TSUNAMI HAZARD AT KE-AHOLE POINT,
NORTH KONA

By
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Summary

The 100-year tsunami runup height at Ke-Ahole Point, Hawaii has been variously estimated as between 6.7 feet and 15 feet above sea level. The estimates have been assigned to various near-shore loci, and at least two different methods have been used to estimate runup profiles transverse to the shoreline and 100-year tsunami inundation limits. By one combination of methods of estimation, the fenced area of the sea-coast test facility of the Natural Energy Laboratory of Hawaii, graded to 11 feet above mean sea level, would be inundated by the 100-year tsunami.

As estimated in the National Flood Insurance Program, the 100-year tsunami runup height at Ke-Ahole is 8.7 feet; the corresponding inundation zone is limited to areas seaward of the fenced part of the facility. Although one of the historic-tsunami runup heights used in deriving these values may have been underestimated, a reestimate made in this study suggests an upper limit of 9.3 feet to the 100-year tsunami runup and confirms the restriction of the corresponding inundation zone to the areas seaward of the fenced part of the facility.

The facility as a whole lies, however, within the tsunami evacuation zone defined by the State Civil Defense Division and should be evacuated when tsunami warnings are issued.
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Introduction

The potential hazards of tsunamis should be of concern at any low lying coastal site in Hawaii such as that of the seacoast test facility of the National Energy Laboratory of Hawaii at Ke-Ahole Point, North Kona, Hawaii. There are appraisals of the tsunami hazard at Ke-Ahole in several documents relating to the facility, but the results, suggesting a significant hazard to the facility, are not in conformity with the appraisal pertinent to the site in the National Flood Insurance Program. Hence, the hazards have been reappraised in this report. Although concerned previously with the hazard to property, the report deals also with the hazard to persons at the Ke-Ahole site.

Tsunami hazard estimation

The magnitude of the tsunami hazard at any land site depends, of course, on the expectable extent of inundation of the land by tsunamis at the site, expectable water depths and velocities within the inundation zone, and the exposure of persons and property within the potential inundation zone. At any site, horizontal extents of inundation of tsunamis, depths of water above ground level, and water velocities, are functions not only of the power of the tsunami waves as they approach the shore but the direction of approach, the wave period, and site terrain and roughness. There is no definite upper limit to the power of tsunamis approaching a coastal site. Hence tsunami hazard must be expressed in terms of expectable average recurrence intervals or recurrence frequencies, or of risks of occurrences within stated periods.

What is expectable in the future can be judged only on the basis of what has occurred in the past, the power of tsunamis that have approached the coast can only be estimated from the extent of inundation and the runup heights on land. Of these two parameters, runup heights, if measured near the shore, are least affected by site terrain and roughness and by the wave period and direction of approach of tsunamis; and of the various measures of the size of historic tsunamis, runup-heights have been reported most commonly. Hence all estimates of tsunami hazard are based directly or indirectly on the runup heights of historic tsunamis, and most are expressed, at least in part, in terms of site-specific runup heights expectable with certain recurrence intervals or frequencies.

Content and organization of report

Among the past estimates of the hazard of tsunamis to property at Ke-Ahole Point, the greatest differences have resulted from differences in the record of historic tsunamis whose runup heights have been utilized in the estimation, differences in the runup heights assumed to pertain to those tsunamis, and differences in the places to which these runup heights were assumed to pertain. For this reason, the reported and estimated runup heights of historic tsunami runup heights at Ke-Ahole and the estimation of expectable runup heights there are reviewed first in this report. The report then addresses the implications of the most valid estimates of expectable tsunami runup heights with respect to the hazard to property at the Ke-Ahole facility. Finally the report discusses the tsunami hazard to persons at the facility.

