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31. *Wave Magnitudes of the Kurile-Kamchatka Tsunamis —Tsunami Effect in Japan.*

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Abstract

Based on tide-gauge records of Japan and other far-field data, the magnitudes of the Kurile-Kamchatka tsunamis during the past 77 years (1904-1980) are investigated. The features of a few tsunamis differ greatly. For example, the Kamchatka tsunami of Apr. 13, 1923 and the Kurile tsunami of Oct. 20, 1963 which accompanied earthquakes with magnitudes of M=7.2-7.3 inundated the coastal areas near the tsunami source 10-20 meters. According to the author's method based on the attenuation of wave-height with distance, the magnitudes (Imamura-Iida scale, m) of these tsunamis are estimated to be m=2.5 and 2 respectively. The magnitudes of several tsunamis judged from the near-field and far-field data were a little different.

At the Hokkaido and Sanriku coasts, North Japan, the wave-heights (above ordinary tides) for the Kurile tsunamis with m=2.5-3 were 1.0-1.5 meters and 0.5 meters respectively. However, the distribution of the wave-heights for the Kamchatka tsunami was different. The wave-heights on the Sanriku coast were greater than those on Hokkaido. The great 1952 Kamchatka tsunami (m=4) inundated the Sanriku coast 2-3 meters. The wave-heights increased especially in the bays with the seiche of 43 min and 20 min.

In the map of the source distribution, a tsunami (seismic) gap of 400-500 km exists along the trench in the North Kurile and West Aleutian Islands regions. In order to predict the travel times of tsunami along the Kurile and Japanese coasts, the refraction diagrams of two imaginary sources are drawn.

1. Introduction

As is well known seismicity in the Kurile-Kamchatka region is the most active in the world and many tsunamis are generated. These tsunamis are often observed by the tidal stations of Japan. The Sanriku coast, northeastern Japan, was suffered severely damaged by the great

1952 Kamchatka tsunami (CENTRAL METEOROLOGICAL OBSERVATORY, 1953). The documents of the Kurile-Kamchatka tsunamis were summarized by SOLOVIEV (1978). Most of the tsunami source areas were estimated on the basis of the tsunami and seismic data (FEDOTOV, 1962; SOLOVIEV, 1965; SOLOVIEV and GO, 1977; HATORI, 1971, 1979).

The focal mechanisms of tsunamigenic earthquakes in the Kurile-

Table 1. List of Kurile-Kamchatka tsunamis (1904-1980).

Date	Location	*M*	*m*	Maximum height
1904 June 25	Kamchatka	8.1	1	
1918 Sept. 7	Urup	8.2	3	Urup I. 12 m
1918 Nov. 8	〃	7.5	2?	
1923 Feb. 3	Kamchatka	8.3	3	Kolegir 6-8 m
1923 Apr. 13	〃	7.2	2.5	Ust'-Kamchatka 20-30 m
1927 Dec. 28	〃	7.3	0	
1933 Jan. 8	N. Kurile		2?	Kharimkotan I. 9 m
1936 Nov. 13	Kamchatka	7.2	2?	Ust'-Kamchatka 13 m
1952 Nov. 4	〃	8.3	4	Paramushir I. 14-20 m
1953 Mar. 17	N. Kurile	6.3?	1	Paramushir I. 3 m
1958 Nov. 6	Iturup	8.1	2	Shikotan I. 4-5 m
1958 Nov. 12	〃	7.5	−1?	Yuzhno-Kurilsk 8 cm
1959 May 4	Kamchatka	7.5	1	Morzhovaya 1.5-2 m
1961 Feb. 12	Shikotan	7.2	−0.5	Shikotan I. 0.5-1 m
1963 Oct. 12	Urup	7.2	−2	Iturup I. 20 cm
1963 Oct. 13	〃	8.2	2.5	Urup I. 4-5 m
1963 Oct. 20	〃	7.3	2	Urup I. 10-15 m
1964 July 24	Simushir	7	−2	Matua I. 15 cm
1965 June 11	Iturup	7.2	−3	Burevestnik 5 cm
1968 Jan. 29	Shikotan	6.9	**0**	Yuzhno-Kurilsk 13 cm
1969 Aug. 11	〃	7.8	2	Shikotan I. 4-5 m
1969 Nov. 22	Kamchatka	7.7	**1.5**	Olikhavaya 10-15 m
1971 Dec. 15	〃	7.8	0	Ust'-Kamchatka 45 cm
1973 Feb. 28	Shumushu	7.5	0.5	Kozurevck 1.5 m
1973 June 17	Nemuro-oki	7.4	**1.5**	Hamanaka 4-4.5 m
1973 June 24	〃	7.1	**0.5**	Hanasaki 63 cm
1974 Sept. 27	〃	6.7	−2	Hanasaki 18 cm
1975 June 10	Shikotan	7.0	**1.5**	Shikotan I. 5.5 m
1976 Jan. 21	Iturup	7.0	**0**	Burevestnik 18 cm
1978 Mar. 23	〃	7.0	**0**	Hiroo 14 cm
1978 Mar. 25	〃	7.3	**1**	Hanasaki 24 cm
1980 Feb. 23	Shikotan	6.8	**0**	Hanasaki 18 cm

