BULLETIN OF THE EARTHQUAKE
RESEARCH INSTITUTE
Vol. 43 (1965), pp. 499-508

32. *Study on Distant Tsunamis along the Coast of Japan.*

Part 1, Distribution of Tsunami Energy and Travel Time.

By Tokutaro HATORI,

Earthquake Research Institute.

(Read Feb. 23, 1965.—Received June 30, 1965.)

Abstract

For seven tsunamis which reached the coast of Japan, from Iturup, Kamchatka, Aleutian, Alaska and Chile, the distribution of tsunami energy are shown along the isobathymetric line of 200 m. As compared with the distribution, given by R. Takahasi (1951), for tsunamis originated in the sea adjacent to Japan, the patterns of energy distribution are approximately similar to each other. The regions in Sanriku and Kishu receive high percentage of the total energy of the tsunami.

The ratio between heights of the initial wave and the maximum wave seems to increase with decreasing seiche period of the bay. Along the Sanriku coast, the tsunami is always high because of particular geographical conditions, concentrated wave energy by refraction, and amplifying by coastal effects.

Refraction diagrams in the adjacent sea of Japan are drawn with the aid of arrival times of the wave fronts observed by the tide-gauge stations.

Introduction

Making use of data of historical tsunamis which occurred in the sea adjacent to Japan, R. Takahasi[1)] calculated the proportion of the tsunami energy which reaches a unit section along the border of the continental shelf and then estimated the degree of tsunami danger which may be expected in the future for each village on the Pacific coast of Japan.

The Japanese Pacific coast, however, suffered severe damage from the 1960 Chilean tsunami which had a notable difference from near tsunami. Distant tsunamis were also generated in regions of the Kurile Islands, Aleutian Islands and Alaska as shown in Fig. 1, but the Pacific coast

1) R. TAKAHASI, "An Estimate of Future Tsunami Damage Along the Pacific Coast of Japan," *Bull. Earthq. Res. Inst.*, **29** (1951), 71.

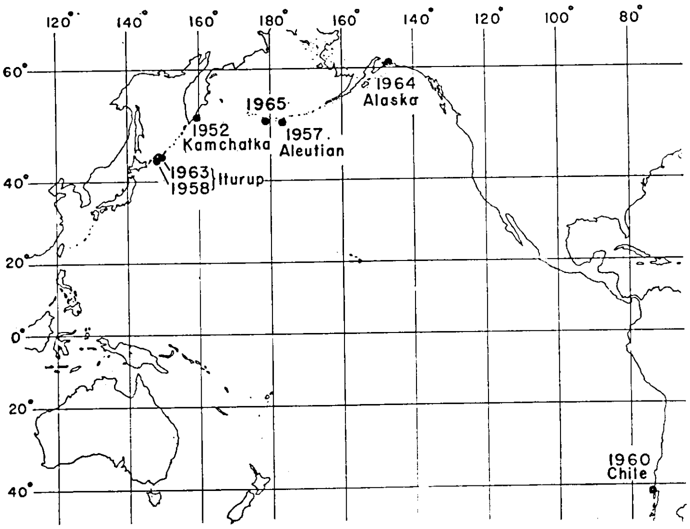

Fig. 1. Distribution of tsunami sources.

Table 1. List of distant tsunamis.

Date	Time (GMT) d	h	m	Epicenter Lat.	Long.	Location	M
1952 Nov.[2]	4	16	58	52.7°N	159.5°E	Kamchatka	8.2
1957 March[3]	9	14	28	51.3 N	175.8 W	Aleutian	8.0
1958 Nov.[4]	6	22	58	44.3 N	148.5 E	Iturup	8.2
1960 May[5]	22	19	11	41 S	73.5 W	Chile	8.5
1963 Oct.[6]	13	05	18	43.8 N	150.0 E	Iturup	8.1
1964 March[7]	28	03	36	61.1 N	147.6 W	Alaska	8.5
1965 Feb.	4	05	01	51.3 N	178.6 E	Aleutian	7.8

2) CENTRAL METEOROLOGICAL OBSERVATORY, "Report of the Investigation on the Kamchatka Earthquake," *Quart. J. Seism.*, **18** (1953), 1, (in Japanese).

3) R. TAKAHASI and K. HIRANO, "On the Aleutian Tsunami of March 10, 1957, as Observed along the Coast of Japan," Monthly Meeting of ERI, March 1957.

