BULLETIN OF THE EARTHQUAKE
RESEARCH INSTITUTE
Vol. 42 (1964), pp. 543-554

28. *On the Iturup Tsunami of Oct. 13, 1963, as Observed along the Coast of Japan.*

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(Read Feb. 25, 1964.—Received July 31, 1964.)

Abstract

The tsunami which was generated off Iturup Island, Kuril Islands, at 14 h 18 m (JST), Oct. 13, 1963, was observed all along the Pacific coast of Japan. The double amplitude of the sea disturbance reached 1 m on the SE Hokkaido and Sanriku coasts. The epicenter of the earthquake was at 44.0°N, 150.0°E, depth 40 km and magnitude 7.9.

The tsunami energy distribution along the Pacific coast of Japan was calculated by drawing a refraction diagram, and was compared with the records of tide-gauges and tsunami recorders. It seems that the heights of the initial wave are well explained by this calculated energy distribution.

The time interval between the arrival of the initial wave and the maximum amplitude wave is proportional to the origin distance measured along the coast. This fact suggests that the tsunami waves are mostly edge waves which were propagated along continental shelves.

Dispersion curves obtained from the records of the 1958 and 1963 Iturup tsunamis coincide pretty well with the calculation for the case of a continental shelf with a width of 25 km and mean depth 200 m, bordering an ocean 2000 m deep.

Records of the 1958 and 1963 Iturup tsunamis are very similar in shape, especially in the earlier part of the record, suggesting a similarity of the source mechanisms, origin positions and the paths.

The appreciable phase change which was observed 8.5 hours after the earthquake might be explained as the reflected waves from the reef between East Caroline and Marshall Islands.

1. Introduction

At 14 h 18 m (JST), Oct. 13, 1963, there occurred a strong earthquake off the east coast of the Island of Iturup, the Kuril Islands. According to the Japan Meteorological Agency (JMA), the magnitude of the earthquake was 7.9, the depth 40 km and the epicenter at 44.0°N, 150.0°E. Accompanying this earthquake, a moderate tsunami was generated and observed all along the Pacific coast of Japan. The tsunami was propagated into the Sea of Okhotsk, too.

The epicenter of the present earthquake was situated in the Kuril seismic zone, which has generated many tsunamis in the past.[1] A fairly recent tsunamis occurred on Sept. 8, 1918 off the Urup I. and a more recent one on Nov. 7, 1958 off the Iturup I.[2),3)] in the southern Kuril Is. As compared with the 1958 tsunami, the present one demonstrated almost the same intensities at the tide-gauge stations on the Pacific coast of Japan. The travel-times were however 10～30 min longer than those of the 1958 tsunami.

In this paper, the propagation of the tsunami energy and the distribution of it along the coast of Japan have been studied. Tide-gauge records of the tsunami have been put to the authors' disposal by the courtesy of JMA, Japan Geographical Survey Institute and Japan Hydrographic Office, to add to the tsunami records obtained at Miyagi-Enoshima, Izu-Ōshima, Kanaya in Chiba prefecture and Miyazaki-Aoshima, the tsunami stations belonging to ERI. The problem of edge waves is discussed by analysing the records obtained at Miyagi-Enoshima.

2. Summary report on the tsunami observation along the coast of Japan.

The maximum range or double amplitude of the present tsunami was only of the order of 1 m even on the southeast coast of Hokkaido, which is the nearest Japan coast to the tsunami source. However, good records were obtained at every tidal station along the Pacific coast of Japan.

Features of the tsunami at different localities can be seen in Table 1. The initial motion of the tsunami is *up* everywhere. In Table 1, the crest-height above the level which the sea would have assumed at the arrival time of that crest, if there was no tsunami, has been defined

1) С. Л. Соловьев и М. Д. Ферчев, "Сводка Данных о Цунами в СССР," Бюлл. Совета по сейсмол. АН СССР, **9** (1961), 23.

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

3) В. Н. Аверьянова, С. А. Федотов и М. Д. Ферчев, "Предварительные Данные о Землетрясении и Цунами 6 Ноября 1958 г.," Бюлл. Совета по Сейсмол. АН СССР, **9** (1961), 89.

Table 1. The tsunami of Oct. 13, 1963, as recorded by tide-gauges and tsunami recorders.