M: Earthquake magnitude. *m*: Tsunami magnitude (Imamura-Iida's scale).
Gothic type: Tsunami magnitudes which were estimated by author's method using far-field data.

Kamchatka region have been analysed using the seismic records of P-waves and long-period surface-waves. Many earthquakes in this region have been caused by low-angle thrust faulting. In some cases, however, low-frequency earthquakes, the so-called "tsunami earthquake" (KANAMORI, 1972) occurred. For example, the tsunamis associated with the Kurile earthquakes on Nov. 20, 1963 and June 10, 1975 were very large for their earthquake magnitude. These focal mechanisms were explained by the low-frequency earthquake (TAKEMURA et al., 1977; NAGAMUNE and CHIUREI, 1976) and a high-angle thrust faulting (FUKAO, 1979).

As pointed out by many investigators (e.g., KELLEHER et al., 1973; FEDOTOV, 1980), remarkable seismic gaps can be seen in the segment of 400–500 km at the North Kurile and West Aleutian regions. Seismic activity in these regions is relatively low, but a moderate tsunami (magnitude of Imamura-Iida scale, $m=2$) was generated off the Komandorski Island in 1849 (SOLOVIEV and GO, 1977; GUCEV et al., 1975).

In the present paper, magnitudes of the Kurile-Kamchatka tsunamis

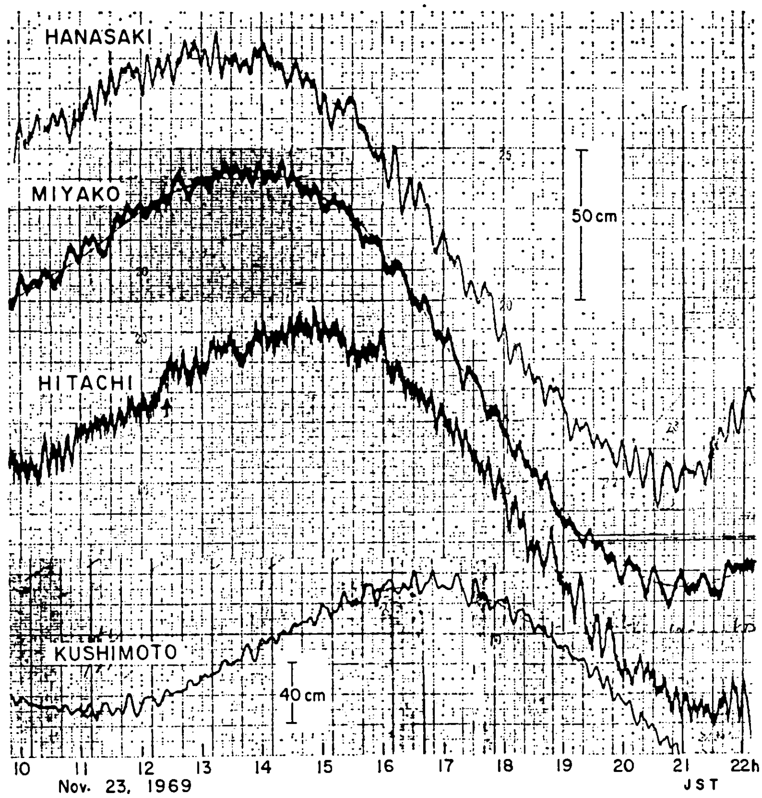

Fig. 1. Tide gauge records of the Kamchatka tsunami on Nov. 22, 1969 observed at the tide stations of Japan.

from 1904 to 1980 are examined by using the tidal records of Japan and other far-field data. From the hypothetical tsunami sources in the siesmic gaps, the refraction diagrams were drawn. The travel times along the Japanese coast were investigated. And the behavior of the 1952 Kamchatka tsunami at the Sanriku coast was reexamined.