4) JAPAN METEOROLOGICAL AGENCY, "The Etorofu-oki Earthquake of November 7, 1958," *Quat. J. Seism.*, **24** (1959), 65, (in Japanese).

5) COMM. FIELD INVEST. CHILEAN TSUNAMI, *The Chilean Tsunami of May 24, 1960*, (1961).

6) T. HATORI and R. TAKAHASI, "On the Iturup Tsunami of Oct. 13, 1963, as Observed along the Coast of Japan," *Bull. Earthq. Res. Inst.*, **42** (1964), 543.

7) T. HATORI, "On the Alaska Tsunami of March 28, 1964, as Observed along the Coast of Japan," *Bull. Earthq. Res. Inst.*, **43** (1965), 399.

of Japan has suffered only small damage. Tsunamis originated in these regions occur frequently, so that the characteristics of the distant tsunamis must be made clear for coastal industry to take proper precautions against tsunamis.

The distributions of crest-height along the Pacific coast of Japan are indicated for seven tsunamis that occurred in regions from the Kurile Islands to Alaska and in Chile as shown in Table 1. The distribution of tsunami energy along the Pacific coast of Japan obtained from the data for the distant tsunamis is compared with that for the near tsunamis.

Refraction diagrams of the wave front for each tsunami are drawn in the sea adjacent to Japan with the aid of arrival times of the wave front registered by tide-gauges.

Distribution of crest-height

Estimated crest-heights of distant tsunamis on the unit length (83 km) of 200 m depth contour are shown in Fig. 2 which follows the same method as R. Takahasi's for the near tsunamis.

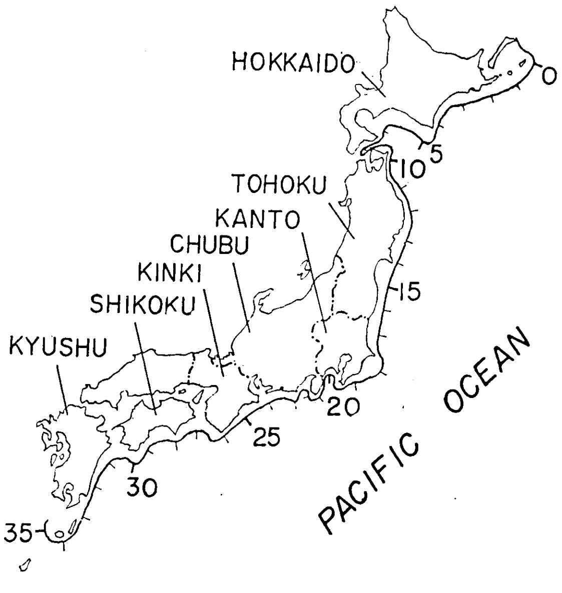

Fig. 2. Unit length (83 km) of 200 m depth line.

Fig. 3 shows the distributions of crest-height (cm) above the ordinary tidal level, where the solid and the hollow circles are for the initial wave