Tide station	Initial wave		Maximum wave		τ
	Travel time	Height**	Height**	Period	
	h m	cm	cm	min	h m
Hanasaki	0 58	60	65	9	1 08
Kushiro	1 00	56	40	36	1 45
Abashiri	0 30	22	36	52	1 00
Monbetsu	1 52	20	26	20	2 00
Wakkanai	3 00	8	15	40	4 00
Hakodate	1 54	20	36	40	4 25
Hachinohe	1 45	26	63	33	3 30
Miyako	1 22	7	6	57	3 33
Kamaishi	1 13	30	38	24	5 20
Ōfunato	1 42	33	60	40	1 40
Enoshima*	1 32	13	12	34	3 55
Onagawa	1 40	35	35	40	3 10
Ayukawa	1 52	12	14	10	3 20
Onahama	1 50	23	37	13	7 18
Choshi	1 52	9	21	10	8 40
Mera	1 57	8	24	5	8 42
Kanaya*	2 02	6	9	35	5 20
Aburatsubo	2 02	5	16	14	6 10
Izu-Ōshima*	1 52	3			
Hachijo I.	2 10	4			
Ito	2 05	5	4	12	9 00
Omaezaki	2 20	6	42	7	9 00
Toba	3 08	3	16	18	10 20
Uragami	3 00	8	26	12	7 53
Kushimoto	2 54	6	46	13	9 18
Kōchi	3 12	8	14	20	9 20
Tosa-Shimizu	3 32	6	22	21	9 32
Hosojima	3 39	4	10	16	10 40
Aoshima*	3 28	2	10	11	8 36
Aburatsu	3 30	3	12	22	8 34
Naze	4 10	4	22	18	12 05

* Tsunami observatory.

** Crest-height above the level which the sea would have assumed if there were only ordinary tides.

τ Time interval between arrival of the wave front and the maximum wave crest.

as the wave-height of the tsunami wave. It can be seen that the period of the wave which has the maximum wave-height roughly coincides with one of the seiche periods of the bay.

Figs. 1 and 2 show the tsunami records obtained at Miyagi-Enoshima, Izu-Ōshima, Kanaya and Aoshima stations. Miyagi-Enoshima[4] and Izu-Ōshima[5] stations are permanent tsunami observatories belonging to the Earthquake Research Institute. Kanaya and Aoshima are temporary stations each equipped with a portable long-wave recorder. The records at Aoshima are mixed up with seiche oscillations of 11 min period. Fig. 1 shows the nature of records of two Iturup tsunamis both obtained by the Van Dorn long-wave recorder at Miyagi-Enoshima. (above: the present tsunami; below: the 1958 Iturup tsunami. Origins are very near to each other.)

It can been seen that several of the initial waves of the present tsunami are similar to those of the 1958 Iturup tsunami. This interesting feature seems to be due to similarities of the source position,

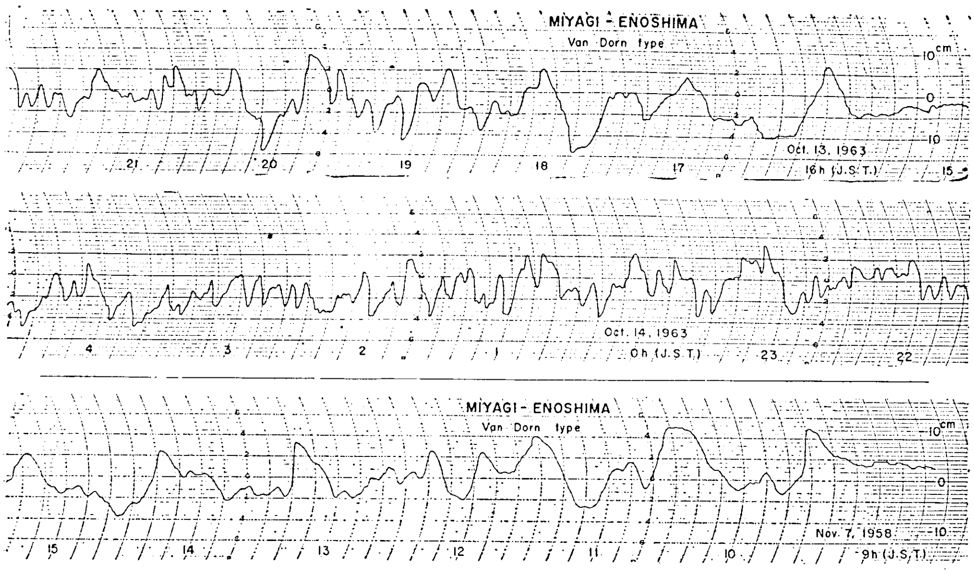

Fig. 1. Records of Iturup tsunami observed at Miyagi-Enoshima (above: the present tsunami; below: the 1958 Iturup tsunami).