2. Tsunami data

From the tsunami catalogue in the Kurile-Kamchatka region (SOLOVIEV, 1978) adding the new data, the maximum heights for each tsunami are listed in Table 1. Here the tidal records of two Kurile-Kamchatka tsunamis obtained from the Japan Meteorological Agency are shown in Figs. 1 and 2. The Kamchatka tsunami of Nov. 22, 1969 which accompanied the earthquake of $M=7.7$ hit the North Kamchatka coast with inundation heights of 10-15 meters (FEDOTOV et al., 1973), but the tsunami heights

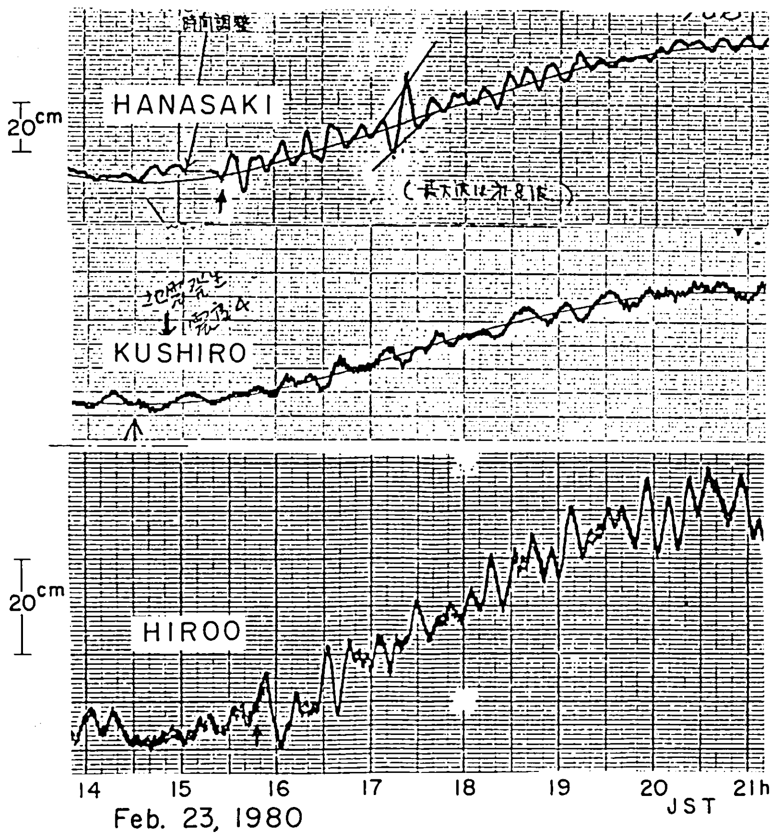

Fig. 2. Tide gauge records of the Kurile tsunami on Feb. 23, 1980 observed in Hokkaido.

on the Japanese coast were a very small. The Kurile tsunami of Feb. 23, 1980 generated off Shikotan Is. was observed with a small amplitude of 15-20 cm at Hokkaido.

