NOAA Technical Memorandum ERL PMEL-16

A PRIMER ON TSUNAMIS WRITTEN FOR BOATERS IN HAWAII

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Joint Tsunami Research Effort
Honolulu, Hawaii

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Seattle, Washington
September 1979

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This technical memorandum gives a general description of the generation, propagation and run-up of tsunamis. The operation of the Tsunami Warning System and the response of the Hawaii State Civil Defense are described. Special emphasis is given to those aspects of Tsunamis important to boaters in Hawaii.

1. GENERAL INFORMATION ABOUT TSUNAMIS

Tsunamis occur in Hawaii frequently enough and in sufficient variety so that it is worth the time of any boat owner or operator to acquire a basic understanding of the phenomenon. Since 1946 there have been six destructive tsunamis in Hawaii and a dozen other events which were either false alarms or very small tsunamis. In addition, approximately once a year earthquakes occurred that were capable of producing tsunamis but did not. It is a rare two-year period when a boat owner does not have to make a decision about whether or not a boat should be moved to deep water.

The usual cause of a tsunami is the deformation of the ocean floor during an earthquake. The explosion of a volcano in or near the sea, or a landslide in or into the sea, can cause a tsunami, but these events are relatively rare, and, although local waves can be large, the total energy in such tsunamis is too small to constitute an oceanwide danger. On the other hand, earthquakes are frequent and almost every year an earthquake somewhere in the Pacific generates a tsunami. Fortunately for Hawaii, earthquakes of the type that generate

tsunamis normally occur around the rim of the Pacific so that several hours elapse between the generation of the tsunami and its arrival in Hawaii. However, on two occasions damaging tsunamis have been generated locally by earthquakes in Hawaii. In 1868 and again in 1975, earthquakes near Kalapana on the southeast coast of the island of Hawaii generated tsunamis. At places near the epicenter the waves were from 20 to 40 feet high. The waves diminished in height rapidly as they spread because of the relatively small source area, so that 20 minutes after the earthquake, waves arriving in Hilo harbor averaged 5 feet. Waves arriving in Honolulu 30 minutes later were about a foot high. A locally generated tsunami can be very large and little or no warning can be given. Any person who is near the shore and actually feels an earthquake should immediately go to higher ground.

In Hawaii, destructive tsunamis have come from Japan, Kamchatka, the Aleutian Islands, Alaska, Peru, Chile, and Hawaii. Numerous earthquakes in the South Pacific in the vicinity of the Solomon Islands have produced tsunamis, but their effects in Hawaii have been slight. Conceivably, a destructive tsunami could come from the California coast, but there is no historical evidence documenting such an occurrence.

In the simplest terms, a tsunami is generated when the ocean floor is deformed abruptly during an earthquake. The deformation produces a sequence of waves radiating outward, much as waves radiate from the point where a stone is dropped into the water. Since the wave fronts are spreading as the wave travels outward, they diminish in size.

The great Alaskan earthquake of 1964 resulted from a crustal displacement in which the northwest side of the fault fell about 9 feet, and the southeast side of the fault rose about 20 feet. The water above this deformation was displaced in a similar manner. As the initial wave spread from the source area, its relative spreading in a direction normal to the fault line was less than the spreading in a direction along the fault line. For this reason most of the tsunami energy from the earthquake was directed at the northwest coast of North America. Hawaii was not in the direction of maximum energy propagation. As the tsunami spread and ran into deeper water, it diminished in size until the portion of the tsunami nearing Hawaii became a sequence of waves of perhaps 2 feet in elevation from trough to crest, traveling at a speed of about 450 miles per hour and with successive crests following one another about an hour apart. Although the wave shape was traveling about 450 miles per hour, the actual water particle velocities in this tsunami wave were at most 1 inch per second (0.05 knot). As the waves approached Hawaii and ran into shallower water, they slowed considerably and were amplified, much as swell and storm waves are amplified when running into shoal water. This increased the wave size so that the 2-foot wave in

the open ocean became a 4 to 6 foot wave at the shoreline. At the same time, water particle velocities increased to 4-5 knots. The wave shape was further changed by local reflections and the tendency of semienclosed bodies of water to oscillate with periods determined by their physical dimensions. Because of these effects there can be enormous variance in the size and shape of tsunami waves from place to place.