4) R. TAKAHASI, *et al.*, Observations at Miyagi-Enoshima Tsunami Observatory during the IGY Period," *Bull. Earthq. Res. Inst.*, **39** (1961), 491.

5) R. TAKAHASI, and I. AIDA, "Spectral Analysis of Long-period Ocean Waves observed at Izu-Ōshima," *Bull. Earthq. Res. Inst.*, **40** (1962), 561, (in Japanese).

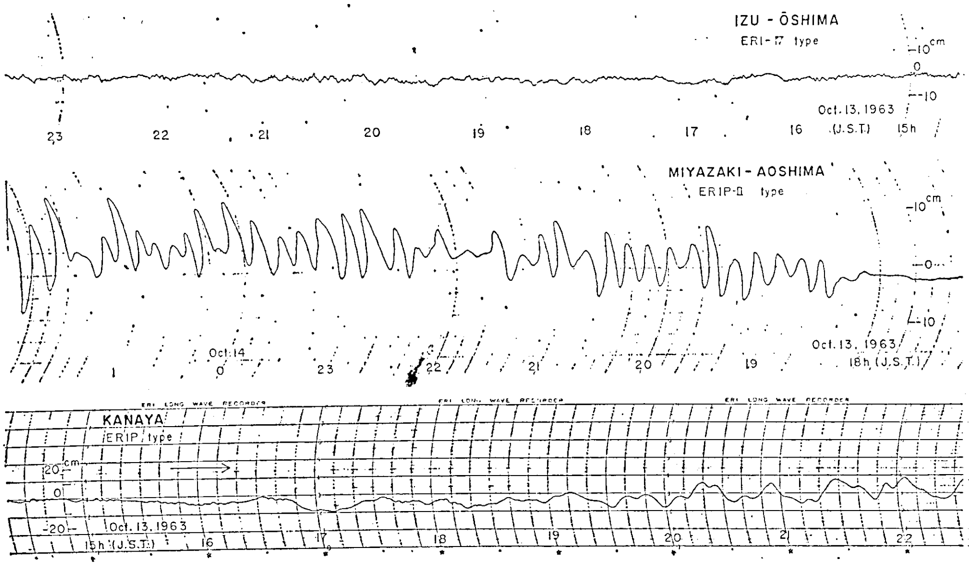

Fig. 2. Records of Iturup tsunami on Oct. 13, 1963, at different stations.

propagation route, and the mechanism of generation.

3. Distribution of the tsunami energy

In order to know how the tsunami energy is emitted from the source toward the Pacific coast of Japan, a refraction diagram was drawn as shown in Fig. 3.

The tsunami source being assumed at 44.0°N, 150.0°E, wave fronts have been drawn at every 3 minute intervals; in Fig. 3, however, only those for every 15 minute intervals are shown.

In the figure trajectories are drawn by broken curves. The azimuth at the origin was devided into twelve equal angles. These angles were again subdivided into equal parts when the interval between trajectories became widered as the wave was propagated. As shown in Fig. 3, the tsunami energy which reached the Pacific coast of Japan has been emitted into a narrow angle of only 2.5 degrees at the source. Moreover, this tsunami energy concentrates for the most part at the coast of southeast Hokkaido and the Sanriku district, as can be seen in the figure. In order to check the refraction diagram on the Izu-Mariana submarine ridge, another diagram was drawn by using a smoothed bathymetric chart in which only the mean depth is given for every one degree square mesh. The two refraction diagrams thus drawn did not

