TSUNAMI INFORMATION IN REGARD TO PROPOSED NUCLEAR POWER PLANT SITE, PACIFIC GAS AND ELECTRIC COMPANY, AT BODEGA HEAD, CALIFORNIA

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6 May 1964
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GENERATION OF TSUNAMIS

The term "tidal wave", which is often used for the water gravity waves associated with submarine seismic disturbances, is now seldom used in the technical literature as the waves are not related to the tides. The Japanese word "tsunami" is usually used instead.

Tsunamis can be generated by several mechanisms. It is known that the explosion of an underwater volcano can cause one, or an island exploding, such as Krakatoa. Explosion of atomic bombs underwater can also cause them. Most tsunamis are associated with earthquakes occurring under the ocean. The exact mechanism, or mechanisms are not known for sure, but large underwater landslides could cause them. It is more likely that the major cause is an abrupt tectonic displacement of the ocean bottom, either fault displacement or more general displacements of the ocean bottom as apparently was the case in the Alaskan earthquake and tsunami of 27 March 1964.

Most earthquakes that occur are of small enough magnitude that no noticeable tsunamis accompany them. In addition, the focal depth of the earthquake must be relatively shallow. Iida's 1963a results for tsunamis in Japan are shown in Figure 1. To the left of line A, no tsunamis of any appreciable height have been observed. The data between lines A and B are important to areas in which the elevations are in the range of 2 to about 10 feet above the normal sea level at the time of the tsunami. The tsunamis designated by symbols (m) 2 and 3, which are to the right of line B, are major, with water running up to 20 feet above the normal sea level at the time of the tsunami for m = 2, and up to 39 feet for m = 3 (see Table 1 for relationships among tsunami magnitude, m, tsunami energy and maximum tsunami run-up elevation). Except under exceptional circumstances, a structure located at an elevation of greater than 20 feet above the normal sea level at the time of the tsunami would be affected only by tsunamis of magnitude, m, greater than 2. Referring to Figure 1, this means that the earthquake (occurring under the ocean) would have to be greater than a Richter scale

TABLE 1

MAGNITUDE, ENERGY, AND RUN-UP ELEVATION OF TSUNAMIS IN JAPAN
(after Iida, 1963a)

Tsunami magnitude Classification	Tsunami energy		Maximum run-up elevation	
(m)	ergs	(ft-lb)	(meters)	(ft)
5	25.6×10^{23}	18.9×10^{16}	>32	>105
4.5	12.8	9.4	24–32	79–105
4	6.4	4.7	16–24	52.5–79
3.5	3.2	2.4	12–16	39.2–52.5
3	1.6	1.2	8–12	26.2–39.2
2.5	0.8	0.59	6–8	19.7–26.2
2	0.4	0.29	4–6	13.1–19.7
1.5	0.2	0.15	3–4	9.9–13.1
1	0.1	0.074	2–3	6.6–9.9
0.5	0.05	0.037	1.5–2	4.9–6.6
0	0.025	0.018	1–1.5	3.2–4.9
−0.5	0.0125	0.0092	0.75–1	2.5–3.2
−1	0.006	0.0044	0.50–0.75	1.6–2.5
−1.5	0.003	0.0022	0.30–0.50	1.0–1.6
−2	0.0015	0.0011	<0.30	<1.0

TABLE 2

TSUNAMI ENERGY
(after Iida, ~~1958)~~ 1963a)

	Date	Tsunami	Earthquake energy		Tsunami energy		Tsunami energy / earthquake energy
			(ergs)	(ft-lb)	(ergs)	(ft-lb)	
1.	Mar. 3, 1933	Sanriku	20.0×10^{23}	14.7×10^{16}	17×10^{22}	12.5×10^{15}	0.085
2.	Nov. 3, 1936	Fukushima	2.2	1.6	0.2	0.15	0.0091
3.	May 23, 1938	Fukushima	0.28	0.21	0.04	0.03	0.011
4.	Nov. 5, 1938	Fukushima	2.2	1.6	0.2	0.15	0.0091
5.	Dec. 7, 1944	Tonankai	6.4	4.7	7.9	5.8	0.12
6.	Feb. 10, 1945	Fukushima	0.56	0.41	0.04	0.03	0.007
7.	Dec. 21, 1946	Nankaido	9.0	6.6	8.0	5.9	0.098
8.	Mar. 2, 1952	Tokachi	9.0	6.6	8.0	5.9	0.098
9.	Nov. 4, 1952	Kamch[illegible]ka	13.0	9.6	15	11	0.11
10.	Nov. 25, 1953	Boso	1.0	0.7	0.7	0.5	0.07

magnitude, M, greater than about 7.75, even for very shallow focal depths, and for focal depths greater than about 60 kilometers the earthquakes would have to have a magnitude greater than about 8.25.

The relationship between the magnitude of the tsunami, m, and the magnitude of the earthquake, M, is shown in Fig. 2. This comes from data of the type shown in Table 2, which relates tsunami energy to earthquake energy. It can be seen from the data in Table 2 that the tsunamis have from less than 1% to about 12% as much energy as the associated earthquake, with the tsunamis associated with the larger earthquakes having a greater percentage of the energy than is the case for the smaller earthquakes.

In order to understand some of the characteristics of the tsunamis, it is enlightening to see the relationship between the aftershock area and the magnitude, M, of the earthquake which cause tsunamis and the relationship between the length of the "fault" with the earthquake magnitude. These are shown in Figs. 3 and 4. The length of the actual displacement as a function of earthquake magnitude is shown in Fig. 5. The amount of energy of a tsunami depends upon the size of the generating area, and the vertical component of the displacement; unfortunately, little information is available of the vertical component, and this is probably largely responsible for the large scatter in the data relating tsunami energy to earthquake energy. A final variable is the effect of the depth of water in which earthquake occurred. Iida (1963a) has found that the deeper the water the greater the magnitude of the tsunami, as can be seen in Fig. 6.

A tsunami rarely consists of one wave, it usually is a series of waves with crests and troughs. The troughs are often very noticeable, with the water level retracting to a position far below the lowest tides in an area. The amount of run-up of a wave at a particular place, especially in a bay, depends upon the period of the tsunami and the various natural periods of a bay, or of a continental shelf, etc. As can be seen in the work of Iida (1936b), shown in Fig. 7, the wave period increases with increasing earthquake magnitude.

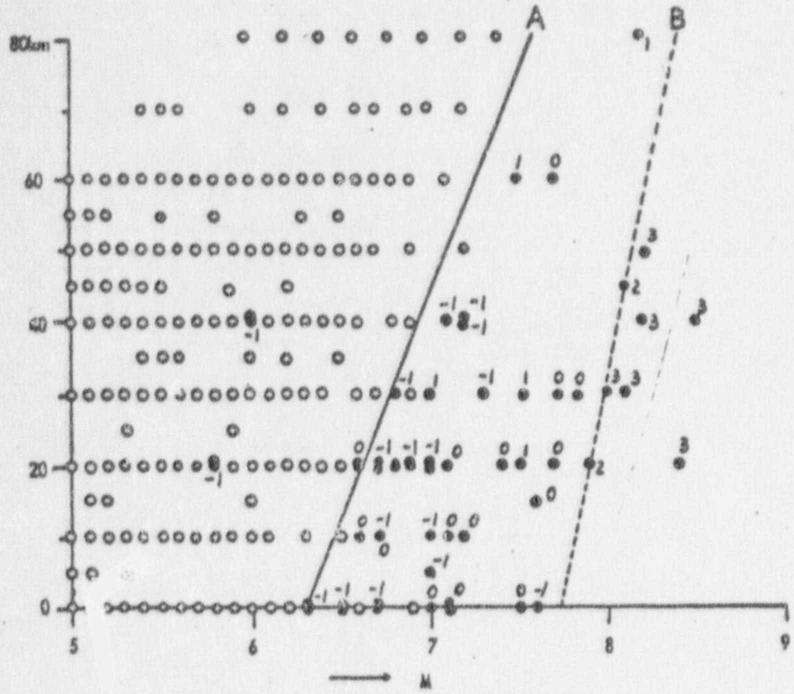


Fig. 1 - Relationship between magnitude M and focal depth H submarine earthquakes during the period from 1900 to 1960.

○ Earthquake not accompanied by tsunamis.

● Earthquake accompanied by tsunamis.