It is a popular belief that the first wave of a tsunami is preceded by a recession of the water. In fact, the first indication of a tsunami is as likely to be a wave crest as a trough. The 1964 Tsunami in Hawaii began with the water rising. Generally, amplification was greater on the north side of each island. The wave amplitude as measured on tide gages in Hilo and Kahului was slightly in excess of 12 feet from trough to crest.

The tsunami of 1964 was classified moderate in Hawaii, but the currents associated with it were impressive. The entrance buoy at Hilo Harbor was moved and the bottom of Hilo Bay was scoured by the resulting currents.

As a large tsunami approaches the shoreline, a bore, or wall of water, may or may not form, depending on the steepness of the wave front. A bore actually moves a little slower than a non-breaking tsunami (about 30 to 40 knots), but the impact of the moving wall of water can be quite destructive. The popular image of a tsunami is that of a bore, but more often a tsunami is like a very high tide that occurs in a span of a few minutes.

Of concern to boaters is the action of tsunamis in harbors which characteristically have narrow entrances to larger, protected areas. To better understand the magnitude of tsunami currents it is helpful to compare them with tidal currents. During the normal changes from low to high tide, a volume of water flows into a harbor over a period of 6 hours sufficient to raise the water level about 2-1/2 feet in Hawaii. During a tsunami that raises the water level in the harbor by 2-1/2 feet, the same volume of water would flow into the harbor in a matter of 10 minutes or so, producing currents perhaps 30 to 40 times greater than tidal currents. Large tsunamis produce correspondingly larger currents but not proportionately so, because frictional and other nonlinear effects begin to play an important part. The currents are strongest near the harbor entrance and diminish as they spread into the harbor area. These currents in the Ala Wai Boat Harbor were strong enough during the 1957 tsunami to break off pilings and docks so that large boats dragging sections of docks with them were being carried back and forth with the changing currents.

2. THE WARNING SYSTEM

The Pacific Tsunami Warning Center in Honolulu, now under the National Weather Service, has issued a tsunami warning for every destructive tsunami in Hawaii since the warning system was established after the 1946 tsunami. A network of seismological stations around the world picks up tremors from every significant earthquake. By coordinating information from two or more seismic stations, the location of the epicenter and the magnitude of the earthquake are determined within a half hour of the time of the earthquake. If the epicenter is close enough to the ocean and the earthquake magnitude is large enough to produce a tsunami, a tsunami watch is instituted. Concerned agencies such as the State and County Civil Defense Agencies, the Tsunami Warning System, police departments, and others are alerted. Then, through a Pacific-wide network of communication channels (mostly the Federal Aviation Administration network), the Tsunami Warning System attempts to learn if a tsunami has been generated, and if so, how big it is. Their information is obtained from tide gages that are part of the system. Personnel at various locations around the Pacific send reports on wave activity, or lack of it, to the Warning Center according to established procedures. If a tsunami has been generated, a tsunami warning is issued, and the public is informed of this through the Hawaii State Emergency Broadcast System (State EBS) announcement on the radio. The probable size of the tsunami in Hawaii is estimated from reported wave heights at other places, from knowledge of past events, and from a general knowledge of wave propagation. If it is judged that there is any chance that a destructive tsunami is on the way, the Hawaii State Civil Defense directs evacuation over State EBS. State and County Civil Defense Agencies institute measures to warn the public and to evacuate coastal areas according to a program carefully worked out in advance. Three hours before the arrival of the first wave at Honolulu, Civil Defense sirens sound the attention/alert signal (3-minute steady siren tone, repeated as necessary), which means, ' turn on your radio'. Radio stations switch to State EBS status and regular announcements are made about procedures to follow and about current tsunami information. The attention/alert signal is sounded again 2 hours before, and again 1 hour before, the estimated first-arrival time of the tsunami at Honolulu. State EBS system and tsunami evacuation areas are described in the front of the telephone directory.