Acknowledgements and facility map

I am indebted to William H. Heaman of the NELH for the supply of several documents in which the tsunami hazard at the Ke-Ahole facility has been discussed and for plans of the facility and a topographic map of its vicinity.
Figure I, a map showing the facility and its surroundings, has been prepared by compiling the pre-existing topography from a survey by H.F. Towill, and the principal present features of the facility from the facility Master Development Plan, taking into account the graded level of the fenced portion of the facility, 11 feet above mean sea level according to Heaman. The topographic map shows only a wave-wash limit at the shoreline. This does not correspond to the shoreline shown on the Plan. Hence the compilation may not quite accurately relate the topography around the fenced area to the fenced area. However no possible inaccuracy in the relation can affect the conclusions of the study.

Runup height evaluation

Historical data

Runup heights that have been reported for historic tsunamis at places on the west coast of Hawaii are listed in Table 1, including some erroneous values to which reference has been made in reports on the Ke-Ahole site. The erroneous values are enclosed in parentheses. Values that have been reported in contemporary sources of information or in standard geophysical references but that have not been referred to in reports on the Ke-Ahole site are enclosed in brackets. In general the Table does not include runup-height estimates derived by interpolation or extrapolation from reported values or by modelling.

Statistical evaluations made specifically for NELH facility

The hazard of tsunamis to property at Ke-Ahole has been expressed in reports pertinent specifically to the site in the form of estimates of the 100-year runup height, that is the runup height that may be expected to be equalled or exceeded on the average only once in a hundred years, or in the form of statistical relations between expectable recurrence frequencies or recurrence intervals and corresponding runup heights from which the 100-year value or values for other recurrence intervals may be determined.

The Master Plan for Ke-Ahole Point (Neighbor Island Consultants, 1976) estimated the 100-year tsunami runup at the site as 15 feet. The method of estimation was not indicated, and an estimate as low as this seems inconsistent with the four historic runup heights reported as if directly pertinent to the site -- including values actually pertinent to the 1946 and 1975 tsunamis at other places on the west coast of Hawaii and to the very high runup height of the April 1868 tsunami that was actually pertinent to Keauhou Landing in Kau (see Table 1).

In comments on the tsunami hazard at Ke-Ahole Point in relation to preparation of an environmental impact statement on the proposed NELH facility there, the U.S. Army Corps of Engineers attributed to Keauhou, Kona, the same 1868 runup that actually pertained to Keauhou Landing, Kau (W. Matthews for Kauai Cheung, letter of 2 April 1976 to W.R. Coops, Research Corp., University of Hawaii).

However, Lau (1976) pointed out the error of attributing to places on Kona the very high 1868 runup at Keauhou Landing. Because, as he recognized, there were no reports of direct observation or estimates of runup heights of historic tsunamis at Ke-Ahole, he estimated a runup-height frequency relationship from the reported runup heights at 11 sites on the west coast as indicated in Table 1. Assuming a linear relationship between runup height and log recurrence Interval (after Loomis, 1976), he plotted the runup heights for Napoopoo and for Kailua, and root-mean-square runup heights for all west-Hawaiian sites, against log recurrence frequencies, and determined the linear relationship by the least-squares method. The line he plotted relates the 13-foot runup height to a 100-year recurrence interval and the 15-foot runup height to a 160-year recurrence interval.
The environmental impact statement on the NELH facility at Ke-Ahole Point (Towill, 1976) adopted the 15-foot value for the 100-year tsunami runup height citing Neighbor Island Consultants (1976) and Lau (1976) without further analysis. Probably because no method of analysis superior to Lau's was available at the time, the Environmental Center raised no question as to the 15-foot value in its review of the Environmental Impact Statement (Cox, 1976).

In a conceptual design report, Parsons Brinkerhoff (1979) cited Lau's findings. Although pointing out that the findings pertained to the west coast of Hawaii in general, and not specifically the Ke-Ahole site, they used the findings as applicable to Ke-Ahole.