The numeral outside of the circle is the tsunami magnitude.

(from Iida, 1963 a)

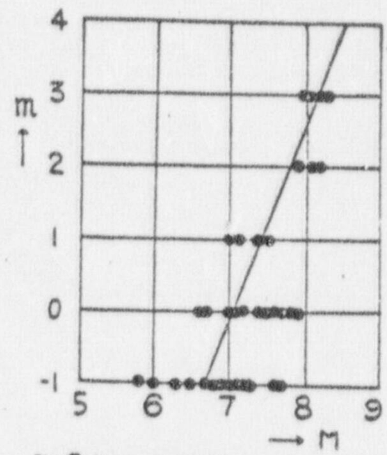


Fig. 2 Relationship between earthquake magnitude M and tsunami magnitude m.

(from Iida, 1963 a)

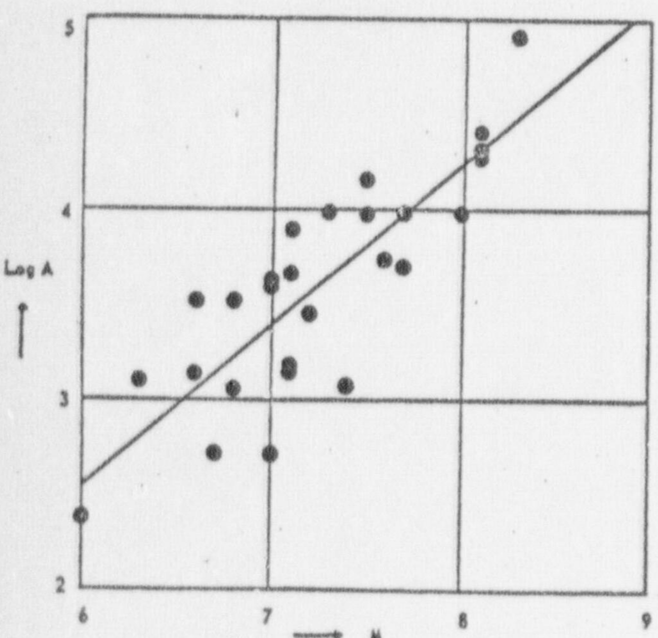


Fig. 3 Relationship between aftershock area and magnitude M of tsunamigenic earthquakes.

(from Iida, 1963 a)

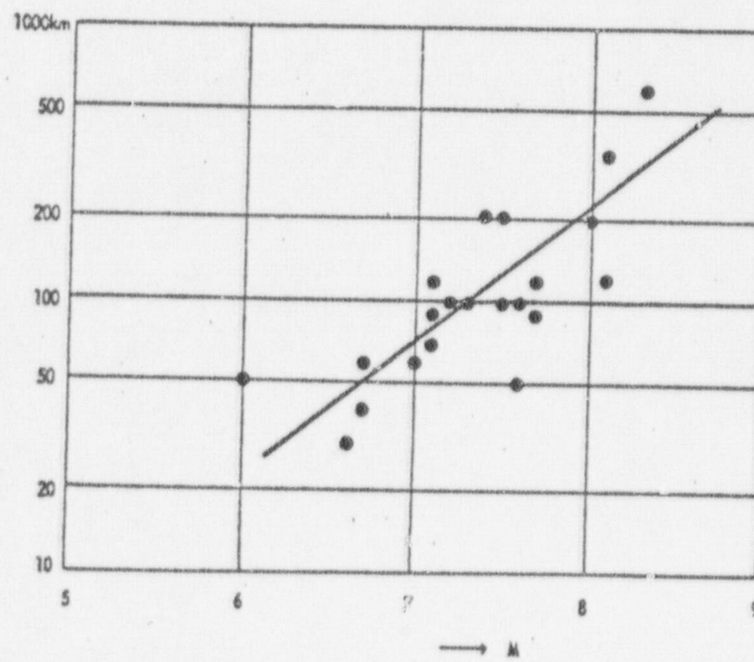


Fig. 4 Relationship between dimension of tsunami origin ~~area~~ length L and magnitude of tsunamigenic earthquakes.

(from Iida, 1963 a)

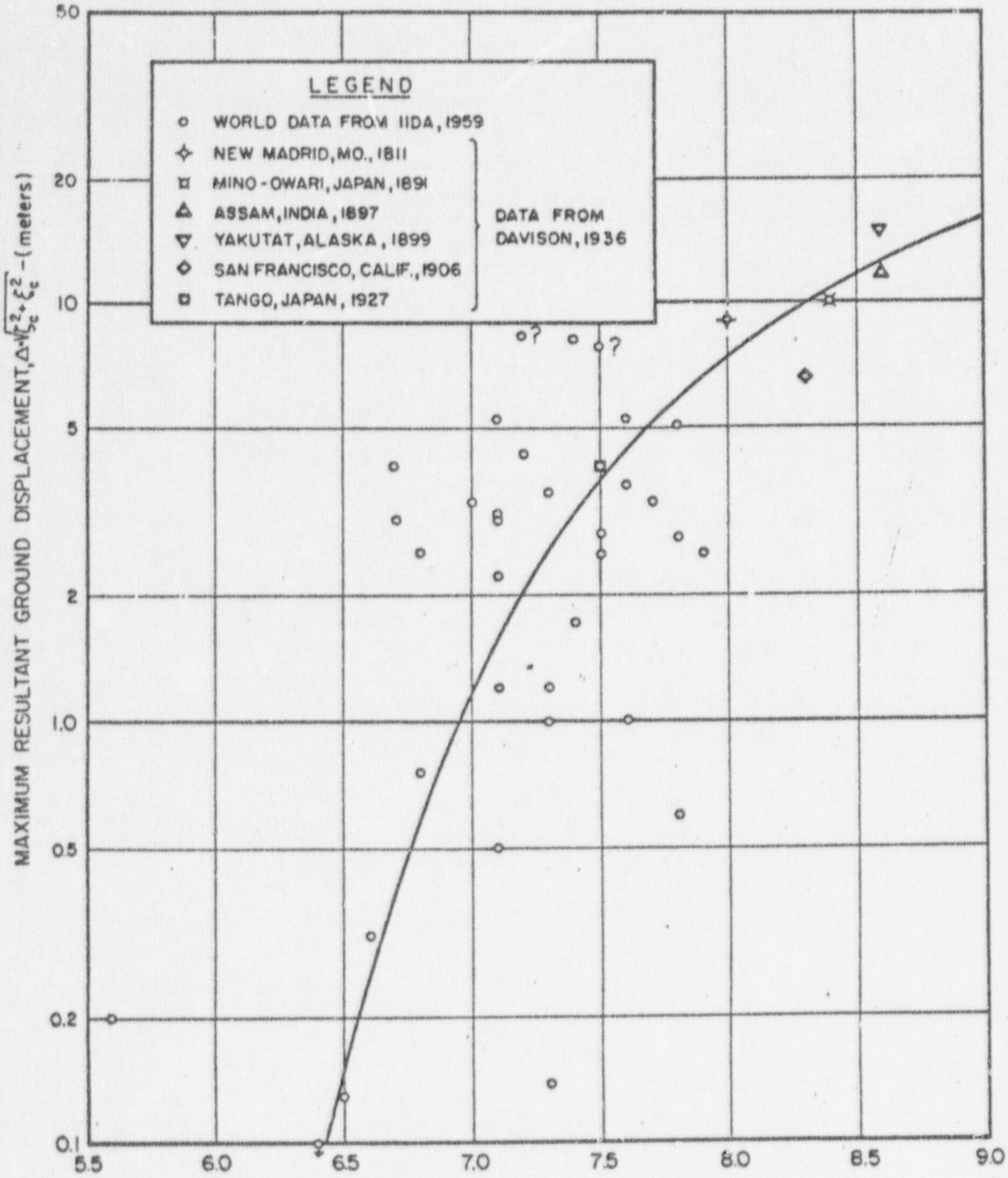


FIG. 5 TREND OF DEPENDENCE OF MAXIMUM RESULTANT GROUND DISPLACEMENT ON EARTHQUAKE MAGNITUDE.
(from Wilson, Webb and Hendrickson, 1962)

