 | Upper IV – lower V |
| 1973 Apr 26 | Hāmākua coast, Hawai'i | 6.2 | Mid V |
| 1981 Mar 5 | Kalohi Channel | 5.0 | Mid V |

* Average intensity, Modified Mercalli scale

at about 2:30 am. on November 21, 1859. This quake was described in a *Pacific Commercial Advertiser* article, the sole source found for information on it, as a "severe shock" that aroused several persons, a description that is the basis for estimation that its Honolulu intensity was probably in the lower part of step IV.

Other than the major earthquake of April 2, 1868, none noted in the geographical literature before 1871 had a Honolulu intensity as high as V. However, Robert Schmitt, State Statistician, has called attention to reports in the *Pacific Commercial Advertiser* of what seem to have been three December 1861 earthquakes not previously noted in the literature, two of which, occurring on the 5th and the 15th of the month, seem to have had Honolulu intensities in the range of step V. Both of these quakes were accompanied by rumbling sounds, and the east-west vibrations of both rattled windows and crockery. The first, at least, was felt by almost everyone in the town. It caused many to run into the streets and some to lose their balance. Plaster fell from some ceilings, and fish jumped from the water in the harbor. The reports suggest for the first an intensity in the middle part of step V and for the second an intensity slightly lower. Together with reports of the effects of the quakes on Maui, they suggest, as noted

in table 2, that the quakes had epicenters in the vicinity of Moloka'i or Lāna'i.

LĀNA'I EARTHQUAKE OF 1871

The historic earthquake with the generally highest O'ahu intensities occurred on February 19, 1871 at 10:11 p.m. In spite of the hour, accounts suggest that it was felt by everyone in Honolulu, and that it woke those who had been asleep. Most if not all were frightened, many ran outdoors, and some who did so were so alarmed that they ran out without clothing. Some people experienced difficulty in walking, and others were nauseated by the earthquake motion. The quake caused hanging lamps to swing, clocks to stop, and crockery, glassware, and statuary to fall.

Several of the newspapers commented afterward that the damages had been small. But the comments seem to reflect a contrast between what was expected by those who had experienced the quake and the destructive effects actually found on inventory. There was significant damage to all of the masonry buildings at Punahou School and to at least eight buildings in downtown Honolulu.

Effects elsewhere on O'ahu included landslides or rockfalls on the Nu'uānu Pali and on the *pali* (cliff) back of Waimānalo, collapse of the wall of a masonry church at Kāne'ohe, destruction of a belfry supported by cast-iron pillars at 'Ewa, and an earth slip at Wai'ānae.

Taken individually, the effects of the quake on people and small objects in Honolulu might suggest intensities anywhere in the range from IV or V to VII; and a more precise estimate depends on interpretation of the reports of the effects on masonry buildings. Furumoto, L. V. Lum, *et al.*⁷ estimated from these and other effects that the quake had an intensity of VII, but G. A. Macdonald considered that Furumoto had either overestimated the extent of structural damage or underestimated the vulnerability of the structures to damage, and that his estimate was one intensity step too high.⁸ Information provided me by architects interested in historic buildings in Honolulu and in the materials and methods used in their construction indicates that the damaged buildings in the downtown area represented only a minor fraction of those then in existence and that the masonry used in some of the buildings was probably fairly prone to earthquake damage. Taking into account this information, but also school records indicating that the damages to the buildings at Punahou School were so extensive that their

abandonment was seriously considered, I have estimated the Honolulu intensity of the quake on the border between VI and VII.

From the geographic distribution of the effects of the earthquake in the Hawaiian Islands generally, it is estimated in this study that it had a magnitude of about 7, agreeing with an earlier estimate by Furumoto and Nielson *et al.*,⁹ and that its epicenter was near the south coast of Lānaʻi.

OʻAHU(?) EARTHQUAKE OF 1895

In *Thrum's Annual*, there is a report that "one of the hardest earthquake shocks experienced in Honolulu in many years occurred a little after 11 p.m. of December 9th, 1895".¹⁰ Newspaper articles indicate that two or three shocks were felt on the 8th and 9th of December but suggest strongly that the most intense occurred at some time between 11:04 p.m. on the 8th and 12:10 a.m. on the 9th. On the basis of the numerous published descriptions of the effects of the quake, its Honolulu intensity is probably in the middle part of step V.