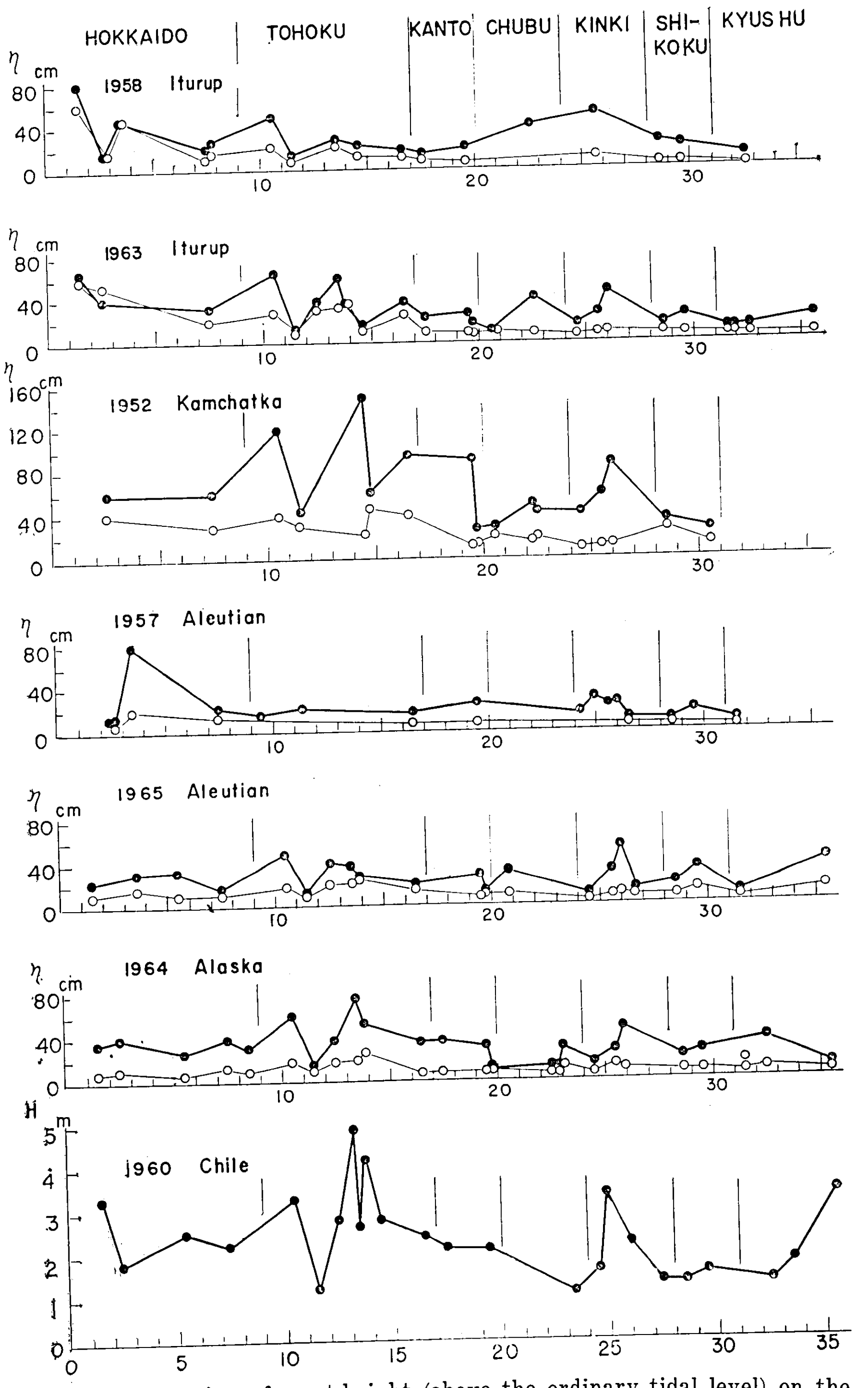

Fig. 3. Distribution of crest-height (above the ordinary tidal level) on the coast of Japan. Numerals on the abscissa correspond to the serial numbers in Fig. 2.
● : Maximum wave, ○ : Initial wave.

and the maximum wave respectively. On the basis of theory the distribution of the initial crest-height is expected to be inversely proportional to the square root of the distance of propagation. The observed crest-height, however, increases locally as a result of the amplifying effect of the coast, and the wave-height at Sanriku (Tohoku district) and Kishu (Kinki district) is higher than in other regions for every distant tsunami.

For the 1960 Chile tsunami shown in Fig. 3, the wave-heights (above M.S.L.) at Sanriku, Kishu and Amami-Ōshima (Kyushu) are conspicuously high. The reason may be sought in oscillational characteristics of the bay and also the refractive effect of the broad submarine topography outside of the region. H. Watanabe[8] and T. Hatori[9] discussed oscillational characteristics of the bay at Sanriku and other places.

For every distant tsunami, Fig. 4 shows the relation between crest-height ratio η/η_0 and the period T of maximum wave at various stations,