In a Preliminary Systems Design Description for the Ke-Ahole facility, Hallanger (1980) presented a table of reported runup heights on the west coast of Hawaii in which again the high runup of the 1868 tsunami at Keahou Landing, Kau, was mistakenly attributed to Keauhou, Kona. However Hallanger also cited without change Lau's estimates based on a more nearly correct record.

Statistical evaluations for National Flood Insurance Program

For use in the National Flood Insurance Program, the U.S. Army Corps of Engineers has estimated 100-year tsunami runup heights near the shoreline for sites closely spaced along coasts of all major Hawaiian Islands from site-specific runup height-frequency distributions based on the record of tsunamis occurring in Hawaii since 1837.

The historic records of tsunami runups for most sites are, of necessity, synthetic ones. Those used in the National Flood Insurance Program in Hawaii have been compiled by Houston et al. (1977). For tsunamis from Kamchatka, the Aleutian Islands, Alaska, and South America, the runup heights for tsunamis known to have occurred in the period since 1837 were estimated using numerical models, and the results were adjusted to whatever actual heights of tsunamis from those regions were available in the geophysical literature for Hawaiian sites. For tsunamis from other source regions, runup heights were interpolated or extrapolated from whatever data was available in the literature. Houston et al. estimated the site-specific frequency distributions as least-square regressions of runup height on log frequency, using for each site the 10 highest estimated historic heights.

After the study of Houston et al. (1977) had been completed but before the results had been used extensively, Cox and Morgan (1977) demonstrated errors in some of the reported runup heights of historic locally-generated tsunamis. From the corrected values, and other estimated from contemporary description of effects, Cox (1979) estimated longitudinal runup profiles for the historic local tsunamis. The results were incorporated in a revision of Houston et al. (1977) and in tabulations of the runup height of the historic tsunami and the least-squares coefficients of the frequency distribution, site by site. (Copies of the tables are on file at the Environmental Center and at the Hawaii Institute of Geophysics).

The significant revised estimates of the runup heights of the historic tsunamis at Ke-Ahole Point are indicated in Table 2. Using the coefficients derived by Houston from the 10 highest estimated runup heights, the near-shore 100-year tsunami runup height at the site would be estimated at 6.7 feet above mean sea level (msl).

Subsequently, Cox (1980) found errors in some of the reported runup heights of tsunamis from Japan, particularly on the Kona coast. According to the Federal Emergency Management Agency, (R.E. Sarden, letter of 31 December 1981 to Herbert T. Matayoshi,
Mayor, Hawaii County), Cox's corrected values have been used in revision the record used by the Corps of Engineers, the frequency distributions, and the hazard zones derived from them. (A table including the corrected values is on file at the Environmental Center.)

The significant estimates of the runup heights of the historic tsunamis at Ke-Ahole Point, revised in accordance with Cox's (1980) data, have been added to Table 2 and plotted against recurrence frequency in Figure 2. (In computing the recurrence frequencies, the period of record, is taken at 144 years (1837 to date).

Re-evaluation in this study

For the present, it seems clear that 100-year tsunami runup heights are best estimated by the method used in the National Flood Insurance Program and, with the possible exception, of the April 1946 Aleutian tsunami, there seems to be no evidence of significant error in the historic tsunami runup heights most recently estimated by the Corps of Engineers (1981).

In Table 3, the runup heights of the 1946 tsunami measured by Shepard et al. (1950) for places along the west coast of Hawaii between Keauhou and Kawaihae are compared with the values reported by Loomis (1976), which Houston et al. (1977) used in adjusting the estimates produced by their numerical model, and with Houston's final estimates. (For convenience the three sets of values will be referred to, respectively as those of Shepard, Loomis, and Houston). The fact that the Houston values are generally a foot smaller than the corresponding Shepard and Loomis values simply reflects a difference in datum planes. The earlier values were of heights above tide level at the time of the tsunami, whereas Houston's were of heights above mean sea level. It will be noted, however that the Houston value for Kailua is 3 feet less than the higher (and more northerly) of the two Shepard values for that place, and that Loomis did not include a value for Kailua in his report. It is doubtful that Houston used the Shepard values for Kailua in adjusting the values estimated from their numerical model, and hence that the Houston final values for the coast between Kailua and Puako are too small.