A number of earthquakes were reported from the island of Hawaiʻi. But their reported times do not agree with those of the principal shock felt in Honolulu, and their Hawaiʻi intensities were smaller than the Honolulu intensity of the principal shock. Although *Thrum's Annual* reported that that shock was felt on Maui, there is no confirmation of its observation on that island. Its source is, therefore, listed as probably in the vicinity of Oʻahu.

MAUI EARTHQUAKE OF 1938

As indicated in Table 2, an earthquake originating north of Kohala, Hawaiʻi, in 1926, had a Honolulu intensity in the upper part of step IV or the lower part of step V. Another one originating in the ocean west of the Kona coast of Hawaiʻi, in 1929, had a Honolulu intensity in the lower part of step V. Of greater importance on Oʻahu, however, was a magnitude 6.8 quake that originated in the ocean north of Maui on the evening of January 22, 1938.

Newspaper accounts carry numerous descriptions of the effects of this quake on Oʻahu and estimates of its Honolulu intensity on a scale in use prior to the development of the MM scale. Other estimates of its Honolulu intensity appear in other contemporary and subsequent reports. Equivalent values on the MM scale range from step IV to, possibly, the lower part of step VI. On the basis of the

published descriptions of the effects, supplemented by a very distinct memory of the extent of damage to one of the buildings at the University of Hawai'i where I was then a student, I estimate that the Honolulu intensity of the quake was on the border between step V and step VI.

O'AHU EARTHQUAKE OF 1948

The earthquake with the generally second highest O'ahu intensities in the historic record was one occurring in June 1948. Although there was at the time a seismograph at Barbers Point, O'ahu, and several on the island of Hawai'i, neither the magnitude nor the epicentral location of this earthquake could be determined from seismographic information. This earthquake is one for which there are multiple entries in the uncorrected historic record because, probably through typographical error, the date was given in one report as June 26th rather than the correct date of June 28th, and some derivative reports list quakes on both dates.

Occurring at about 1:40 a.m., the quake woke most but not all residents of O'ahu, many of whom "scurried into the streets," some in their nightclothes. Plaster cracks were reported in at least 20 Honolulu buildings. Books were thrown from shelves to the floor in the Judiciary Building, and books, artifacts, and specimens were thrown down in the Bishop Museum. Sidewalks were cracked in Kaimukī, and a waterpipe was broken in Mānoa. Large plate-glass windows were broken in the Theo. H. Davies building on Bishop Street.

The major damages in Honolulu were: one, at Fort Shafter where there was considerable cracking in several buildings, including a 70-foot crack in a new barracks; two, at the American Can Company warehouse and office in Iwilei, whose reinforced concrete walls were cracked; three, at Tripler Hospital, then nearing completion, where there was evidence of nearly two inches differential motion on joints designed to accommodate such motion; and, four, on Tantalus, where water tanks were moved, developing leaks.

Landslides blocked Kamehameha Highway in Kipapa Gulch and Moanalua Road at Red Hill.

The average Honolulu intensity of the quake is estimated at VI, but it probably had an intensity of VII on Tantalus and in Iwilei. From the distribution of its intensities on other islands, it seems probable that the quake had a magnitude of only about 4.8, its high Honolulu intensity being due to the location of its epicenter in the ocean only a few miles south of the city.

This location lends some support to the hypothesis advanced by Furumoto and Lum, *et al.*,¹¹ on the basis of the approximate alignment of the epicenters of several later earthquakes, that there is a fault extending north-northeastward from Diamond Head and Koko Head. Some of the later earthquakes had higher magnitudes than that estimated for the 1948 quake, but none of their Honolulu intensities were large, and some of them were not even felt. Furthermore, there is in the historic record no other quake with a Honolulu intensity approaching that of the 1948 quake whose epicenter could have been on the trend of the possible fault.

RECENT EARTHQUAKES

Since 1948 there have occurred only three earthquakes whose Honolulu intensities might have been as great as step V. Surprisingly, one occurring in October 1964 had a magnitude of only 5.5 and an epicenter a little south of Ka Lae, the south point of Hawai'i. A Honolulu intensity on the border between steps IV and V has been estimated for that quake.