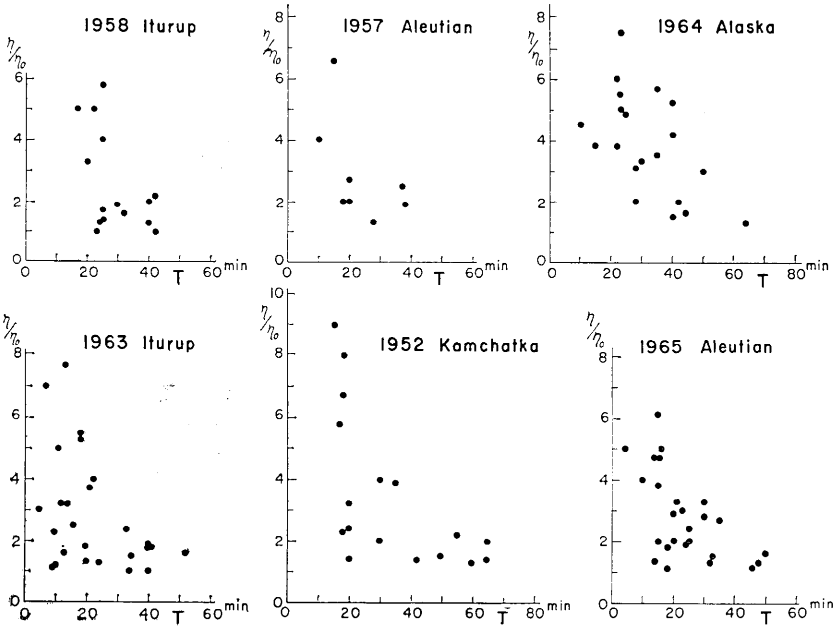

Fig. 4. The relation between crest-height ratios (η: Maximum wave, η_0: Initial wave) and period of the maximum wave.

8) H. WATANABE, "Studies on the Tsunamis on the Sanriku Coast of Northeastern Honshu in Japan," *Geophys. Mag.*, **32** (1964), 1.

9) T. HATORI, "On the Propagation of Chilean Tsunami of 1960 in the Adjacent Sea of Japan," *Rep. Chilean Tsunami, Field Invest. Comm. Chilean Tsunami* (1961), 103, (in Japanese).

where the initial and the maximum crest-heights are denoted by η_0 and η respectively. The period of the wave which has the maximum wave-height roughly coincides with one of the seiche periods of the bay. In Fig. 4, it can be seen that the ratio η/η_0 is large when the seiche periods of the bay are 20 min or less. Although the seiche period is 40 min at Ōfunato Bay in the Sanriku district, the wave-height is higher than other regions for every distant tsunami but the initial wave-height is also high. From the distribution of the initial crest-height, the height at Sanriku coast can be seen as higher than other regions for every distant tsunami as shown in Fig. 3.

Distribution of the tsunami energy

For near tsunamis, R. Takahasi calculated the distribution of tsunami energy passing through a unit length (83 km) of 200 m depth contour (see Fig. 2) by the following formula:

$$\int_Q \phi(Q)D(P, Q)dS\ ,$$

where a quantity of energy $\phi(Q)dS$ is emitted uniformly in all directions from an area dS around a tsunami source Q within the next 100 years, and $D(P, Q)$ represents the distribution function of energy at P from the source Q, and its numerical value can be obtained graphically from refraction diagrams. Calculated values obtained with the data of historical tsunamis are shown in above figure of Fig. 5.

On the basis of the crest-height distribution for the distant tsunamis shown in Fig. 3, the sum of square of the maximum crest-height $\sum\eta^2$ is shown in the lower figure of Fig. 5. In this figure, A indicates the total of seven tsunamis, and B shows tsunamis which occurred in the regions from Iturup to Alaska only. The distribution of energy of the distant tsunamis is compared with that for near tsunamis in Fig. 5, which shows that the proportion of energy to be received at Tohoku and Kinki districts from the distant tsunamis is somewhat similar to the near tsunamis. The distribution of energy for near tsunamis has two peaks, because a tsunami occurs more frequently in sea adjacent to the Sanriku and the Kishu districts than in other regions.

It is noticed that these regions also receive more energy than other regions even for distant tsunamis. As an additional note it may be mentioned that for distant tsunamis, the wave-height at Amami-Ōshima

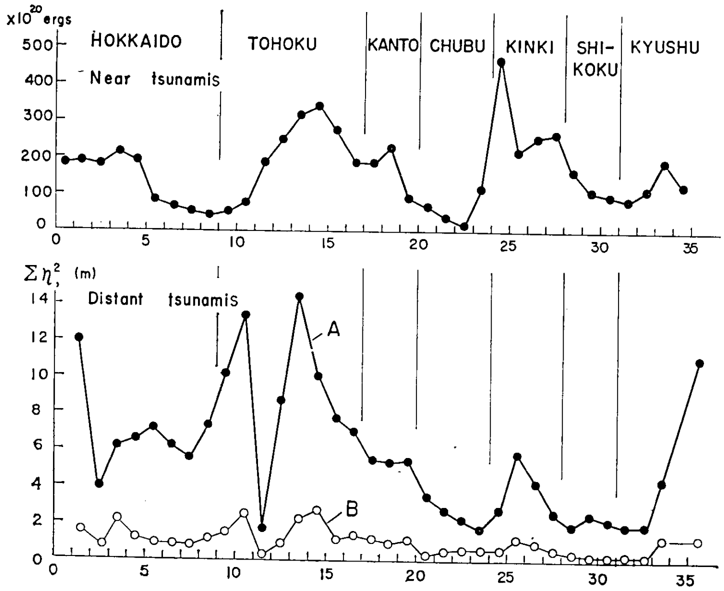

Fig. 5. Comparison of distribution of tsunami energy on the coast of Japan between the near tsunamis and the distant tsunamis.

was very often high, and the height at Miyako was low in spite of the fact that this station is situated in Sanriku region.