It seems clear that the Houston numerical model suggested that the runup heights of the 1946 tsunami at Honokohau and Ke-Ahole were smaller than at Kailua and Puako. However, even if this were actually the case, the runup height estimated for Ke-Ahole would probably have been at least two feet and possibly three feet higher than that estimated without adjustment to the Kailua runup height. It seems probable, therefore, that the runup height of the 1946 tsunami at Ke-Ahole was at least 8 ft. msl., and possibly 9 ft. msl.

If the 9-foot value is substituted for the Houston 6-foot value, the 1946 tsunami is ranked second highest at Ke-Ahole in the period since 1837, rather than 4th highest (Table 3), and the estimate of the runup height of the 100-year tsunami is increased to 9.3 ft. msl. (Figure 2).

Hazard to property

Estimation specifically for NELH facility

Neighbor Island Consultants (1976) considered that the 15-foot runup height that they estimated for the 100-year tsunami applied "at the coast" (presumably at the shoreline), and suggested that the runup-height profile transverse to the shoreline might be considered to have a 1 percent slope (presumably downward inland). (For the probable source of the 1-percent-slope concept, see section on "Hazard to persons".)
Between the shoreline north of Ke-Ahole Point and the fence along the northeast site of the NELH facility there is a distance of about 37.5 feet, and between the shoreline southwest of the point and the southeast fence there is a distance of about 300 feet. Hence if the 100-year runup height at the shoreline and the slope of the runup profile were as estimated, the 100-year runup height along the seaward-most edges of the fenced area would be 11-1/2 to 11-3/4 feet, slightly higher than the surface of the present fill, at 11 feet.

It is very rarely possible to measure the runup height of the tsunami at the shoreline, and in the absence of contrary indications it may reasonably be assumed that the heights measured in the surveys of the runups of recent tsunamis were about 200 feet inland from the shoreline (Cox, 1978), and hence that 100-year runup heights derived from measured runup heights also apply there. If the 15-foot runup height estimated for the 100-year tsunami were valid and applied 200-feet inland from the shoreline, and if the 1-percent slope were valid, much of the fenced area of the Ke-Ahole facility would be within the 100-year tsunami inundation zone.

Making the common assumption that tsunami runup heights are distributed in time in accordance with Poisson's distribution, Lau (1976) estimated from his frequency distribution of runup heights that the probabilities of exceedence during the next century would be 50 percent for a runup height of 15 feet, 68 percent for a height of 13 feet, and 90 percent for a height of 10 feet.

Apparently making the same assumptions as Lau, Parsons Brinkerhoff (1979) estimated the runup heights corresponding to various probabilities of exceedence ranging from 10 to 90 percent within periods ranging from 20 to 200 years.

Neither Lau (1976) nor Parsons Brinkerhoff (1979) related runup heights to horizontal extents of tsunamis inundation, nor did Hallanger, who cited Lau's estimates of exceedence probabilities.

Estimation for National Flood Insurance Program

In the National Flood Insurance program, the locus of 100-year tsunami runup heights derived from frequency distributions of the runup heights of historic tsunamis is considered to be 200 feet inland from the shoreline except where the ground rises inland so that at this locus it is already higher than the 100-year runup height. The transverse runup profile is estimated in the Program for each coastal site by a method recommended by Bretschneider and Wybro (1976) (referred to hereafter as the Bretschneider method) that takes into account the ground profile and roughness at the site. In the derivation of the method it is assumed that the shoreline is straight, that ground-level contours are parallel to the shoreline, and that the tsunami inundation is normal to the shoreline. Whether the tsunami advances inland as a bore or not is taken into account, but the period of the tsunami waves is not.