The next quake, occurring on April 26, 1973, had an epicenter off the Hāmākua coast of Hawai'i and a magnitude of 6.2. It was felt strongly enough to cause evacuation of several buildings in downtown Honolulu and nearby Ala Moana. Its Honolulu intensity is estimated in the middle of step V.

The most recent was one of two quakes felt in Honolulu in March 1981 whose epicenters were in the Kalohi channel between Moloka'i and Lāna'i. The larger, occurring on the 5th of March at 4:10 a.m. with a magnitude of 5, woke sleepers and broke a few dishes. The Honolulu intensity estimated for it also is in the middle of step V.

SUMMARY AND CONCLUDING REMARKS

It should be recognized that this study has not related to earthquake prediction—that is, forecasting the date and size of the next significant earthquake, but to the estimation of earthquake hazard in terms of the relationship between the intensities of quakes and their average exceedence frequencies. Such hazard cannot be estimated closely for periods exceeding greatly the historical period for which a reliable and complete record of intensities can be compiled. It was found in this study, as in others, that historical records compiled for other purposes cannot be assumed to be either complete or reliable. Furthermore, there is no substitute for the use of contemporary

documentation of historical events in making a record as complete and reliable as possible.

The results of the study can be summarized very briefly. At least 113 earthquakes have been felt on O'ahu since 1859. The highest intensity experienced in Honolulu was that of the 1871 quake, on the border between Modified Mercalli steps VI and VII. Included in Table 2 are all that had average Honolulu intensities of V or greater. The full record compiled probably includes all with Honolulu intensities of IV or greater that occurred since 1910.

The number of earthquakes felt on O'ahu, and the possibility that compilation of so extensive, complete, and reliable a record of earthquake intensities at Honolulu, was not anticipated when the study was begun. But the quality of that record lends considerable confidence to the reliability of frequency distributions of Honolulu intensities based on it.

NOTES

- ¹ D. C. Cox, *The Lanai Earthquake of 1871* (Honolulu: U of Hawai'i Environmental Center, 1985); *The Oahu Earthquake of June 1948, Associated Shocks, and the Hypothetical Diamond Head Fault* (Honolulu: U of Hawai'i Environmental Center, 1986); and *Earthquakes Felt on Oahu, Hawaii, and Their Intensities* (Honolulu: U of Hawai'i Environmental Center, 1986).
- ² H. O. Wood and F. Neumann, "Modified Mercalli Intensity Scale of 1931," *Bulletin Seismology Society of America*, vol. 21, no. 4 (1931): 277-281.
- ³ C. F. Richter, *Elementary Seismology* (San Francisco: Freeman, 1958).
- ⁴ A. S. Furumoto, N. N. Nielsen, and W. R. Phillips, *A Study of Past Earthquakes, Isoseismic Zones of Intensity, and Recommended Zones for Structural Design in Hawaii* (Honolulu: Hawai'i Institute of Geophysics, 1973).
- ⁵ The manuscript translations by Esther Mookini, noted Hawaiian scholar, are in my possession. Historical newspaper accounts are available at the U of Hawai'i Hamilton Library, AH, HHS Library, and the Hawai'i State Library.
- ⁶ A. S. Furumoto, "Seismicity of Hawaii, Part I, Frequency-energy Distribution of Earthquakes," *Bulletin Seismology Society of America* (1966) 1-2.
- ⁷ A. S. Furumoto, L. V. Lum, N. N. Nielsen, and J. T. Yamamoto, *A Study of Earthquake Losses in the Honolulu Area: Data and Analysis*, rept. Dept. of Defense, Civil Defense Division, State of Hawai'i, 1980.
- ⁸ G. A. Macdonald, personal communication to Walter Lum, soils engineer, 1973 (copy provided by A. S. Furumoto).
- ⁹ A. S. Furumoto, N. N. Nielson, et al, *A Study of Past Earthquakes*.
- ¹⁰ HAA 1896.
- ¹¹ A. S. Furumoto, L. V. Lum, et al, *A Study of Earthquake Losses*.