Thus the degree of danger for the distant tsunamis in the Sanriku district is always large, similar to the cases of near tsunamis. The danger of tsunami in these coasts seems to be mostly governed by geographical conditions, concentration of the energy due to the path of propagation, together with amplifying effect of the coast.

Refraction diagrams

To predict the wave-height along the coast of Japan due to a distant tsunami from the knowledge of earthquake magnitude and the location of tsunami source is rather difficult in practice and the information as shown in Fig. 3 will be of great help to estimate the wave-height for future tsunamis.

For the ordinary method of drawing the travel time of wave front along the coast of Japan for distant tsunamis, the uncertainty of time is about 10 min or more in comparison with the observation because of the limitation of accuracy in making a refraction diagram. Figs. 6. (a)

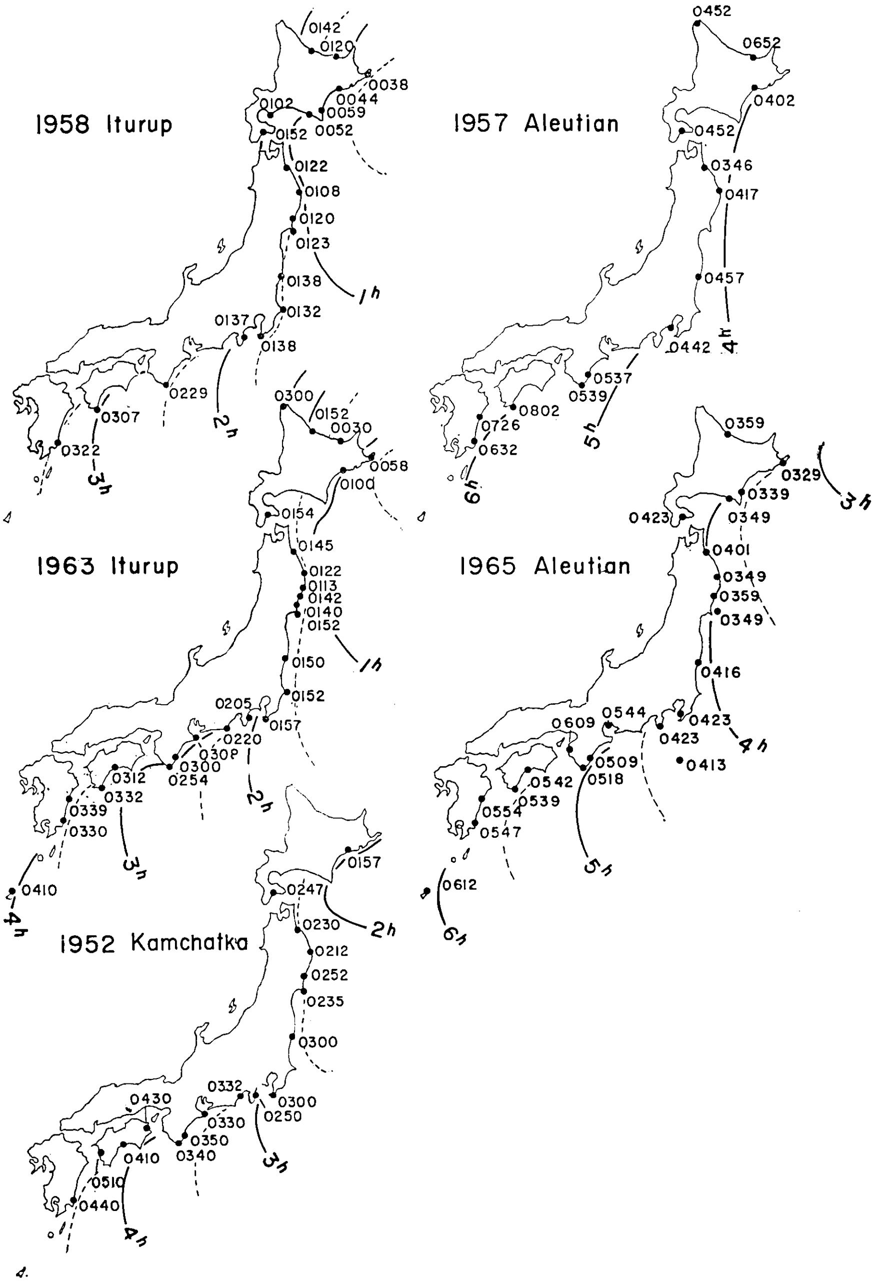

Fig. 6 (a). Refraction diagrams obtained from the arrival times of wave fronts. Arabic numerals indicate travel time (h, m).

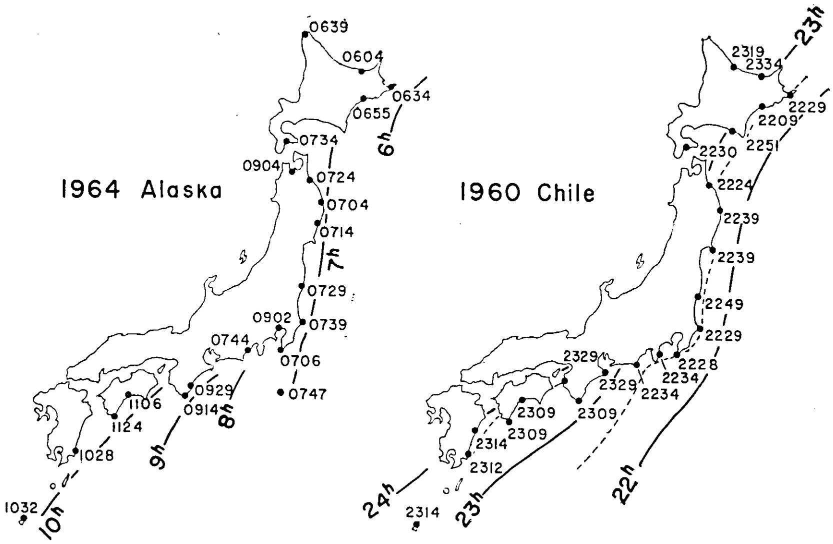

Fig. 6 (b). Refraction diagrams for the cases of the 1964 Alaska and the 1960 Chilean tsunamis.