Based on the tsunami and aftershock data (SOLOVIEV, 1965; SOLOVIEV

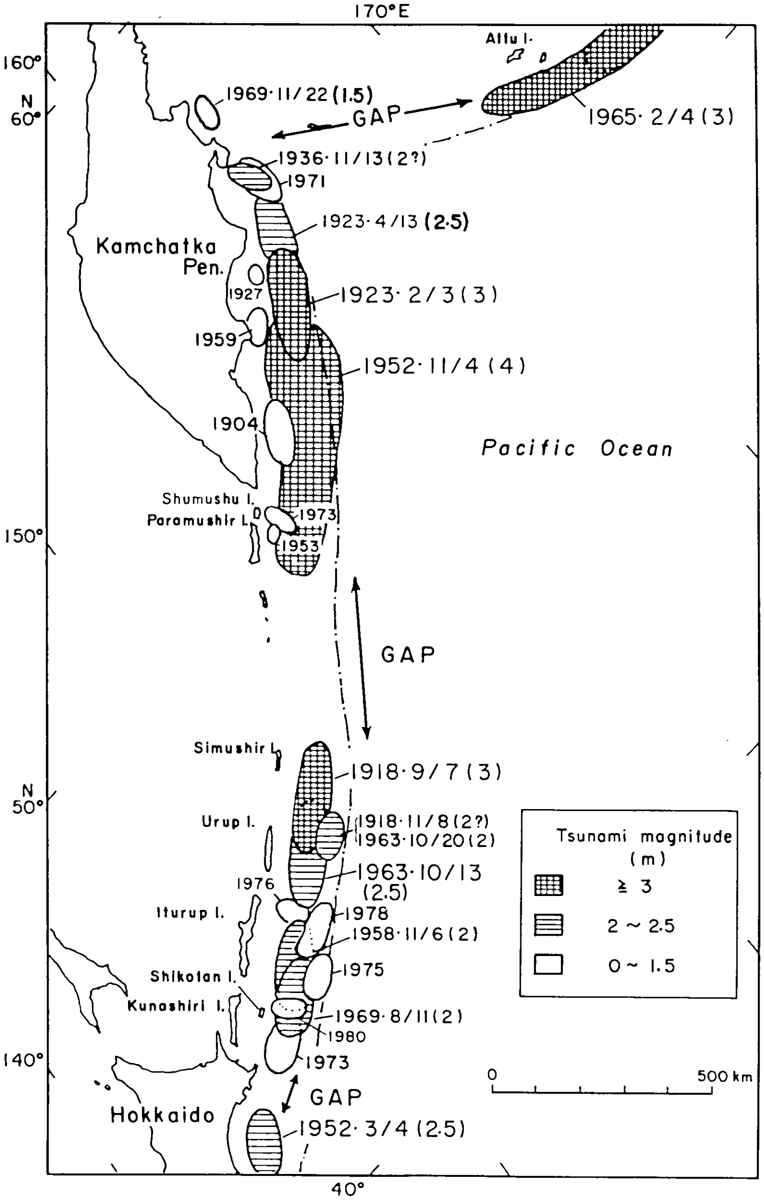

Fig. 3. Geographic distribution of the source areas of the Kurile-Kamchatka tsunamis from 1904 to 1980. Dates and tsunami magnitudes (Imamura-Iida scale, m) are indicated.

and GO, 1977; FEDOTOV, 1962; FEDOTOV et al., 1980; GUCEV et al., 1975; HATORI, 1971, 1979, 1981), the source areas of the Kurile-Kamchatka tsunamis from 1904 to 1980 are compiled in Fig. 3, where a chain line indicates the trench axis. The tsunami magnitudes of Imamura-Iida scale, m, are shown in the parentheses, and the source areas of small tsunami $m<0$, are omitted. In the geographic distribution of the tsunami sources, a remarkable tsunami (seismic) gap of 400–500 km exists along the trench. There is also a small gap in the Hokkaido region. Distribution of the source areas in the Kurile region is different from that in the Kamchatka region. The sources of small tsunamis are mixed with those of large tsunamis along the trench. In the Kamchatka region, however, the areas of small tsunamis mostly lie below a bathymetric contours of 2,000 m in the shallow sea and those of large tsunamis on the continental slope near the trench.

3. Tsunami magnitude

Using the author's method (HATORI, 1979), which is based on the attenuation of wave-height with distance from the epicenter, the tsunami magnitude of the Imamura-Iida scale, m, is determined in Fig. 4. The wave-heights are the half-amplitude of the maximum wave above the