Tsunami waves travel at velocities that depend on the depth of the ocean according to the rule:

$$\text{velocity} = 32.2 \times \text{depth} \quad \text{(feet/second)}$$

In the deep ocean this works out to about 450 miles per hour. This information allows one to calculate the travel time for a wave to travel between any two points in the ocean. A travel time chart centered on Honolulu is shown in the figure on the final page. These charts are done by computer and exist for every place which could conceivably have a need for one. By means of such charts, given the location of a tsunami generating area, arrival time at Honolulu or any other place in the Pacific can be estimated accurately. Thus, in the case of a tsunami originating in the Aleutians near Adak, Alaska, it is known that it will take 4-1/2 hours to reach Honolulu. It is also known that it will have reached Kodiak in 2-1/2 hours, Midway in 3-1/2 hours, etc., so that information becomes available in the form of positive or negative reports from tide stations closer to the source before a decision has to be made about Hawaii. If a tsunami is generated in the North Pacific, prompt wave reports to the Tsunami Warning System from Japan, Russia, Canada, and the United States provide adequate information on which to base a decision about the danger to Hawaii. From areas south of Hawaii, information is less dependable although a considerable effort is being made by the United States to improve this situation. At present, in the case of an earthquake in Peru or Chile, there is a great deal of uncertainty in trying to decide whether or not a destructive tsunami is headed for Hawaii. The Tsunami Warning System has erred on the side of caution in the past in dealing with such cases.

3. WHAT TO DO ON RECEIVING THE TSUNAMI WARNING

If a tsunami warning is issued and radio broadcasts indicate the possible arrival of even a small wave, then boats located where large currents may form are better off in deeper water, i.e., 100 fathoms or greater. Every person with responsibility for a boat has to weigh estimates of weather, seaworthiness of the boat, the time and inconvenience of moving the boat, and the relative safety of the boat where berthed in deciding whether or not to move it. If Civil Defense has directed an evacuation of all low-lying coastal areas, the chances are good that at least a moderate wave will arrive, and it is more urgent that a boat exposed to waves and/or strong currents be taken to deeper water unless the factors mentioned above override the risk to the boat.

At sea it is important to listen to State EBS bulletins and remain in deep water until all significant wave action has ceased. The period of tsunami wave action could last for several hours.

In considering what to do with a boat during a tsunami, it is important to decide well before the tsunami is due to arrive. It is hazardous for a boat to be away from the dock and in the harbor or in a channel during a period of even small tsunami wave action. In addition to the rise and fall of the water in the harbor, there will be strong currents with which to contend, more so in some locations than in others. Just imagine the tidal currents with which one is familiar multiplied many times to get an idea of the magnitude of tsunami currents. Another consideration is that on Hawaii and Oahu, the police have the authority to require evacuation of public coastal areas if this is directed by Civil Defense.

When a tsunami is from the north, Hilo, Kahului, Hanalei, and Haleiwa are particularly exposed and have a history of high waves and serious damage. There is less danger for a boat well inside Kaneohe Bay, Keehi Lagoon, or the Hawaii Kai marina than for most other areas. The Ala Wai Boat Harbor is moderately exposed and is susceptible to strong currents at the Ewa end.

The Table on the next page gives wave heights from previous tsunamis , but this represents only the recent history and a small fraction of the tsunami wave heights that are possible.

The responsibility for the safety of a boat lies with the boat owner. In making a decision about whether or not to move a boat, the information in this report should prove useful.

Maximum height in feet above mean sea level					
Location by Island	1946	1952	1957	1960	1964
OAHU					
Ala Wai	6	-	6	6	-
Kaneohe	3	1	1	2	-
Haleiwa	10	13	13	10	15
Pokai Bay	14	11	10	8	-
Hawaii Kai (outside)	4	3	2	6	-
Kauai					
Hanalei	14	-	19	9	6
Nawiliwili	14	-	10	6	-
Port Allen	8	-	9	8	-
Maui					
Kahului	22	-	13	15	12
Maalea	9	-	8	11	-
Lahaina	7	-	4	9	-
Hawaii					
Hilo	25	5	14	35	10
Kawaihae	12	2	5	9	3
Kailua	11	2	5	8	-

Table 1

Maximum Wave Heights in Hawaii Harbors from Recent Tsunamis. Note that a "-" means no measurement was reported, not that the wave height was zero.