and (b) show the refraction diagrams obtained from the arrival times of wave fronts, in which the travel time is indicated. The initial wave front arrived at the coast of East Hokkaido first, and then propagated along the Sanriku district 30 mins later, and took about 1h 20 mins from Sanriku to Kishu in Fig. 6.

The author believes that the refraction diagrams in the sea adjacent to Japan for distant tsunamis will be useful to estimate the propagation of future tsunamis.

32. 日本太平洋沿岸における遠地津波の効果
第1報　津波エネルギーの分布および伝播時間

地震研究所　羽鳥徳太郎

日本に伝播した7個の遠地津波 (浪源: Iturup, Kamchatka, Aleutian, Alaska および Chile) について，日本太平洋沿岸に沿つた 200 m 等深線上に津波エネルギー分布を求め，高橋 (1951) が示した近地津波の総エネルギー分布と比較したとき，かなり傾向が相似し，三陸および紀州地域が受ける津波エネルギーの割合が他地域に比して大きい．

湾の周期特性と，湾口と湾奥の波高増幅度との関係について，渡辺 (1964) は 1933 年の三陸津波と 1960 年のチリ津波との相異を理論的に説明したが，概して遠地津波の場合，一観測点における最高波と第1波の波高比，すなわち波高の増幅度は，短周期のセイシュを持つ湾程，大きい．遠地津波に際し，しばしば三陸沿岸地域の波高が他地域に比し高いのは，沿岸効果による波高増幅以外に，地理的条件による津波エネルギーの集中に原因するものと思われる．

検潮記録を用い第1波の到達時間を基に，沿岸付近における遠地津波の伝播図を作図した．また各津波の波高分布から (Fig. 3 の波高は，最高波を黒丸で，第1波を白丸で示し，いずれも平常の潮位からの片振幅 cm で表わす．また横軸の数字は Fig. 2 に示した 200m 等深線上を 83 km 毎に分割した地域に対応する.) 将来これら地域に発生する津波に対して，波高および伝播時間の推定に役立つことと思う．