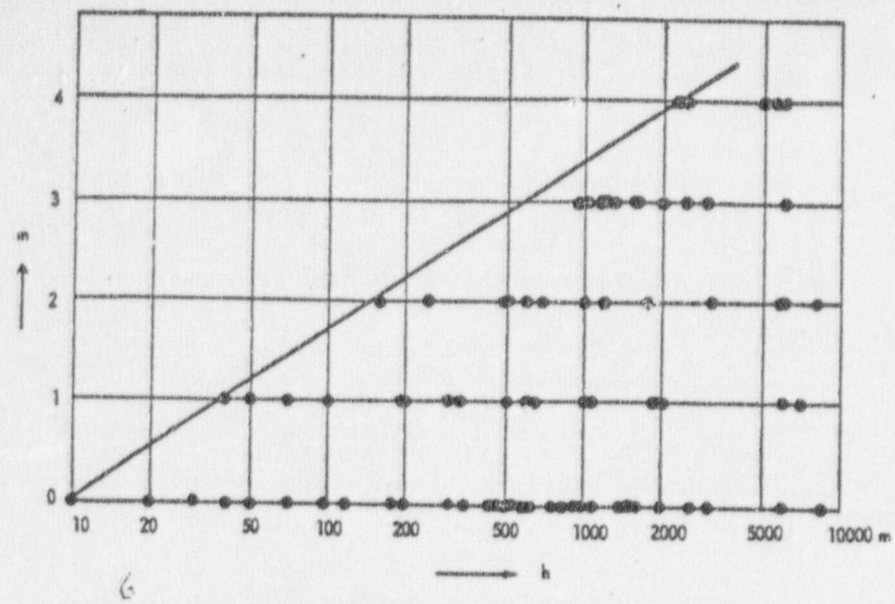


Fig. 6 - Relationship between tsunami magnitude m and water depth h at the earthquake epicenter.
(from Iida, 1963 a)

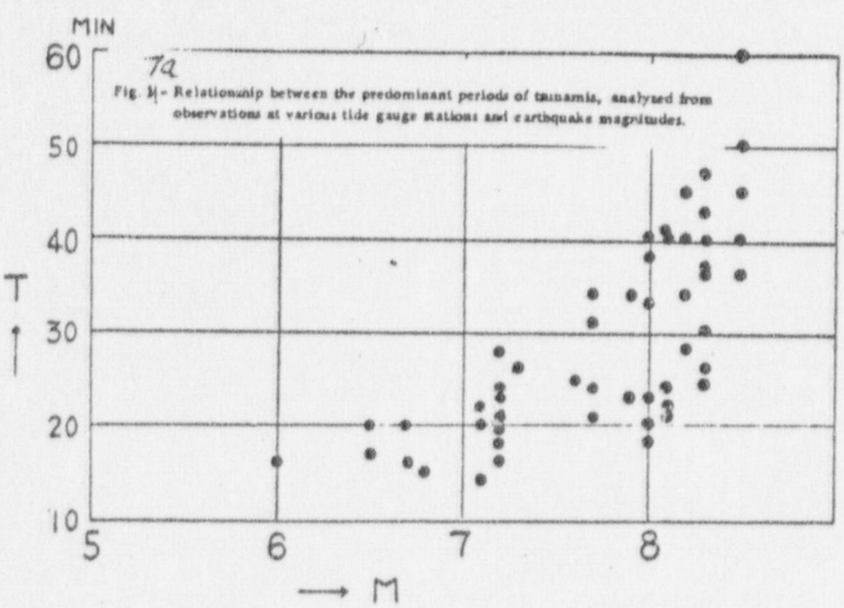


Fig. 7a - Relationship between the predominant periods of tsunamis, analysed from observations at various tide gauge stations and earthquake magnitudes.

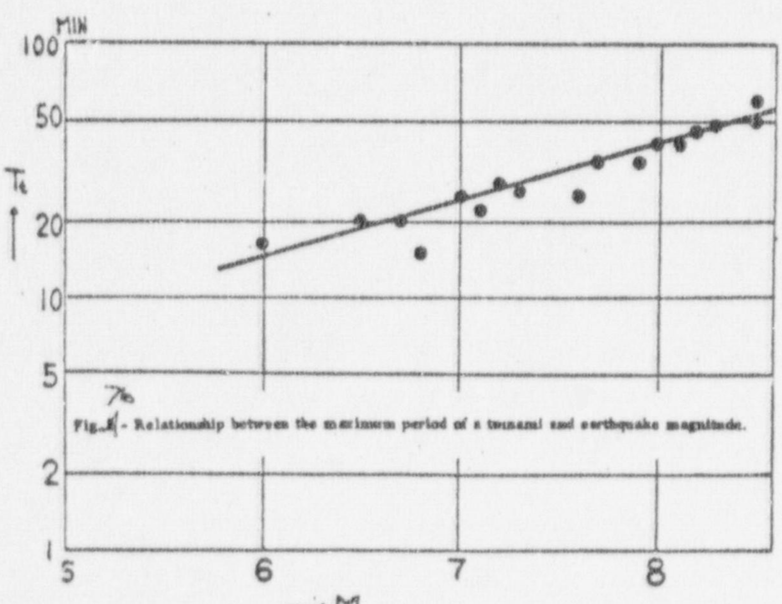


Fig. 7b - Relationship between the maximum period of a tsunami and earthquake magnitude.

Fig. 7 (from Iida, 1965 b)

TSUNAMI HEIGHT AT THE SHORE

It is generally agreed that in the open ocean tsunamis are very long and low; for example, of the order of 50 miles in length and less than 2 feet in height. They travel at the speed of $\sqrt{gh}$ ft/sec, where g is the acceleration due to gravity (32.2 ft/sec^2) and h is the water depth (in feet). In the open ocean, with a water depth of the order of 16,000 feet, they travel at a speed of $\sqrt{gh} = \sqrt{32.2 \times 16,000} =$ 720 ft/sec = 490 miles per hour. Because of the effect of the water depth on the speed of the wave, the wave bends in water of varying depth. This process is known as refraction.

In the case of large tsunamis the origin is more like a line source than a point source, so that the wave moves out as a spreading ellipse rather than as a spreading circle as would be the case for the waves generated by throwing a rock in a pool. If the ocean were of uniform depth the maximum wave heights would lie nearly along a great circle route drawn normal to the source line, but modified slightly by the Coriolis force. Refraction modifies this, but it still is an approximation to the real solution. Using this concept one can easily explain the great damage along the coast of Hokkaido in Japan due to the 22 May 1960 tsunami which originated off Chile (see Fig. 8 for the source). If one takes the preliminary data from the 28 March 1964 earthquake epicenters in Alaska (Fig. 9) and draws a possible causative fault through the epicenters, and then places this line on a terrestrial globe and draws a great circle normal to the line, from the center of the source line, it can be seen that it heads nearly to the northern California and southern Oregon area; this would explain the relatively low waves in Hawaii and Japan, and the relatively high waves at Crescent City.

The effect of refraction in the near vicinity of the coastline can be seen clearly in Fig. 10 for the island of Hawaii. The orthogonals (lines perpendicular to the wave fronts) converge in some areas to cause an increase in wave height, and diverge

Intensity is measured by the Modified Mercalli (MM) scale in a range from I to XII and indicates the violence or shaking at a given point (see Fig. 13).

Magnitude is measured on the Richter scale, in arabic numerals, and is a measure of the total energy released by the earthquake and does not vary from one locality to another. Measured on a Wood-Anderson seismometer, the relationship is defined as the logarithm of the amplitude of the movement in microns at a distance of 100 km. The largest earthquakes recorded have magnitudes of about 8½.