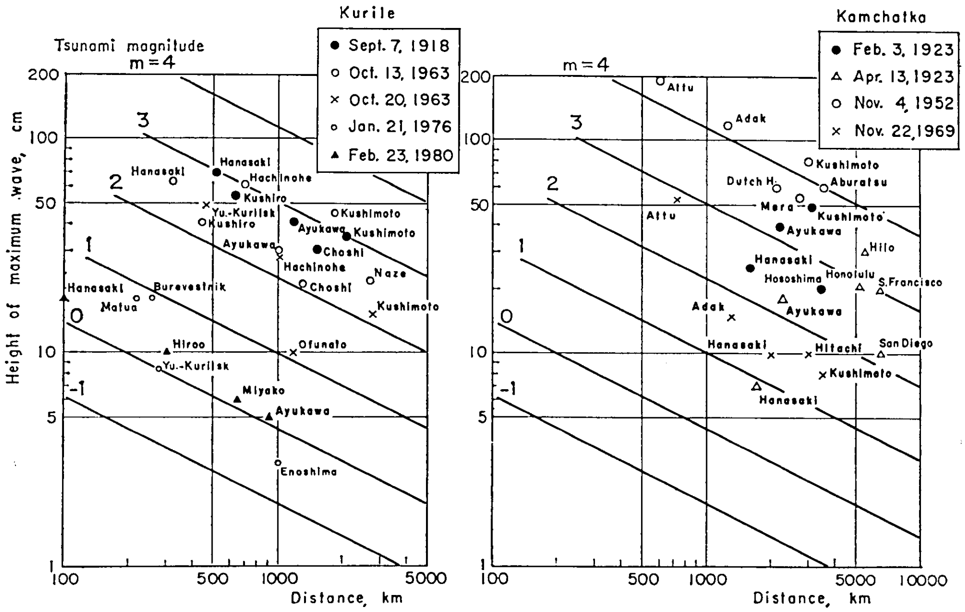

Fig. 4. Attenuation of the maximum wave-height (semi-amplitude) with distance from the epicenter. m: Tsunami magnitude denoted by the Imamura-Iida scale.

ordinary tidal level on the records. The tsunami magnitudes estimated by the present method are given with the gothic type in Table 1.

In the Kurile region, the Urup tsunami of Sept. 7, 1918 was the largest with a magnitude was $m=3$. For the Urup tsunami of Oct. 20, 1963, inundation heights of 10–15 meters were surveyed at Urup Island (SOLOVIEV, 1965a, b). The local inundation heights were similar to the 1918 tsunami, but the tsunami magnitude is estimated as $m=2$. The wave-heights were suddenly reduced at the far-field stations. The magnitude of the Shikotan tsunami of Feb. 23, 1980 is determined to be $m=0$.

In the Kamchatka region, the magnitudes of the tsunamis on Feb. 3, 1923 and Nov. 4, 1952 are determined to be $m=3$ and 4, respectively. At the tsunami of Apr. 13, 1923, which accompanied an earthquake of $M=7.2$, the inundation height at Ust'-Kamchatka reached 20–30 meters. This tsunami was also observed in California, Hawaii and Japan (SOLOVIEV, 1978; IMAMURA and MORIYA, 1939). Data points in Fig. 4 are widely scattered because of topographic effects such as the direction of the island

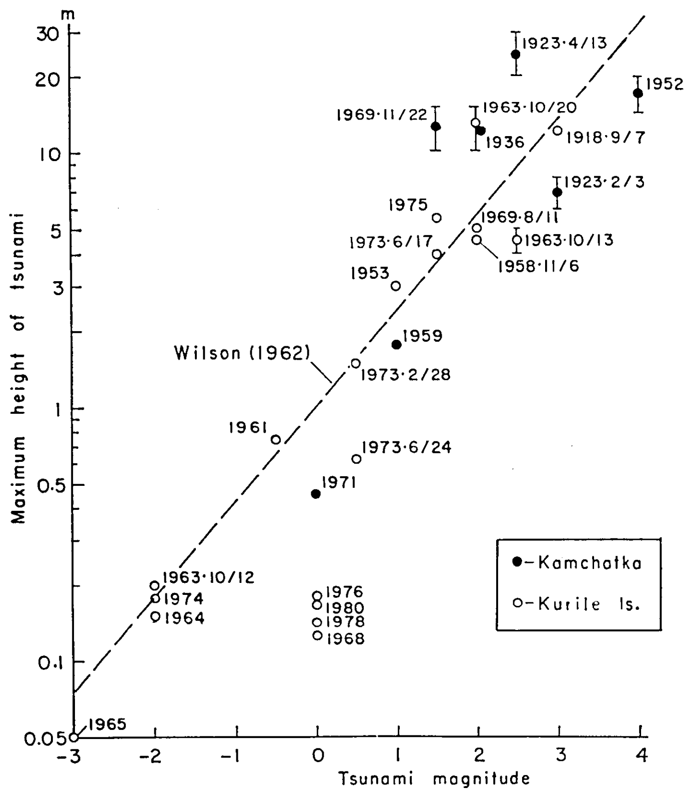

Fig. 5. Relation between tsunami magnitude (Imamura-Iida scale) and maximum height of the Kurile-Kamchatka tsunamis.

arc, shoaling, etc. On the average, the tsunami magnitude is estimated to be $m=2.5$. As shown in Fig. 1, the tsunami of Nov. 22, 1969 was observed with small amplitude at the Japanese coast. The magnitude of the 1969 Kamchatka tsunami seems to be $m=1.5$.