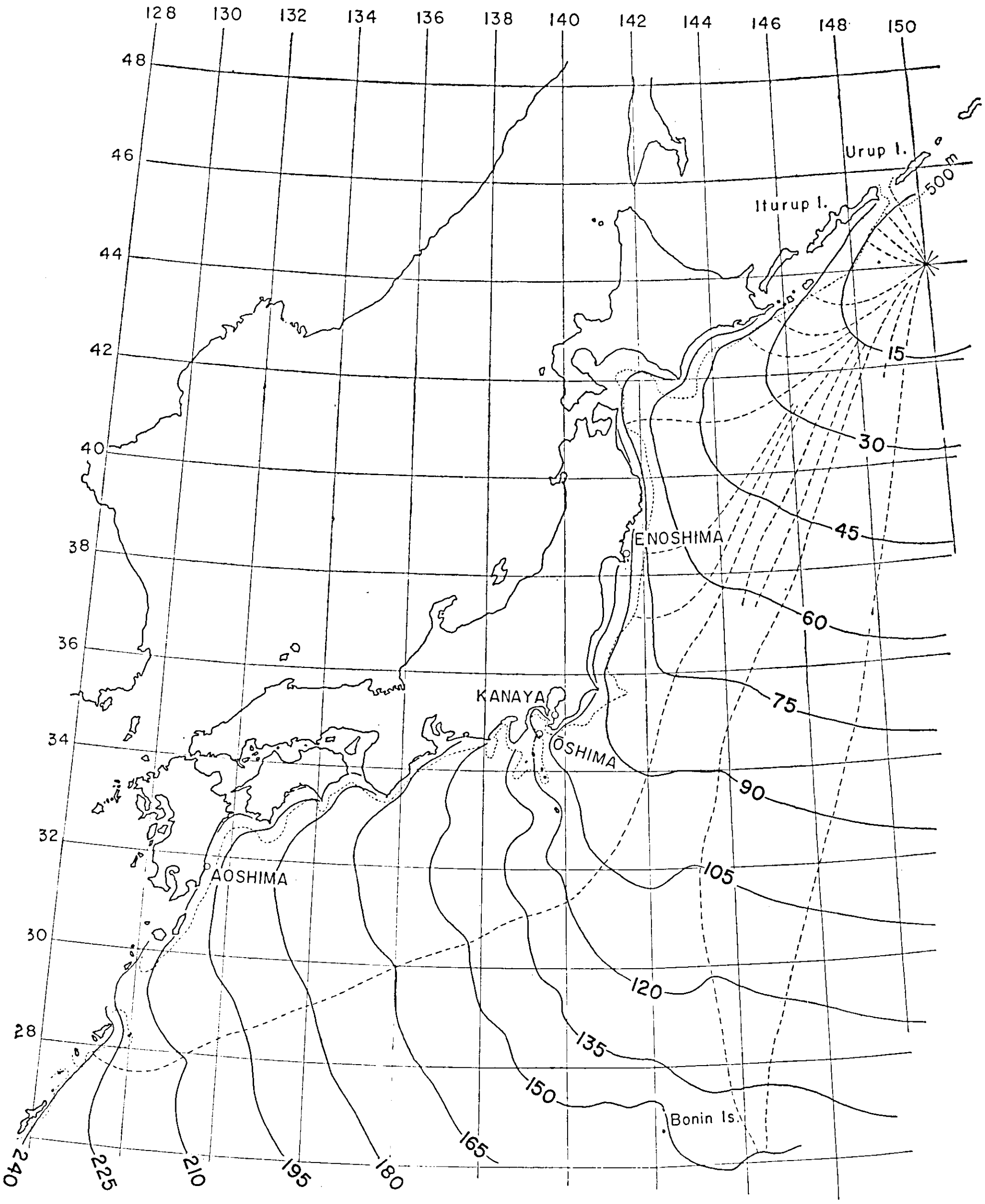

Fig. 3. Refraction diagram of wave fronts corresponding to every 15 min intervals.

show much difference.

In the case of the Urup tsunami of Sept. 8, 1918, A. Imamura and M. Moriya[6] reported that a wave-height of 280 cm (double amplitude) had been observed at Futami Bay in the Bonin (Ogasawara) Islands. A conspicuous wave-height also occurred at the Island of Hachijo at that time. Tidal records of four Japanese stations have been published by these researchers. It is noticeable that some inundated houses were reported at Futami Bay (Bonin Is.) in the case of the 1918 Urup tsunami.[7),8)] It can be noticed from the present refraction diagram that tsunami energy has a tendency of being concentrated at the east of the Bonin Islands as shown in Fig. 3. Greater precaution should therefore be taken in these areas in case of future tsunami originating from the Southern Kuril Islands.

After the 1933 Sanriku tsunami, J. Kawase[9] studied the relation between the distribution of wave energy as obtained from the refraction diagram and the wave-height observed at the coast. The energy of tsunami which is emitted from the source into the angle between two trajectories can be expressed as $1/2 \cdot \rho g \eta^2 v l$ per unit time, where η is wave-height, $v=\sqrt{gh}$, and l, the width between the two trajectories.