Legend

1 to 10 Mag-5 Earthquakes

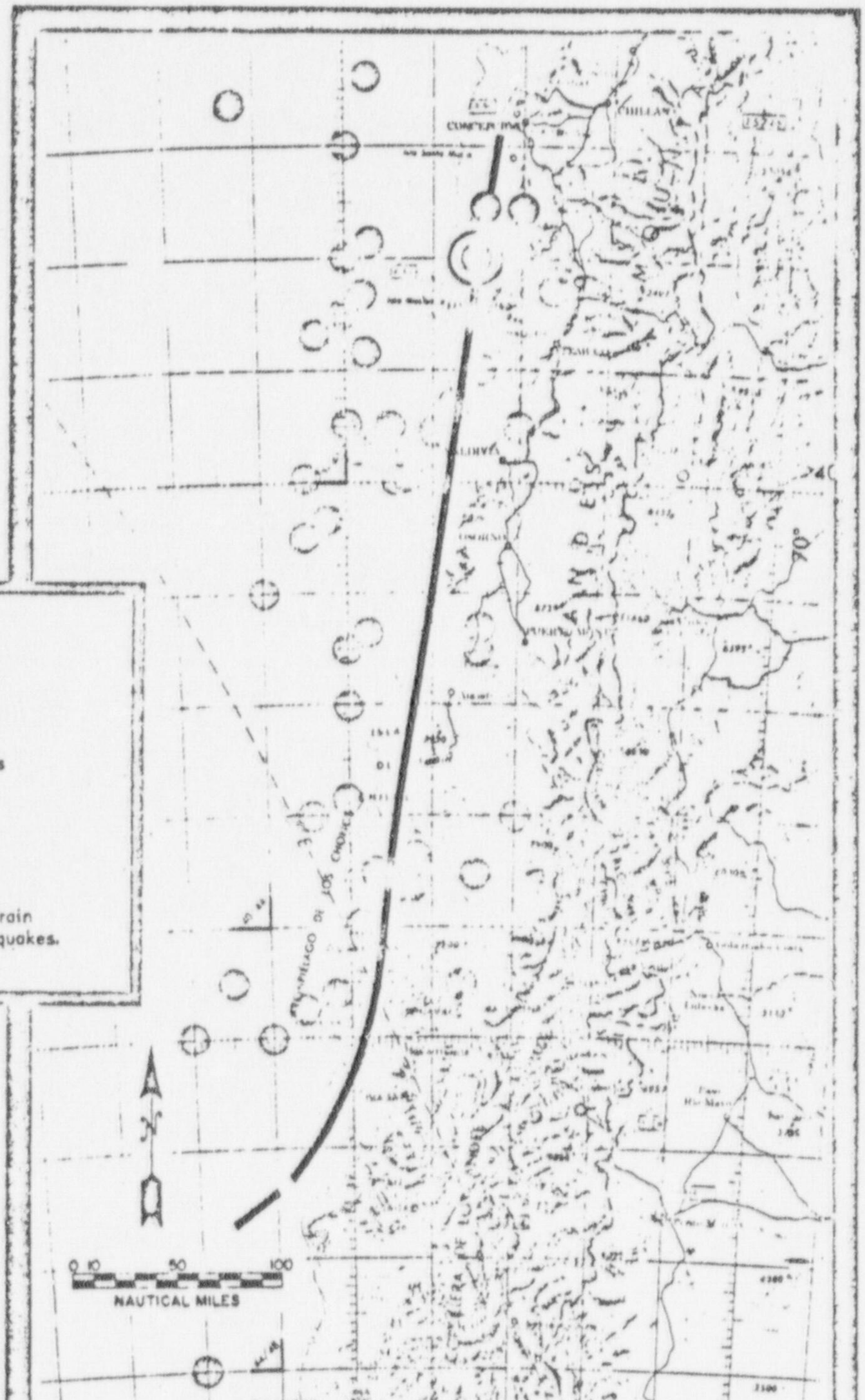
10 to 100 Mag-5 Earthquakes

More than 100 Mag-5 Earthquakes

Main Shock, Mag 8.4 (Equiv. 525 Mag-5 Earthquakes)

Probable Causative Fault

Color of dots indicates sum of strain released in terms of Mag-5 earthquakes.



Earthquake Area of Chile Showing Magnitudes (Richter Scale).

Fig. 8 (from Saint-Amand, 1961)

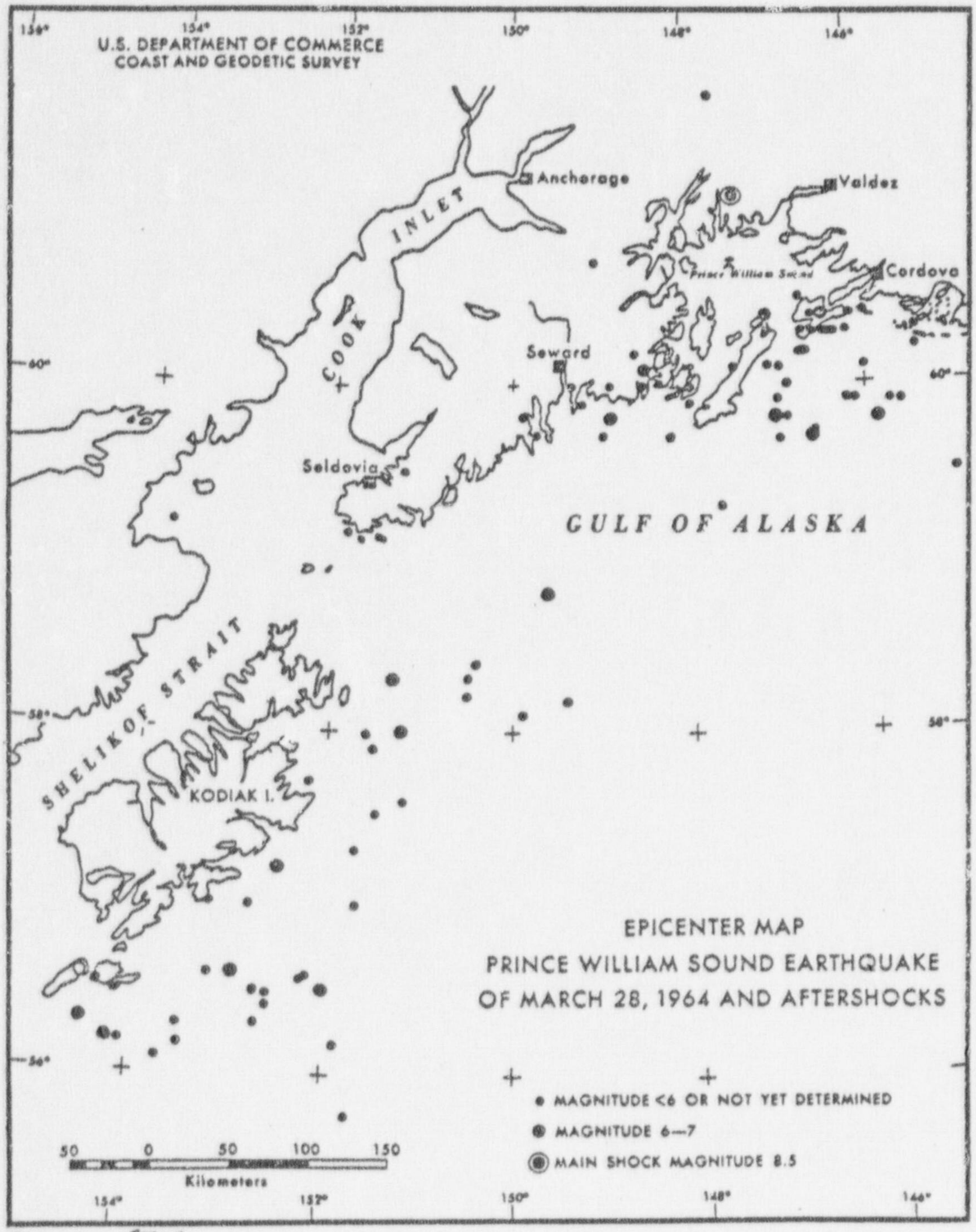


Figure 9

(from U.S. Coast and Geodetic Survey, 1964) in others, with the resulting decrease in wave height. In general, an underwater ridge running into the direction of the advancing wave would cause convergence (note St. George's Reef off Crescent City), and a submerged canyon would cause a divergence of wave energy density in the immediate area. In comparing the details shown by the refraction drawing for Hawaii with the details of the tsunami height along the shore it must be cautioned that other effects such as diffraction and bottom slopes play an important part also, and greatly affect the run-up heights.

As a wave moves into more and more shallow water, it becomes shorter and higher. Thus, a wave 2 feet high in 16,000 feet of water will become nearly 9 feet high when it moves into water 40 feet deep, just because of the decrease in depth. It doesn't continue to do this indefinitely, of course, or it would become "infinitely" high in water of approximate zero depth. Its characteristics at a shoreline are understood only in the crudest form at the present time. Sometimes the wave moves upward in a manner similar to a rapidly moving tide, while at other times it forms a bore which behaves somewhat like a breaker on a beach.