The 6.7-foot 100-year runup height originally estimated by Houston for the Flood Insurance Program is less than the ground altitude 200 feet inland from the shoreline at Ke-Ahole except at a swale about 450 feet north of the Ke-Ahole light house. Hence, except at this swale, the 100-year inundation zone originally estimated would have been at the 6.7-foot msl and seaward of the fenced area of the NELH facility. At the swale, the inundation zone would have extended inland to the edge of fill of the fenced area.
The 8.7-foot 100-year runup height reestimated for the Flood Insurance Program taking into account Cox's data for tsunamis from Japan is higher than the ground level 200 feet inland from the shoreline at several places along the coast at Ke-Ahole. However, even at these places the inland limit of the inundation zone estimated for the Flood Insurance Program using the Bretschneider method would be at lower altitudes than 8.7 feet msl and hence outside the fenced area of the NELH facility at 11 feet msl.

Reestimation in this study

Cox (1978) has demonstrated that invalidity of the assumption that the locus of 100-year runup heights estimated on the National Flood Insurance Program is 200-feet inland from the shoreline may not be restricted to sites where the altitude of the ground at the distance from the shoreline is greater than the estimated runup height. The limiting height of 9.3 feet estimated in this study for the 100-year tsunami runup is, at several places along the coast at Ke-Ahole Point more than 200 feet inland from the shoreline. However, at the Ke-Ahole site, any invalidity of the locus assumption will be of no practical significance.

Where the terrain is as irregular as at Ke-Ahole, the strict normality of tsunami advance to the shoreline assumed in the Bretschneider method is invalid. With the spread of water advancing in swales into low areas inland of high area along the shoreline, the elevation of the inundation limit will be lower than that estimated by that method. Hence there is no chance that a tsunami with a 9.3 foot msl runup height at the limit of inundation at the high areas along the shoreline and 200 feet inland elsewhere will inundate the fenced area of the NELH facility at 11 feet msl.

It is certain, then, that the only parts of the NELH facility that are within the 100-year tsunami inundation zone are sections of the seawater intake pipes seaward of the fenced area. To inundate the fenced area of the NELH facility, a tsunami would have to have a near-shore runup height of a little over 11 feet. From the limiting frequency distribution of tsunami runups estimated in this study (Figure 2), it appears that the average recurrence interval of tsunamis with near-shore runup heights equal to or greater than 11 feet is 200 years.

If tsunamis are distributed in time in accordance with the Poisson distribution, the probabilities of occurrence of a tsunami with a 200-year average recurrence interval are 0.005 for a year, 0.05 for a decade, 0.22 for a half century, 0.39 for a century, 0.63 for a two-century period, and 0.92 for a 5-century period. However, the pertinence of these probabilities to the occurrence of tsunamis with runup heights equal to or exceeding 9.3 feet at Ke-Ahole depends on the association of the runup height with average recurrence interval of 200 years. It should be recalled that the frequency distribution making this association was based on a historic record in which the runup height of the 1946 tsunami (the second highest) was assumed to be at the upper limit of the range that seemed possible, hence the probabilities of occurrence of a 9.3-foot tsunami are more likely to be smaller than larger than those indicated.

Hazard to persons

The method used in the National Flood Insurance Program to estimate the hazard of tsunamis to property could be used quite rationally for the estimation of the hazard to persons. However, in the estimates of the latter hazard it would seem appropriate to use an average recurrence interval longer than the 100-years used in the estimation of the former.
Pending application of the National Flood Insurance Program methodology to the estimation of the hazard to persons, using an average recurrence interval of, say, 200 or 500 years, the tsunami evacuation zones defined by the State Civil Defense Division should be used. These were based on "potential tsunami inundation areas" outlined by Cox (1961). He found that, except along a few parts of the Hawaiian coasts, a line representing the intersection with the ground of what may be considered an "energy surface" lay inland of points having altitudes equal to the measured runup heights of the tsunamis that occurred between 1946 and 1960. The "energy surface" was defined as sloping downward inland at 1 percent from heights of 30 feet or 50 feet above sea level at the 10-foot bathymetric contour offshore. The 30-foot height was used to define the lines along southeastern coasts of the island, and the 50-foot height along other coasts.