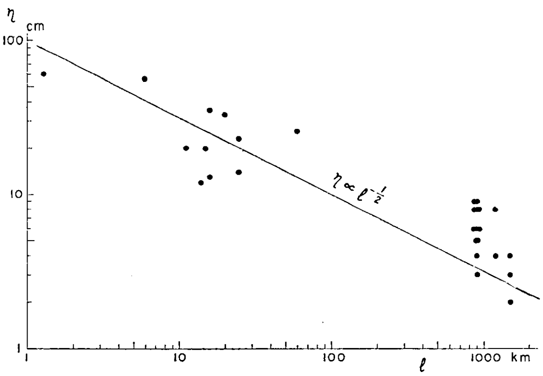

Fig. 4. The relation between the initial wave-height and the width between two adjacent trajectories at the 500 m depth line.

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6) A. Imamura and M. Moriya, "Mareographic Observations of Tsunamis in Japan during the period from 1894 to 1924," *J. Astr, Geophys. Japan,* **17** (1939), 119.

7) G. Shigetomi, "Tsunami in Futami-byochi in Chichi-shima on November 8, 1918," *J. Meteorol. Soc. Japan,* [i], **37** (1918), 404, (in Japanese).

8) T. Hatori, "Report on Chilean Tsunami of 1960 along Hachijo Island," *Rep. Chilean Tsunami, Field Invest. Comm. Chilean Tsunami* (1961), **318**, (in Japanese).

9) J. Kawase, "Some Remarks on the Tsunami," *Zisin,* **5** (1933), 56, (in Japanese).

This value should be constant without regard to the distance from the tsunami source, if the energy is not dissipated by the effect of partial reflection and diffraction. This expression gives $\eta \propto h^{-1/4} l^{-1/2}$, the well known Green's law.

As to the present tsunami, Fig. 4 shows the relation between the initial wave-height and the width between two of the trajectories when they reached the 500 m depth line. The trajectories are supposed to start the origin at every one minute of angle. The initial wave-height at each station on the Japanese Pacific coast seems to follow roughly to Green's law, although the wave-height reduction to the value at 500 m depth is neglected. Rather small wave-height and long period of the present tsunami seem to have favored this neglect.

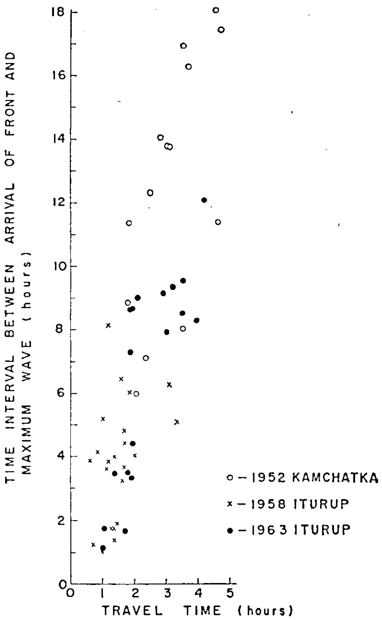

Fig. 5. The relation between travel time of the initial wave front and the time interval between arrival of front and the maximum wave.

4. Edge wave

F. Omori[10] has once suggested that the time interval between the arrival of the front and the maximum wave seems to elongate as the distance of the tsunami origin increases. Fig. 5 shows these relations in the cases of the tsunami of 1952 (Kamchatka), 1958 (Iturup) and the present tsunami. One of the present authors[11] at one time made the following remarks about the tide-gauge records of the 1952 Kamchatka tsunami: The shapes of the envelope of the wave train of tsunami records might be classified into triangular, spindled and mixed types. The triangular type is obtained at the Pacific islands and seems to be due to direct waves. The spindled type is obtained at stations on the coast along a continental shelf and seems to be due to edge waves which are propagated along the shelf,

10) F. OMORI, "On Tsunami or Destructive Sea-waves in Japan," *Rep. Imp. Earthq. Inv. Comm.*, **34** (1901), 5, (in Japanese).

11) R. TAKAHASI, "*Some Problems on the Tsunamis,*" *Text book of summer school* (1958), Japan Soc. of Civil Engineer, (in Japanese).

just like the Love seismic wave does along the surface of the earth's crust. K. Yoshida[12] theoretically discussed this feature.