Some areas, such as Hilo, Hawaii, act as a wave trap. The tsunami waves from the 1960 Chilean earthquake probably reflected from the cliffs along the west side of the bay, then because of the local hydrography, refracted in such a manner that they turned around, and headed towards the town of Hilo, rather than reflecting back out to sea. In the 1 April 1960 tsunami from the Aleutians the main waves apparently reflected as a Mach-stem (Wiegel, 1963), locking onto the west cliff in a non-linear manner, and swinging right into the town of Hilo. In some areas resonance apparently plays an important part, but because of the large frictional losses that must occur in some areas, such as Bodega Bay (because of its narrow entrance and very shallow water), it is not always important.

Because of this lack of knowledge of the behavior of tsunamis at the present time, it is necessary to rely upon empirical data, tempered by our small amount of knowledge of the physics of the phenomenon.

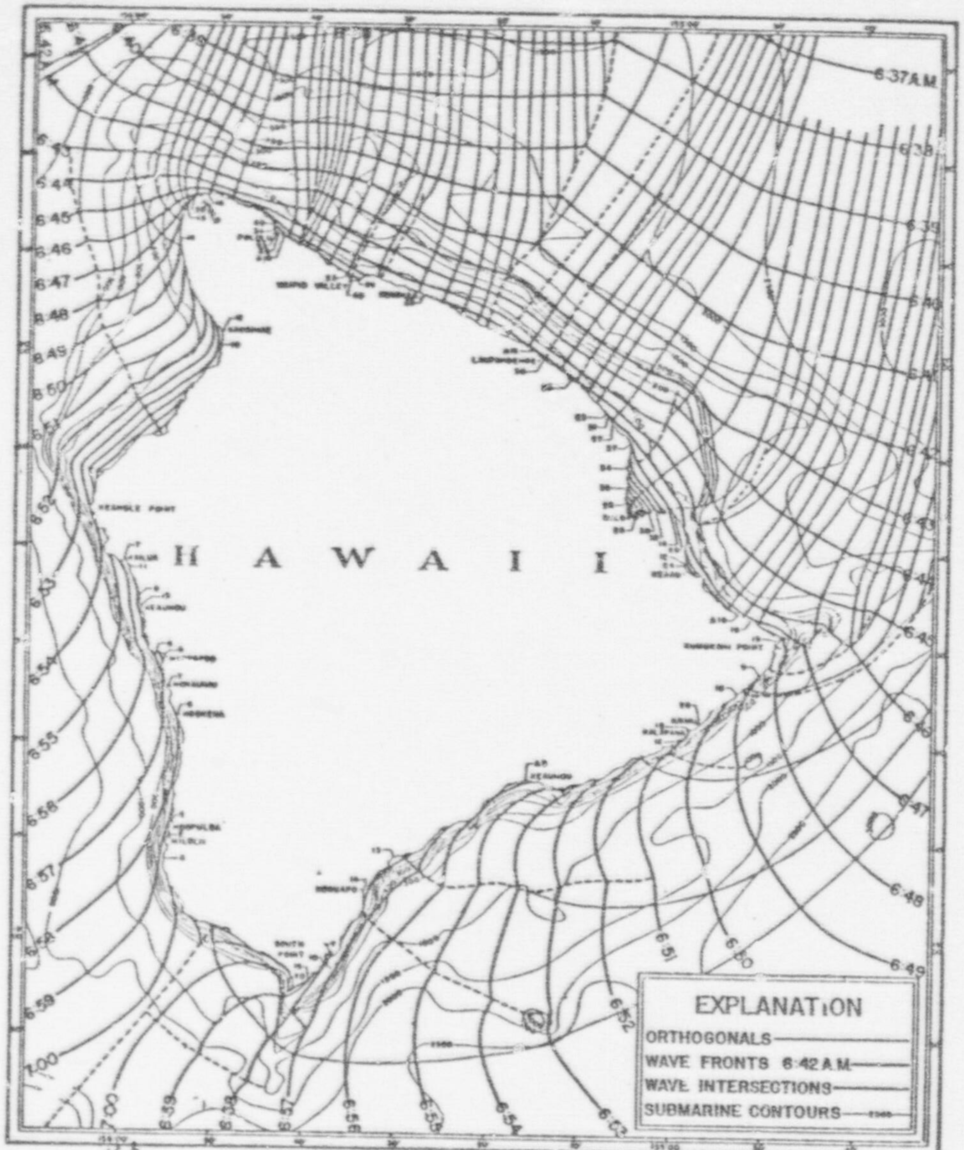


Fig. 10b. Map of the island of Hawaii, showing heights (in feet above lower low water) reached by the water during the tsunami, wave fronts, orthogonals, and submarine contours (in fathoms). Times refer to computed time of arrival of first wave.
(from Shepard, MacDonald and Cox, 1950)

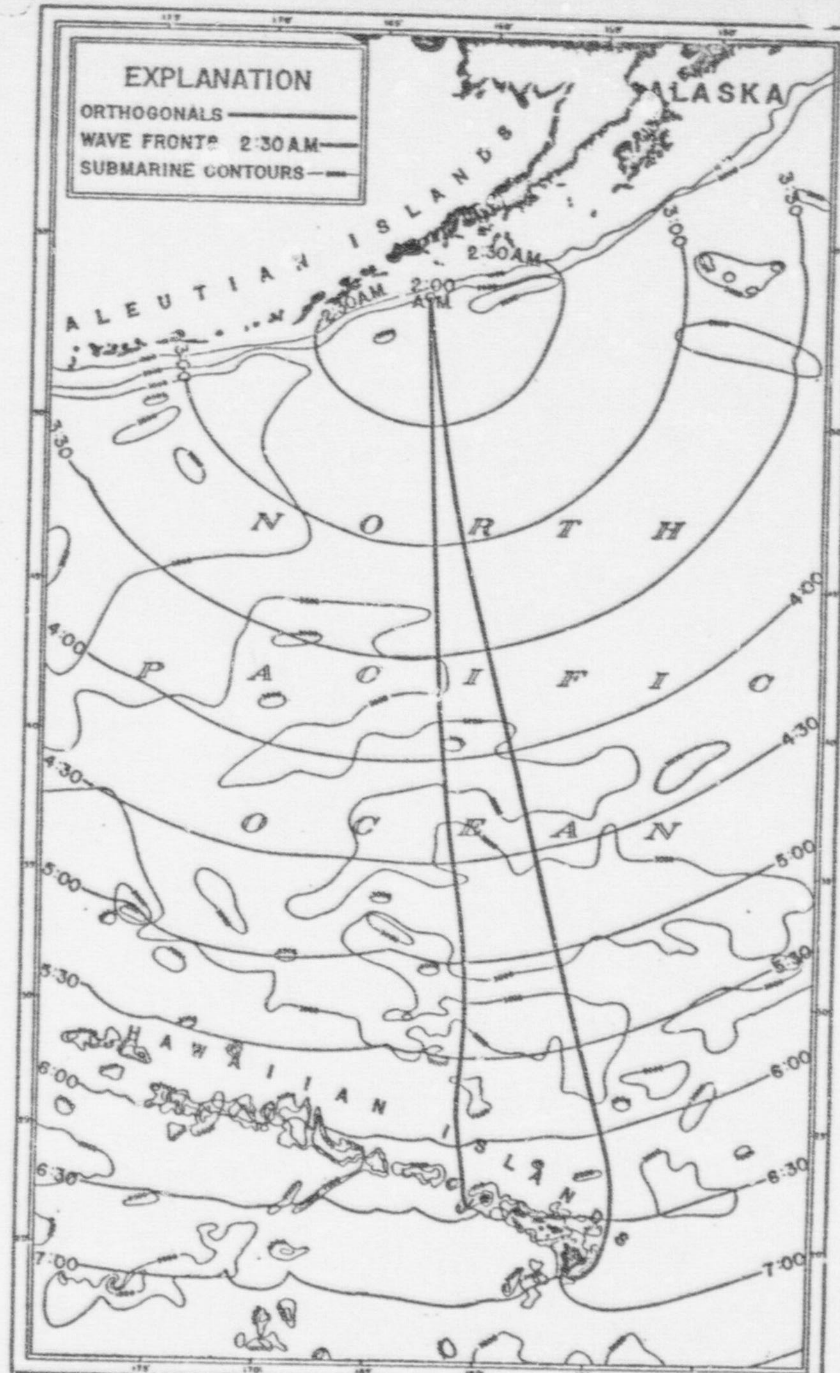


Fig. 10a. Submarine topography (contours in fathoms) between the Aleutians and Hawaii, showing wave fronts and orthogonals of the tsunami. Times refer to computed time of arrival of first wave.
(from Shepard, MacDonald and Cox, 1950)