Except where there were broad offshore reefs, or bays with narrow entrances, or where the runup-height records indicated needs for spacial treatment, the lines so defined were considered the inland limits of the "potential tsunami inundation zones. With slight adjustments to make them correspond with easily recognized features such as streets, these limits were adopted by the Civil Defense Division, as the inland boundaries of zones to be evacuated on the occasion of tsunami warnings. The evacuation zones thus defined are delineated in the green pages of the telephone books for the several counties.

Neither the exceptions recognized by Cox nor the adjustments introduced by the Civil Defense Division are pertinent to the Ke-Ahole Point area. Hence the inland boundary of the evacuation zone at Ke-Ahole is defined as in Cox's general method, taking the offshore height of the "energy surface" as 30 feet. It should be recognized that this height is not a runup height. Although Cox's work seems to have been the basis for the assumption of a 1-percent slope for runup profiles, for example by Neighbor Island Consultants (1976), he did not apply the 1-percent slope to runup heights.

All parts of the Ke-Ahole facility of the NEHL lie within the tsunami evacuation zone as thus defined. The results of this study suggest that, unless an average recurrence interval of inundation as short as 200 years is adopted at some time in the future as the standard in defining the tsunami evacuation zone, the zone will include the entire facility even when redefined. In any case, unless and until the evacuation zone is redefined so as to exclude the NEHL facility, the facility should be evacuated wherever there is a tsunami warning.
References


Cox, D.C., 1978 The Locus of Tsunami Frequency Distributions, Univ. Hawaii Environmental Center SR:0021.


Hallanger, L.W., 1980 OTEC Seacoast Test Facility, Preliminary Systems Design Description, Natural Energy Laboratory of Hawaii.


Table 1. Reported runup heights of historic tsunamis on the west coast of Hawaii.

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Notes: 

- [a]- [o] indicate references or additional data sources.
- * indicates an estimated height.
- [ ] indicates a range of heights.
- () indicates a note or additional information.
General note

All values are given in feet. Differences in datum planes are ignored. Values estimated by interpolation or extrapolation from reported values, and values estimated from reported effects (event as noted) are not included. Values shown in parentheses are erroneous. Values shown in brackets are reported values not referred to in Ke-Ahole reports.