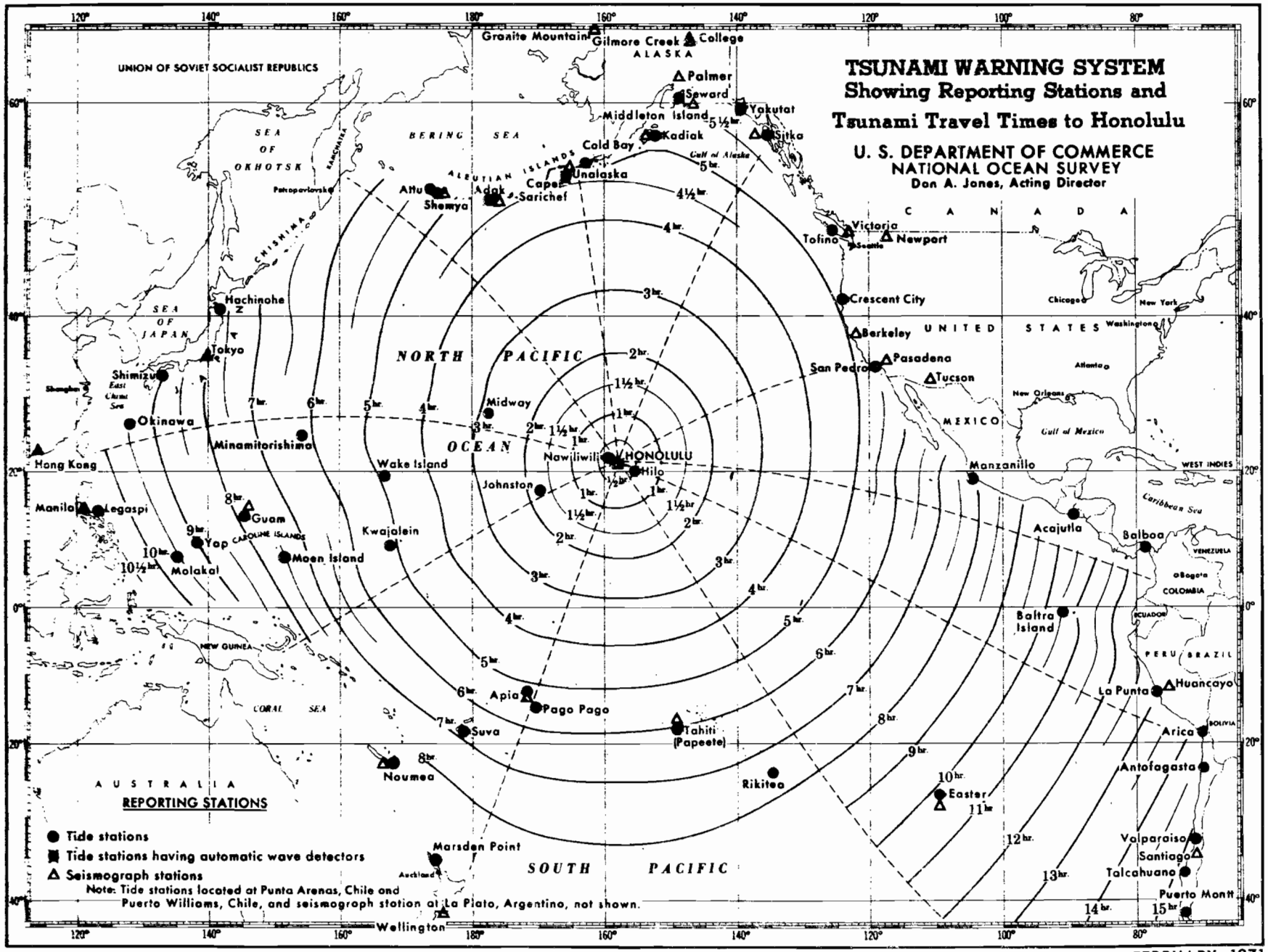

Figure 1. Tsunami travel time chart centered on Honolulu.

GPO: 1979--677-143/364