Let us look at the maximum elevations to which tsunamis rose along a coast for the case of tsunamis which originated far away, but which hit the coast "head-on". One example is the 1 April 1946 tsunami which originated in the Aleutian Trench. It can be seen that the run-up in the Hawaiian Islands was high throughout the exposed area, and appreciable even in the lee areas (see Fig. 10b). (It must be cautioned here that diffraction, which cannot be discussed in a report of this limited extent, plays an important part in the height of run-up on an island.) The same tsunami was not nearly as high along the California Coast because of the glancing incidence of the waves with respect to the coast of California, although it certainly was appreciable and caused some damage. Glancing incidence, together with refraction, causes the wave energy to spread out over a greater area, thus causing a decrease in wave energy density, on the average. The same thing was true with respect to the tsunami resulting from the Chilean earthquake of 22 May 1960. The tsunami from the 28 March 1964 Alaskan earthquake was directed towards the coast of California, rather than Hawaii, and very little run-up occurred in the Hawaiian Islands. The reason that the run-up along the coast of California was as low as it was was due to the glancing incidence (look at a terrestrial globe to see this), even though the tsunami was apparently directed towards the Oregon-California area.

The discussion presented above has emphasized the run-up height of tsunamis. It must be remembered that tsunamis are waves, and at the shore they have a drawdown which is usually at least as great as the run-up, when measured from the normal tide level at the time of the tsunami. For example, the maximum drawdown at Avila, in southern California, was about 11 feet below the normal tide level at the time in the 27 March 1964 tsunami, and this was greater than the maximum run-up. (U.S. Coast and Geodetic Survey, 1964) These drawdowns may be of importance in regard to some structures such as cooling water intakes, and should be considered in their design. It may also be important in the design of bulkheads with fill behind them. The earth may become saturated if the tsunami overtops the bulkhead, and then may fail when the water retreats to a level much lower than was taken into consideration when designing the bulkhead.

TSUNAMIS ALONG THE COAST OF CALIFORNIA

Nearly all tsunamis recorded along the coast of California originated elsewhere, and traveled across the ocean to California. On occasion they have done extensive damage in particular locations to buildings and facilities in relatively low areas. For example, the large amount of damage which occurred in Crescent City due to the tsunami of [illegible] March 1964 was in portions of the city adjacent to the water's edge, and lying at an elevation of less than 20 feet above the normal tide level at the time of the tsunami.

Some regions seem to be subject to relatively low wave run-up, while other areas have relatively high run-up. Bodega Bay seems to be subjected to relatively low wave run-up, as can be seen in Table 3. One could say, on the basis of past records, that the wave run-up inside the harbor proper would be less than about 3 feet above the normal tide level at the time of the tsunami, and probably less than about 5 feet just a little ways inside the entrance. This statement refers only to tsunamis originating many thousands of miles from Bodega Bay.

TABLE 3. TSUNAMI HEIGHT AT BODEGA BAY, CALIFORNIA

Tsunami Date	Source of Information	Tsunami Height feet	Remarks
1 April 1946	Bascom, 1946	$3\frac{1}{2}$ feet above tide level at the time. Height at entrance to bay.	Dusty Rhodes (wharf owner). Moving boats at time of wave and noticed ten knot current through piling. Crab traps rolled and skiff nearly capsized. Other persons along water saw nothing. Fish boat noticed very strong current flowing in between jetties
22 May 1960	Magoon, 1962	About 1 foot above tide level at the time.	No effects observed at "Tides Dock"
28 March 1964	Joslin, 1964	About 2 feet above tide level at the time.	Concensus was that the water level in the harbor would vary from 2 feet to 4 feet every 20 to 40 minutes. There was no evidence of the water level at the harbor ever exceeding the normal high tide or receding much below a normal low tide.

A detailed list of tsunamis and their elevations is not available for the coast of California (telephone conversation between R. L. Wiegel and Dr. William Van Dorn of the Scripps Institution of Oceanography on 4 May 1964, and between R. L. Wiegel and Mr. B. Zetler of the U.S. Coast and Geodetic Survey on 5 May 1964). There are probably only two areas for which such detailed lists have been prepared, these being Japan and Hawaii. The compilation of the world wide distribution of tsunamis by Heck (1947) refers to tsunamis in 1812, 1855, 1885, 1903, and 1923 (his list is only up to 1934). The tsunami of 21 December 1812 apparently originated someplace near Santa Barbara and was reported to have done some damage to the harbor of Refugio, west of the Santa Barbara Mission (Gutenberg and Richter, 1949). Gutenberg and Richter also report that a small tsunami was generated by the earthquake off Point Arguello on 4 November 1927. The others reported in Heck's list, which must be far from complete, originated elsewhere.

The list of tsunamis arriving at Hilo, Hawaii (and other areas in Hawaii), which was prepared by Professor Doak Cox of the University of Hawaii, is probably the most complete list that has been compiled for a specific area (Cox, 1962). This is of considerable importance in regard to the coast of California as it lists the origins of the tsunamis, where known. As Hilo, Hawaii is particularly sensitive to tsunamis, it makes a good reference point. The list is for the interval of 1837 - 1962, and is reproduced in Table 4. It shows that only one tsunami originated in California (or Oregon or Washington, for that matter) during that interval. This is in agreement with the work of Gutenberg and Richter, who list only the 21 December 1812 and the 4 November 1927 tsunamis as originating off the coast of California.

The reason for the importance of the small number of tsunamis originating off the California Coast is that the heights of tsunamis are larger close to the source than they are far from the source, all other things being equal. Thus the design of a structure along the coast of California, which can be made using probabilities of events occurring, must be related to this information. These probabilities are in the field

TABLE 4. TSUNAMIS REACHING THE HAWAIIAN ISLANDS; RUN-UP AND DAMAGE AT HILO, HAWAII
(after Cox, 1962)

Year	Date	Source	Period of initial wave (minutes)	Maximum run-up (feet)	Earthquake magnitude	Damage (dollars)
1837	Nov. 7	Chile	?	20?		Many houses destroyed
1841	May 17	Kamchatka	?	3		
1854	Dec. 23	Japan	No record at Hilo			
1868	Apr. 2	Hawaii	?	10		Minor
1868	Aug. 13	Peru, Chile	?	15		Small
1869	July 25	Peru, Chile	No record at Hilo			
1872	Aug. 23	Hawaii ?	6	4		
1877	May 10	Chile	?	16		Moderate (14,000)
1878	Jan. 20	Chile ?	?			
1883	Aug. 27	Krakatoa eruption				
1896	June 15	Japan	6 ?	8	7.6	
1901	Aug. 9	Japan	?	4	7.7	
1906	Jan. 31	Colombia	30	3	8.6	
1906	Aug. 16	Chile	?	5	8.4	
1913	Oct. 11	New Guinea	No record at Hilo			
1914	May 26	New Guinea	No record at Hilo		7.9	
1917	May 1	Kermadec Is.	No record at Hilo		8	
1917	June 25	Samoa Is.	No record at Hilo		8.3	
1918	Aug. 15	Philippine Is.	No record at Hilo		8.3	
1918	Sept. 7	Kurile Is.	?	5	8.3	
1919	Apr. 30	Tonga Is.	?	2	8.3	
1922	Nov. 11	Chile	?	7	8.3	
1923	Feb. 3	Kamchatka	?	20	8.3	Considerable
1923	Apr. 13	Kamchatka	?	Small wave	7.2	
1927	Nov. 4	California	20	1.5	7.3	
1927	Dec. 28	Kamchatka	25	0.2	7.3	
1928	June 17	Mexico	22	0.8	7.8	
1929	Mar. 6	Aleutian Is.	15	0.6	8.1	
1931	Oct. 3	Solomon Is.	13	0.3	7.9	
1932	June 3	Mexico	18	0.6	8.1	
1932	June 18	Mexico	?	0.1	7.8	
1932	June 22	Mexico	?		6.9	
1933	Mar. 2	Japan	?	2	8.3	
1938	Nov. 10	Alaska	No record at Hilo		8.3	
1943	Apr. 6	Chile	No record at Hilo		7.9	
1944	Dec. 7	Japan	No record at Hilo		8.0	
1946	Apr. 1	Aleutian Is.	?	27	7.4	Great (26,000,000)
1946	Dec. 20	Japan	No record at Hilo		8.2	
1948	Sept. 8	Tonga Is.	No record at Hilo		7.8	
1951	Aug. 21	Hawaii	12	0.2	6.9–7.0	
1952	Mar. ?	Japan	16	0.2	8.2	
1952	Nov. 4	Kamchatka	18	12	8.3	Moderate (300,000)
1953	Sept. 14	Fiji		0.2	6.8	
1956	Mar. 30	Kamchatka	No record at Hilo			
1957	Mar. 9	Aleutian Is.	18	14	8.0	Moderate (400,000)
1957	Oct. 31	?				
1958	Nov. 6	Kurile Is.	20	0.6	8.3	
1959	May 4	Kamchatka	22	0.5	8.2	
1960	May 23	Chile	34	35	8.5	Great (22,000,000)