Figure 5 shows the relation between the tsunami magnitude and maximum height of the tsunamis, h_{max}. The formula, $0.375\,m=\log_{10} h_{max}$, corresponds to the Imamura-Iida's scale shown with a broken line (WILSON, 1962). The inundation heights of tsunamis on Apr. 13, 1923 (Kamchatka),

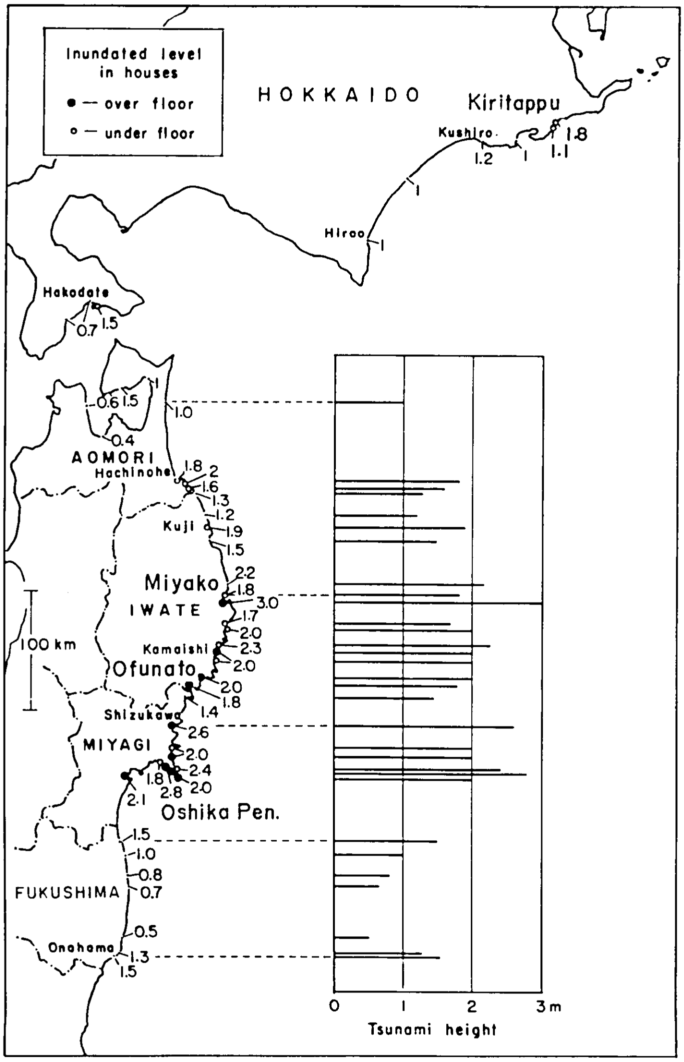

Fig. 6. Distribution of inundation heights (above M. S. L., unit: meter) of the 1952 Kamchatka tsunami.

Oct. 20, 1963 (Kurile) and Nov. 22, 1969 (Kamchatka) reached 10–15 meters in local coastal areas near the source. However, Jundging from the far-field data, the tsunami magnitudes are determined to be $m=1.5$ to 2.5. These tsunamis were generated by earthquakes with magnitudes of $M=$ 7.2 to 7.7. In contrast to the magnitude, the wave-heights of the Kurile tsunamis in 1968, 1976, 1978 and 1980 were very small, because the near-field data was no available.

4. Tsunami behavior in Japan

Since 1918, many Kurile-Kamchatka tsunamis were observed at the Japanese tidal stations. Wave-heights (above ordinary tides) for the 1958 Iturup, 1963 Urup and 1969 Shikotan tsunamis were 1.0–1.5 meters in East Hokkaido and 0.5 meters on the Sanriku coast (HATORI, 1970). The wave-heights for the Urup tsunami on Sept. 7, 1918 were a little high on the Hokkaido coast, and the largest height of 270 cm (double amplitude) was observed at the tidal station of Chichijima, Ogasawara (Bonin) Islands (NAKAMURA, 1918) and 12 houses at Okumura village were inundated. According to the refraction diagram of the 1963 Urup (Iturup) tsunami, wave energy concentrated in the neighborhood of Ogasawara Islands (HATORI and TAKAHASI, 1964).