Specific notes

- Values listed by Lau (1976) and Hallanger (1980)
- Values listed only by Hallanger (1980)
- Runup heights of November 1975 tsunami reported by Tilling et al., 1976.
- Apparently runup height of April 1868 tsunami at Keaau Landing, Kau, district mistakenly attributed in Neighbor Island Consultants (1976) to Ke-Ahole, and in other reports to Keauhou, Kona.
- Apparently runup heights of April 1946 tsunami at Kailua, mistakenly attributed in Neighbor Island Consultants, (1976) to Ke-Ahole.
- Probably runup height of April 1960.
- Probably range of runup heights of November 1975 tsunami at other places, perhaps Kawaihae and Anaehoomalu, mistakenly attributed in Neighbor Island Consultants (1976) to Ke-Ahole.
- Runup height of the 1975 tsunami reported by Loomis (1975) at other sites at Honokohau than that where the 7-foot runup was reported by Loomis (1975) and by Tilling et al. (1976).
- Both the 7-feet and 11-feet runup heights of the April 1946 tsunami at Kailua were measured by Shepard et al. (1930). Only the 11-feet value has been used in Ke-Ahole reports.
- Apparently runup height of April 1946 tsunami at Kahaluu, mistakenly attributed in Loomis (1976) and Hallanger (1976) to Honaunau.
- Runup heights of the November 1975 tsunami reported by Loomis (1975) at other sites at or near Kahaluu than that where the 9-foot runup was reported also by Loomis.
- Runup heights of the November 1975 tsunami reported by Tilling et al. (1976) at a site at Kahaluu different from those for which Loomis (1975) reported values.
- Runup heights of the April 1868 tsunami actually pertaining to Keauhou Landing, Kau, mistakenly attributed to Keauhou, Kona by Corps of Engineers (see text) and in Hallinger (1981).
- Of the four runup heights shown for the June 1896 tsunami at Keauhou: The 35-foot value was reported in a contemporary newspaper. A mistake was made in incorporating this as a 30-foot value in the standard geophysical literature (e.g. Paresas-Carayannis, 1969). The 12-foot value was estimated by Loomis (1976) who was unaware of the report of the 18-foot value. The 18-foot value, also reported in a contemporary newspaper, has been accepted as the most probable value (Cox, 1980).
- The 8-foot runup height of the November 1975 tsunami was reported by Loomis (1975) for a different site at Keauhou than at which the 9-foot value was reported.
- The 30-foot runup heights of the June 1896 tsunami at Kaawaloa and at Napoopoo were reported in the same newspaper as that which reported the 35-foot value at Keauhou. The 12-foot runup heights were estimated by Loomis (1976), recognizing the probable errors in the 30-foot reports. The value accepted by Cox (1980) as the most probable for both Kaawaloa and Napoopoo is 17 feet.
- The 7-foot and 11-foot runup height of the November 1975 tsunami were reported by Tilling et al. (1976) and by Loomis (1976) for different sites at Napoopoo than that for which the 12-foot value was reported by Loomis.
- Runup height of the November 1975 tsunami at Honaunau reported by Tilling et al. (1976).
- Of the runup heights of the four 1896 tsunami at Hookena, the 12-foot and 8-foot values were reported in Honolulu newspapers. The 10-foot value was estimated by Loomis (1976). The value considered most probable by Cox (1980) is 9½ feet.
- Runup height of the November 1975 tsunami reported Loomis (1976) for a different site at Hookena than that of the 6-foot value.
- Limiting runup of the November 1975 tsunami at Milolii reported by Tilling et al. (1976).
Table 2. Estimated runup heights of historic tsunamis at Ke-Ahole Point.

<table>
<thead>
<tr>
<th>Date</th>
<th>Source revision</th>
<th>1979&lt;sup&gt;a)&lt;/sup&gt; Corps of Engineers</th>
<th>1981&lt;sup&gt;b)&lt;/sup&gt;</th>
<th>This Study</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Height ft., msl. Rank</td>
<td>Height ft., msl. Rank</td>
<td>Height ft., msl. Rank</td>
</tr>
<tr>
<td>1837 Nov</td>
<td>S. Chile</td>
<td>5.0 5</td>
<td>5.0 7</td>
<td>5.0 7</td>
</tr>
<tr>
<td>1841 May</td>
<td>Kamchatka</td>
<td>1.3 1</td>
<td>1.3 1</td>
<td>1.3 1</td>
</tr>
<tr>
<td>1868 Apr</td>
<td>Kau-Puna</td>
<td>5.0 6</td>
<td>5.0 8</td>
<td>5.0 8</td>
</tr>
<tr>
<td>1868 Aug</td>
<td>Peru-Chile</td>
<td>3.0 9</td>
<td>3.0 9</td>
<td>3.0 9</td>
</tr>
<tr>
<td>1877 Feb</td>
<td>S. Kona</td>
<td>-- 0</td>
<td>2.5 0</td>
<td>2.5 0</td>
</tr>
<tr>
<td>1877 May</td>
<td>N. Chile</td>
<td>4.0 7</td>
<td>4.0 9</td>
<td>4.0 9</td>
</tr>
<tr>
<td>1896 Jun</td>
<td>Sanriku, Japan</td>
<td>8.0 1</td>
<td>9.5 1</td>
<td>9.5 1</td>
</tr>
<tr>
<td>1901 Aug</td>
<td>Sanriku, Japan</td>
<td>-- 0</td>
<td>5.5 6</td>
<td>5.5 6</td>
</tr>
<tr>
<td>1923 Feb</td>
<td>Kamchatka</td>
<td>1.8 10</td>
<td>1.8 10</td>
<td>1.8 10</td>
</tr>
<tr>
<td>1933 Mar</td>
<td>Sanriku, Japan</td>
<td>-- 0</td>
<td>7.9 2</td>
<td>7.9 2</td>
</tr>
<tr>
<td>1946 Apr</td>
<td>E. Aleutian</td>
<td>6.0 3</td>
<td>6.0 4</td>
<td>9.0? 2?</td>
</tr>
<tr>
<td>1952 Nov</td>
<td>Kamchatka</td>
<td>1.0 1</td>
<td>1.0 1</td>
<td>1.0 1</td>
</tr>
<tr>
<td>1957 Mar</td>
<td>C. Aleutian</td>
<td>4.0 8</td>
<td>4.0 10</td>
<td>4.0 10</td>
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<tr>
<td>1960 May</td>
<td>S. Chile</td>
<td>7.0 2</td>
<td>7.0 3</td>
<td>7.0 3</td>
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<tr>
<td>1975 Nov</td>
<td>Kau-Puna</td>
<td>6.0 4</td>
<td>6.0 5</td>
<td>6.0 5</td>
</tr>
</tbody>
</table>