of an expert seismologist, as there is much more information on earthquakes of magnitude greater than 7.75 on the Richter scale than there is on tsunamis. Some feeling for this can be obtained by looking at the distribution of shallow earthquakes (shallow being defined for the purpose of this figure as focal depths of less than 60 kilometers) as shown in Figure 11 for earthquakes of magnitudes between 7 and 7.7 and of 7.75 and over. Details of the Pacific Coast of the U.S. can be seen in Figure 12, which can be compared with details for the coastal area of Alaska which is shown in Figure 13. It is recommended that a table similar to the one prepared by Housner (1952) (see Table 5) be prepared with respect to earthquakes occurring off the coast of California, with particular attention being given to the region of the Mendocino Escarpment.

TABLE 5. EXPECTED NUMBER OF CALIFORNIA EARTHQUAKES (from Housner, 1952)

Of Magnitude Greater Than	Per Period of Years			
	25	50	100	200
6.0	25	50	99	198
6.2	18	36	73	146
6.4	13	26	53	106
6.6	9.3	19	37	74
6.8	6.4	13	26	51
7.0	4.3	8.6	17	34
7.2	2.6	5.2	10	21
7.4	1.7	3.4	6.7	13
7.6	.97	1.9	3.9	7.8
7.8	.51	1.0	2.0	4.1
8.0	.28	.56	1.1	2.2
8.2	.13	.26	.51	1.0
8.4	.04	.08	.17	.34

Table 5 shows that an earthquake of magnitude 8.2 (San Francisco, 1906) or greater can be expected to occur in California on the average of once every 200 years. An earthquake of magnitude 6.7 (El Centro, 1940) or greater can be expected to occur in California on the average 63 times during a 200-year interval. Shocks of magnitude 6.25 (Long Beach, March 10, 1933) or greater can be expected on the average 138 times during a 200-year interval.

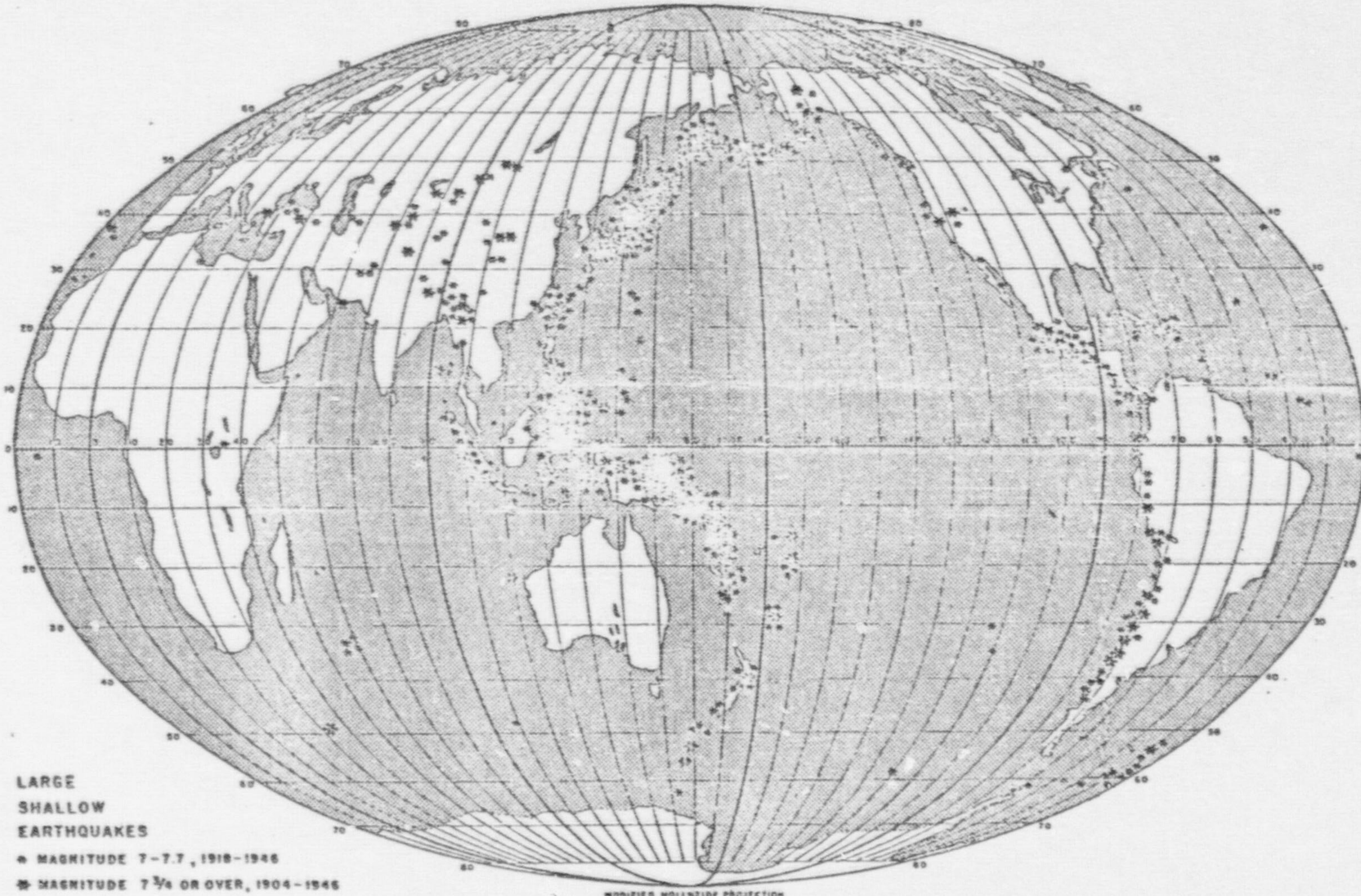


FIGURE 3 11. World map of shallow earthquakes: class a 1904-1946; class b 1918-1946.

(From Gutenberg and Richter, 1949)