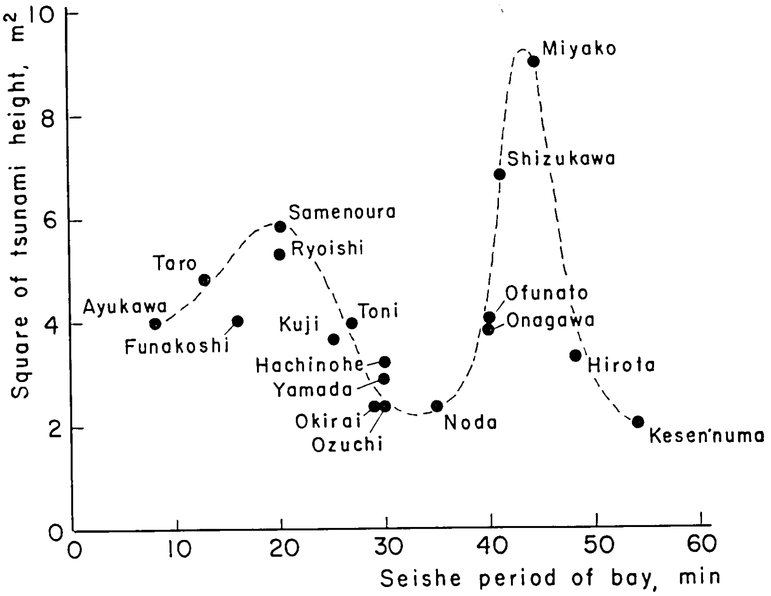

Fig. 7. Relation between the seiche period of bays in the Sanriku region and the square of wave-height of the 1952 Kamchatka tsunami.

From the report of field investigation for the 1952 Kamchatka tsunami (CENTRAL METEOROLOGICAL OBSERVATORY, 1953), the inundation heights (above M. S. L.) in northeastern Japan are shown in Fig. 6. The heights on the Sanriku coast are greater than those on Hokkaido. The tsunami overflowed the land 1.5 meters and the floors many houses were inundated 2.0 meters or more. On the spectral analyses of the tidal records for the 1952 Kamchatka tsunami, the long-period waves of 40 min or more were found (TAKAHASI and AIDA, 1963). Figure 7 shows the

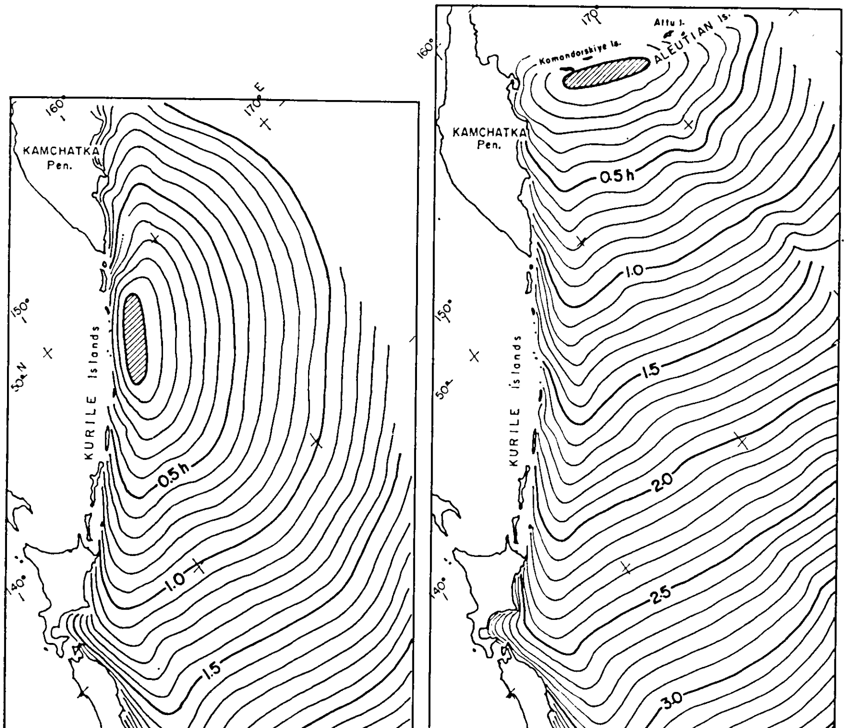

Fig. 8. Refraction diagrams of the imaginary tsunami sources in the North Kurile and West Aleution Is. regions. Time interval: 5 min.

relation between the seiche periods in bays on the Sanriku coast and the square of tsunami height. It can be seen that the two peaks fall in those bays whose seiche periods are 43 min and 20 min. The response of the bay seiche had a strong resemblance to those of the 1960 Chile tsunami.