This will also be the case in the present tsunami which was generated near the continental shelf along the Kuril Is. The edge waves must have been propagated along the continental shelf from Kuril Islands to the Japan Island arcs. Fig. 6 shows the relation between the distance of propagation measured along the 500 m depth line and the travel time

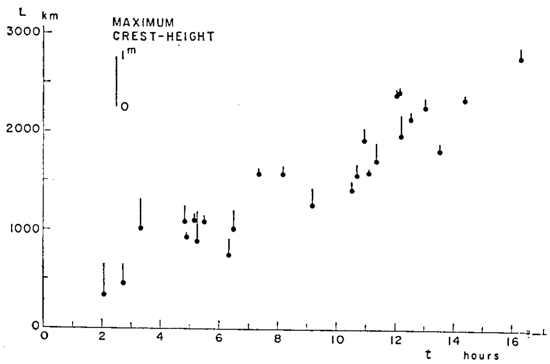

Fig. 6. The relation between the distance of propagation along 500 m depth line and travel time of the maximum wave.

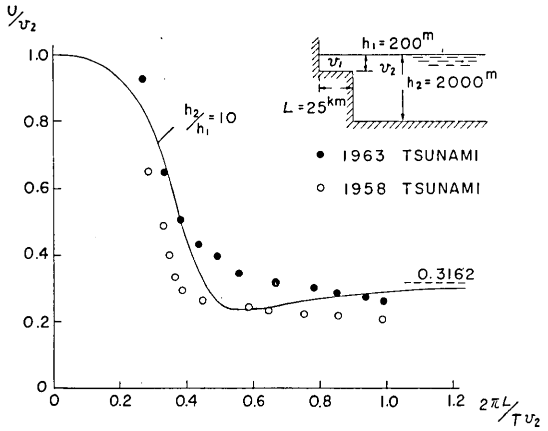

Fig. 7. Dispersion curves of Iturup tsunami records obtained at Miyagi-Enoshima. The figure shows also a model of continental shelf and the theoretical dispersion curve (solid) of the first mode edge wave after Nakamura.

12) K. Yoshida, "A Hypothesis on Transmission of Energy of Tsunami Waves," *Rec. Oceanograph. Works in Japan,* **5** (1959), 14.

of the maximum wave. The propagation velocity, as obtained graphically from the figure, is 47 m/sec. The bars in Fig. 6 show the maximum crest-height above the ordinary tide level at that time at each station.

Though theoretical studies have been given by many investigators, edge waves are difficult to observe in ordinary tide-gauge records because most of them are masked by seiche oscillations of the bay in which the tide-gauge is installed. In the records obtained at Enoshima, however, edge waves seem to be detectable in the cases of the present and the 1958 tsunamis.

K. Nakamura[13] calculated dispersion curves of edge waves which are generated along a model continental shelf as shown in Fig. 7, when cylindrical long waves are incident to the continental shelf from a source in the outer sea. The breadth L of the shelf was assumed to be 25 km, $h_1=200$ m and $h_2=2000$ m.

From records at Enoshima for the 1958 and the present Iturup tsunamis, dispersion curves of the waves were plotted as shown in Fig. 7, in which the distances of propagation along a 500 m depth line from the sources to Enoshima are estimated at 980 km and 1080 km respectively. Theoretical dispersion curve for the case cited above seems to fit roughly into these observed values.

5. Reflected waves

It can be noticed in the records at Miyagi-Enoshima that an appreciable change of phase can be observed 8 h 30 m and 13 h 37 m respectively after the occurrence of the earthquake. D. Shimozuru and T. Akima[14] indicated, in the case of the 1946 Nankai tsunami, the existence of reflected waves from Guam Island and its surrounding reef, by filtering off short waves from the records.

To elucidate the cause of these remarkable phase changes, normal and inverse refraction diagrams were drawn, starting from the tsunami source and Miyagi-Enoshima respectively, as shown in Fig. 8, and the positions of reflectors sought. The first change of phase at 8 h 30 m after the earthquake seems by this analysis to be due to the reflection from shallow seas at the E. Caroline and Marshall Islands shown in

13) K. NAKAMURA, "The Generation of Edge Waves by Cylindrical Waves impinging from the Outer Sea," *Sci. Rep. Tohoku Univ., Geophys.* [v], **14** (1962), 27.