Notes:

a) As revised on the basis of Cox (1979).

b) As revised on the basis of Cox (1980).

c) See text.
Table 3. Reported runup heights of 1946 tsunami, Keauhou to Kawaihae.

<table>
<thead>
<tr>
<th>WES site no.</th>
<th>HIG site no.</th>
<th>Place</th>
<th>Shepard, et al. 1950</th>
<th>Loomis 1976</th>
<th>Houston</th>
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<tr>
<td>24.4</td>
<td>25-1</td>
<td>Keauhou</td>
<td>13</td>
<td>13</td>
<td>12</td>
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<tr>
<td>25</td>
<td>25.2</td>
<td>Kahaluu</td>
<td>8</td>
<td></td>
<td>7</td>
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<tr>
<td>25.5</td>
<td>25-3</td>
<td>Holualoa</td>
<td></td>
<td>8&lt;sup&gt;d)&lt;/sup&gt;</td>
<td>7</td>
</tr>
<tr>
<td>27.3</td>
<td>c)</td>
<td>Kailua</td>
<td>11</td>
<td></td>
<td>8</td>
</tr>
<tr>
<td>27.4</td>
<td>c)</td>
<td>Kailua</td>
<td>7</td>
<td></td>
<td>8</td>
</tr>
<tr>
<td>30</td>
<td>c)</td>
<td>Honokohau</td>
<td></td>
<td></td>
<td>7</td>
</tr>
<tr>
<td>32</td>
<td>c)</td>
<td>Keahole</td>
<td></td>
<td></td>
<td>6</td>
</tr>
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<td>47.2</td>
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<td>Puako</td>
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<td>10</td>
<td>9</td>
</tr>
<tr>
<td>47.7</td>
<td>1-2</td>
<td>Kawaihae</td>
<td>12</td>
<td>12</td>
<td>11</td>
</tr>
</tbody>
</table>

Notes:

a) WES (Waterways Experiment Station) designations of nodal points in the numerical analysis of Houston et al. (1977).

b) HIG (Hawaiian Institute of Geophysics) site numbers refer to Loomis's (1976) map number and sites on each map numbered clockwise around island.

c) Loomis's (1976) maps do not include the coast from Kailua to Hapuna.

d) Apparently the Shepard et al. (1950) Kahaluu value misplaced.
Figure 2. Frequency distribution of estimated runup heights of historic tsunamis at Ke-Ahole Point