Assuming two tsunami sources in the seismic gaps of the North Kurile and West Aleutian regions, the refraction diagrams of the imaginary sources are shown in Fig. 8, where either source length took 400 km. Although the travel times in North Japan for the 1952 Kamchatka tsunami took 2.5 hours (HATORI, 1965), those for the North Kurile tsunami are 1.5 hours and 3.0 hours for the West Aleutian tsunami. In North Japan, the wave fronts for the two tsunami sources are approximately parallel to each other. Taking the effect of directivity into account, the West Aleutian tsunami may be directly propagated into North Japan.

5. Conclusion

The magnitude of the Kurile-Kamchatka tsunamis during the past 77 years were investigated, using tide-gauge records obtained in the far-field stations. The features of each tsunami differ greatly. The tsunamis on Apr. 13, 1923 (Kamchatka), Oct. 20, 1963 (Kurile) and Nov. 22, 1969 (Kamchatka) inundated 10–15 meters in coastal areas near the source, but these tsunami magnitudes are estimated to be m=1.5-2.5 on the amplitude-distance diagrams. The tsunamis on Apr. 13, 1923, Oct. 20, 1963 and June 10, 1975 (Kurile) were generated by earthquakes with the magnitudes of M=7.0–7.3, but the tsunami magnitude were relatively large.

The North Kurile and West Aleutian regions have had low seismic activity since historic times. Two seismic (tsunami) gaps can be seen in the segment of 400–500 km along the trench. On the refraction diagrams of the hypothetical tsunami sources, the travel times in North Japan are 1.5 hours for the North Kurile source and 3.0 hours for the West Aleutian source. Future tsunamigenic earthquakes with magnitudes of $M \geqq 8$ occurring in the Kurile and West Aleutian regions should be watched.

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31. 千島・カムチャツカ津波の規模
—日本沿岸における津波挙動—

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1900年以降の80数年の間に，千島・カムチャツカ沖でおきた津波は，日本沿岸各地でしばしば観測され，ときには北海道・三陸や小笠原諸島に被害をもたらした．ことに1952年11月のカムチャツカ津波では，三陸沿岸で 2〜3 m の波高（平均海水面上）に達し，沿岸水産施設の災害のほか家屋の浸水被害もあって，遠地津波の挙動に注目を集めた最初の津波である．

これらの津波規模を日本の検潮記録をはじめ，遠隔地で得られた波高データから，筆者の方法で検討を加えた．1975年6月の色丹島沖地震（$M=7.0$）で予想をこえる大きい津波を記録したが，そのほかに異常な津波が 2〜3 ある．例えば，1923年4月のカムチャツカ，1963年10月20日のウルップ津波は局地的に 10〜15 m の波高に達したが，広域の波高データから津波のマグニチュード（今村・飯田スケール）は，$m=2.0\sim2.5$ と推定される．それにしても地震の規模（$M=7.2\sim7.3$）に対して，津波は異常に大きい．

Fedotov, Soloviev, 羽鳥の解析データから，千島・カムチャツカ地域における波源域の分布を示した．多くの地震学者が指摘しているように，千島北部とアリューシャン列島西部に 400〜500 km にわたる広域に，地震空白域が認められる．

両地域に長さ 400 km の津波の波源を想定して，伝播図を作図してみた．それによると，三陸沿岸の伝播時間は千島北部からのものが 1.5 時間，アリューシャン西部からでは 3.0 時間になる．そして三陸沿岸には，波面はいずれも同じような向きになった．津波の指向性を考えれば，アリューシャン西部からの津波は，波源の短軸方向から伝播することから，三陸沿岸では千島北部のものより波高は大きくなるであろう．1952年カムチャツカ津波の挙動からみて，津波エネルギーは北海道よりむしろ三陸沿岸に集まる．また，波源の長さが 400 km にもなれば，港湾のセイシュ周期40〜45分の大型湾に顕著な波高の増幅がおこされよう．