14) D. SHIMOZURU and T. AKIMA, "Reflections on the Tsunami of Dec. 21, 1946," *Bull. Earthq. Res. Inst.*, **30** (1952), 223.

Fig. 8 by shaded areas. The cause of the second change of phase at 13 h 37 m is still unknown. Remarkable aftershocks occurred at 01 h 01 m, 13 h 06 m and 22 h 22 m (JST), Oct. 14, 1963, that is, 10 h 43 m, 22 h 48 m and 32 h 04 m after the main earthquake. There seems to be no justification that the second phase change was due to a second tsunami caused by one of these aftershocks.

In conclusion, the authors wish to express their sincere thanks to the Japan Meteorological Agency, Japan Geographical Survey Institute and Japan Hydrographic Office for putting their tide-gauge records to authors' disposal.

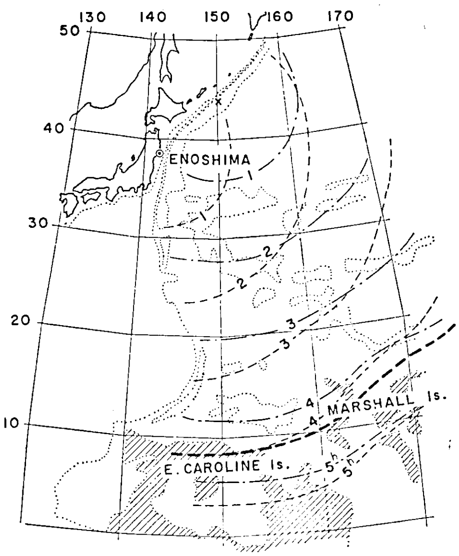

Fig. 8. Refraction diagram to locate reflectors.

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28. 1963年10月13日 エトロフ沖津波について

地震研究所 羽鳥徳太郎
高橋龍太郎

1963年10月13日14時18分(JST)エトロフ沖に発生した地震に伴つた津波は，日本太平洋沿岸全域に伝搬し，北海道南東部および三陸海岸で全振幅約1m，オホーツク海に面した北海道でも観測された．各地の津波概要をTable 1に示す．気象庁の発表によると，この地震震央は44.0°N，150.0°E，深さ40km，マグニチュード7.9である．

気象庁，海上保安庁水路部および国土地理院から提供された検潮記録をはじめ，Fig 1, 2に示す筆者らが観測した宮城江ノ島，伊豆大島，金谷および青島の津波計記録をもとに，今回の津波の主として伝搬を吟味し，日本太平洋沿岸地域に到達した津波エネルギーの配分，Edge waveの存在などについて検討した．

Fig. 3の伝搬図に示すごとく，浪源のエネルギーの内，僅か2.5°の角内に輻射されたものが日本太平洋沿岸地域に伝搬され，かつその大部分は北海道南東部に集中している．また小笠原諸島東方にエネルギーの集中がみられる．1918年Urup 沖津波の際，父島二見港で波高2.8m，浸水家屋の被害があつたが，これは将来の南千島の津波に対しても警戒すべき地域である．浪源から1′毎に輻射された波が500m水深線に到達した幅と，各地の第1波の波高との関係は，Fig. 4に示すごとく，ほぼGreenの法則が成立つ．

第1波が届いてから最高波が到達に要する時間が遠地津波ほど長くなることは，大森(1901)によつて指摘されたが，Fig. 5はその例を示す．Fig. 6は陸棚に沿つて伝わると考えたときの最大波(直接波と合成されたものと思われる)の伝搬速度を示している．中村(1962)はFig. 7に示す陸棚のモデルに沿つて伝搬するEdge waveについて，分散曲線を計算した．いま陸棚L=25km，h_1=200mおよびh_2=2000mと仮定して，1958年および今回のエトロフ沖津波における宮城江ノ島の記録につき分散曲線を求めると，中村の理論と近似しEdge waveが実際に観測されたようにみえる．

江ノ島の記録について，1958年と今回のを比較すると，Fig. 1に示すように最初の数波の波形が非常に合致し，浪源位置，伝搬径路および津波発生機構などの類似を暗示し興味がある．その他今回の江ノ島の記録について，地震後8h 30mに顕著な位相変化が認められたが，Fig. 8の伝搬図に示すように，東Caroline，Marshall諸島間のreefから反射してきた波とすると時間的に都合がよい．