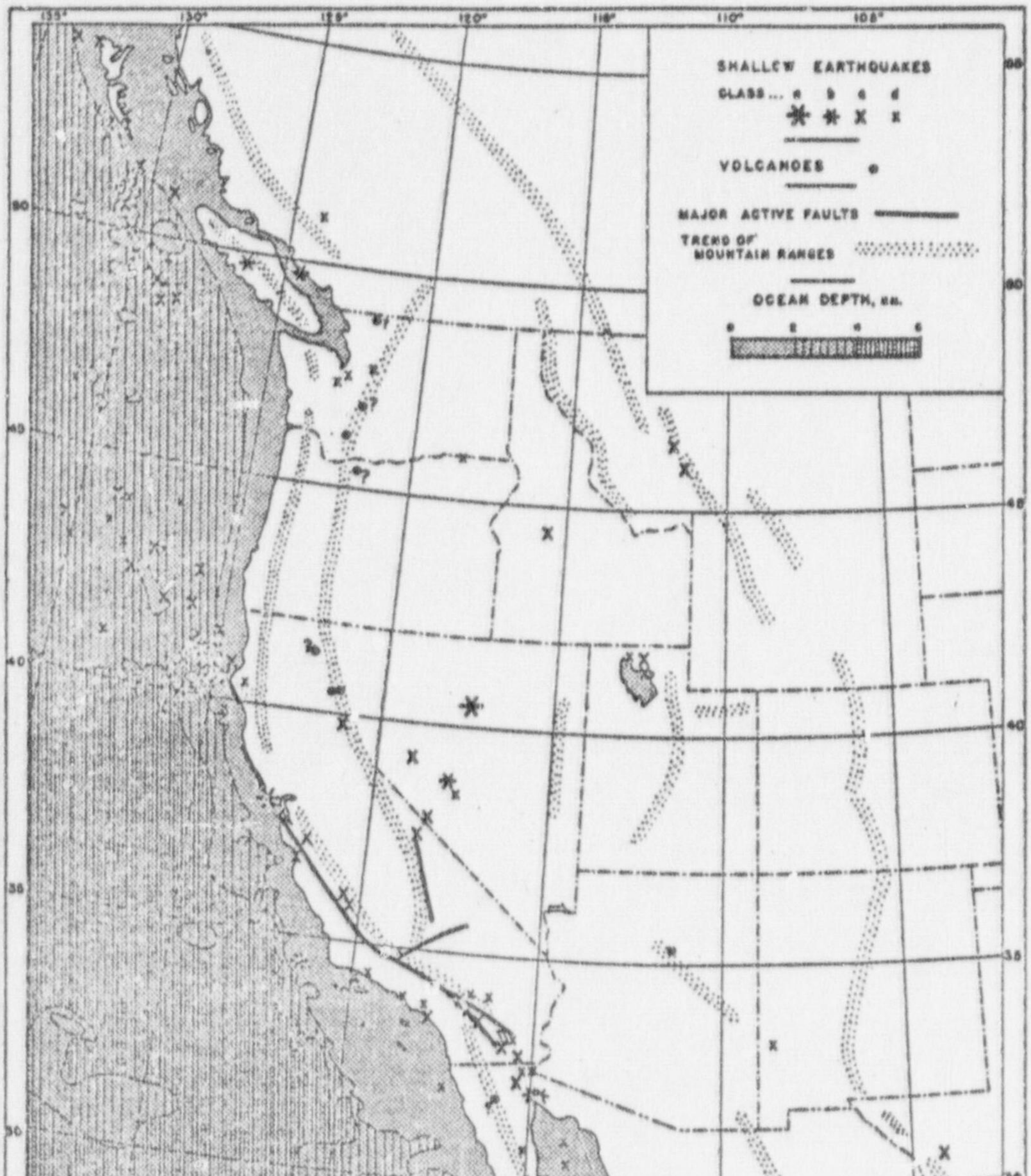


FIGURE 12. Western United States.

(from Gutenberg and Richter, 1949)

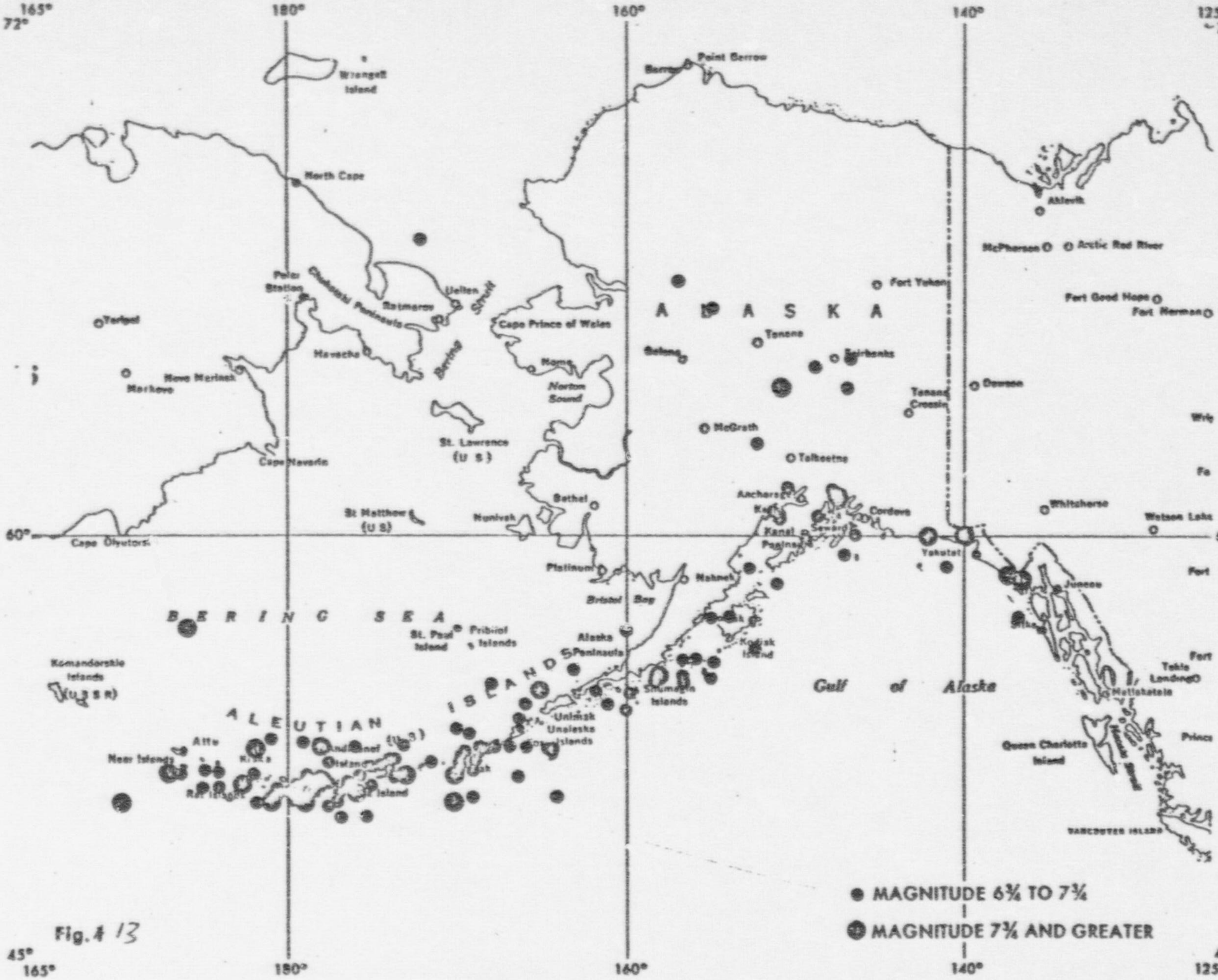


Fig.4 13

ALASKAN EARTHQUAKES THRU MARCH 1964 MAGNITUDE 6¾ AND GREATER

(from U.S. Coast and Geodetic survey, 1964)

DESIGN OF STRUCTURES TO WITHSTAND DAMAGE FROM TSUNAMIS

A study of the report on the structural damage in Hilo, Hawaii, from the 1960 Chilean tsunami by Matlock, Reese and Matlock for the Defense Atomic Support Agency (1961) reveals that although all light frame buildings and most heavy timber structures were demolished, good standard reinforced concrete structures withstood the force of the tsunami. It was further found that the reinforced concrete buildings tended to shield weaker structures in their lee. Such structures should be designed with "shear walls", and in the absence of further information they should be designed to withstand a dynamic loading of at least 1,000 lbs/ft^2, and preferably 1,900 lbs/ft^2. Much additional evidence of structural strength will undoubtedly be forthcoming from a study of the damage in Crescent City, California, and in Seward, Kodiak, etc., Alaska. This evidence should be examined to see if the loads given above should be modified. It appears even at this early date (5 May 1964) that the building must be tied into the foundation, and that this foundation must be tied into rock. This is to prevent the building from floating off its foundation, and to prevent the scouring of soil from under a foundation by the action of the currents associated with a tsunami. (See also Horikawa, 1961 and Iwasaki and Horikawa, 1960.)

As was mentioned in a previous section, the drawdowns may be of importance to some structures such as cooling water intakes. Appropriate devices must be installed to insure shut-down of a plant if the drawdown is so great that adequate cooling water cannot be obtained. As ten knot currents have been observed in Bodega Bay (see Table 3), the cooling water intake foundation must be protected from scouring to prevent a possible structural failure of the intake.

If any bulkheads are to be used, they must be designed to stand under the condition of no hydrostatic backpressure from the bay, in the case of a major drawdown, and must have adequate drainage.

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APPENDIX II