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24. An Investigation of the Tsunami generated by the East Hokkaido Earthquake of August, 1969.

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Abstract

A tsunami was generated off Shikotan Island, in eastern Hokkaido, at 21 h 28 m (GMT) on August 11, 1969. According to JMA, the epicenter of the main shock was at 42°42′N, 147°37′E, with a depth of 30 km and the earthquake magnitude 7.8. Tsunami height observed at the coast of eastern Hakkaido was the largest among tsunamis generated recently in the vicinity of the South Kuril Islands. At Hanasaki, the maximum height of 1.5 m was recorded. Wave-heights in northeastern and southwestern Japan are in the ranges of 40~60 cm and 20~30 cm, respectively. The initial motion of the tsunami was in an upward direction at most stations, but at Hanasaki, the initial disturbance began with a conspicuous downward motion, suggesting the subsidence of the sea bottom in a part of the tsunami source. The source area estimated by means of an inverse refraction diagram lies on the continental slope, extending about 170 km parallel to the Kuril Arc. Judging from the attenuation of the initial wave height with distance, the total wave energy seems to be equal to that of the 1958 Iturup tsunami. The prodominant period of tsunami incident to the shelf is inferred to be about 30 min by comparing the spectrum of tsunami with that of the records at the ordinary time near Miyagi-Enoshima.

1. Introduction

At 21 h 28 m (GMT) on August 11, 1969, there occurred a strong earthquake off Shikotan Island, in eastern Hokkaido. This earthquake was named as East Hokkaido-oki Earthquake by the Japan Meteorological Agency (JMA). According to the seismological bulletin of JMA, the epicenter of the main shock is 42°42′N, 147°37′E with a depth of 30 km, the earthquake magnitude being 7.8. A violet foreshock activity began twenty minutes preceding the main shock. Accompanying the main shock, a moderate tsunami was generated and observed by tide gauges along the Pacific coasts of Japan. This tsunami was also observed on the coast of Hokkaido facing the Okhotsk Sea. According to the U.S. Coast and Geodetic Survey, the maximum wave-height (crest to trough) at several Pacific Islands were as follows: Midway 49 cm, Kahului, Hawaii 43 cm, Wake Island 24 cm and not more than 1 meter in the Kurils.

As is well known, seismicity in the vicinity of the southern Kuril Islands is very active. Many tsunamis have been generated. The tsunami of Nov. 6, 1958 inundated with the height of 3~4 m on Iturup Island [AVERIYANOVA *et al*, 1961]. The behavior of tsunami along the coast of Japan was reported by JMA [1959]. A large tsunami which generated off Urup Island on Oct. 13, 1963 was investigated by SOLOV'EV [1965], and HATORI and TAKAHASI [1964]. A small tsunami which generated off Shikotan Island on Jan. 29, 1968, was also observed by tide gauges in eastern Hokkaido.

In this paper, the behavior of the present tsunami is investigated on the basis of tide gauge records. The records of tsunami at 39 tide statiods have been put at the author's disposal by the courtesy of Japan Meteorological Agency (18), Hydrographic office (8), District Port Construction Bureau (2), Hokkaido Development Bureau (3), Prefectural Office (7), and Faculty of Science, Tohoku University (1). The source area of tsunami is estimated by means of an inverse refraction diagram based on the arrival time of the wave front. Making use of the records observed at Miyagi-Enoshima, the feature of the present tsunami is compared with the 1958 and 1963 tsunamis in terms of spectra.

2. Summary report

Good records were obtained at every tidal station along the Pacific coast of Japan. Features of the tsunami at different localities are given in Table 1.

Figs. 9~13 show the principal records of tsunami where an arrow indicates the time of commencement of the tsunami. The initial wave at most stations except in the region of eastern Hokkaido, began with an upward motion. The refraction diagram drawn on the basis of the arrival times of wave fronts, and the double amplitude, in centimeters, of the maximum wave are shown in Fig. 1. The upper part of Fig. 1 indicates distribution of the tide stations where arabic numerals of the stations correspond to the serial number in Table 1.

The initial wave front along the coast of eastern Hokkaido arrived at about 30 min after the occurrence of the main shock and then propagated along the Sanriku district 30 min later. The double amplitude of 1 m or more was observed at the coast of eastern Hokkaido. Especially, the maximum wave of 2.5 m was recorded at Hanasaki. In the regions of northeastern and southwestern Japan, double amplitude is in the ranges of 40~60 cm and 20~30 cm, respectively. The initial wave at most stations was observed with the period of about 30 min. Although in eastern Hokkaido the maximum height was found in the 1st or 2nd

Table 1. The tsunami on Aug. 11, 1969, as recorded by tide gauges.

No.	Tide station	Initial wave			Max. wave			Re-mark**
		Travel time	Rise	Period	Double ampl.	τ	H	
		h m	cm	min	cm	h m	cm	cm
1	Wakkanai	2 56	6	30	23	2 04	13	
2	Monbetsu	1 52	16	12	25	1 56	17	
3	Abashiri	1 30	16	24	34	1 46	26	
4	Hanasaki	32	−22	12	253	1 56	150	126
5	Kushiro	38 ?	− 3	40	79	4 06	47	33
6	Hiroo	50 ?	− 4	30	>140	16	78	78
7	Urakawa	1 00	15	20	126	3 20	62	
8	Tomakomai	1 25	10	65	32	10 42	20	
9	Muroran	1 30	6	62	20	2 12	12	
10	Hakodate	1 42	8	30	41	3 15	23	
11	Hachinohe (Same)	1 10	20	48	59	3 00	35	
12	Hachinohe (Minato)	1 16	15	52	108	2 57	66	
13	Shimanokoshi	1 00	35	10	52	1 32	38	
14	Miyako	1 04	27	26	55	2 46	29	
15	Kamaishi	1 07	16	30	26	5 14	16	
16	Ofunato (Nagasaki)	1 08	20		25	2 47		
17	Ofunato	1 11	34	36	46	2 43	34	
18	Kesen'numa	1 17	33	42	85	2 10	44	
19	Enoshima*	1 10	13	60				
20	Onagawa	1 26	31	32	48	3 02	31	
21	Ayukawa	1 24	18	28	68	6 00	40	
22	Matsukawaura	?			25		14	
23	Onahama	1 37	10	22	36	3 48	26	
24	Hitachi	1 39	16	42	38	11 55	25	
25	Choshi	1 34	22	32	33	5 06	22	
26	Mera	1 55	8	18	36	9 50	27	
27	Kozu I.	1 52 ?	2		11	6 50	6	
28	Miyake I.	?			15		10	
29	Minami-Izu	1 56	4	20	20	8 54	10	
30	Omaezaki	2 06	6	22	24	8 08	13	
31	Owase	2 44	6	14	31	11 08	17	
32	Uragami	2 40	6	23	27	5 37	15	
33	Kushimoto	2 34	5	28	58	7 00	30	
34	Muroto	2 58	5	36	35	9 20	21	
35	Kochi (Katsurahama)	?			11		8	
36	Tosa-Shimizu	3 12 ?	4	36	28	7 46	16	
37	Kabae	3 48	7	20	26	6 58	12	
38	Aburatsu	3 19	7	34	21	11 46	12	
39	Nishino-omote	?			4			
40	Naze	3 34	6	22	20	9 05	10	

H: Tsunami height above ordinary tides.
τ: Time interval between the arrival of front and the maximum wave.
* Tsunami observatory.
** Following rise of the initial wave.

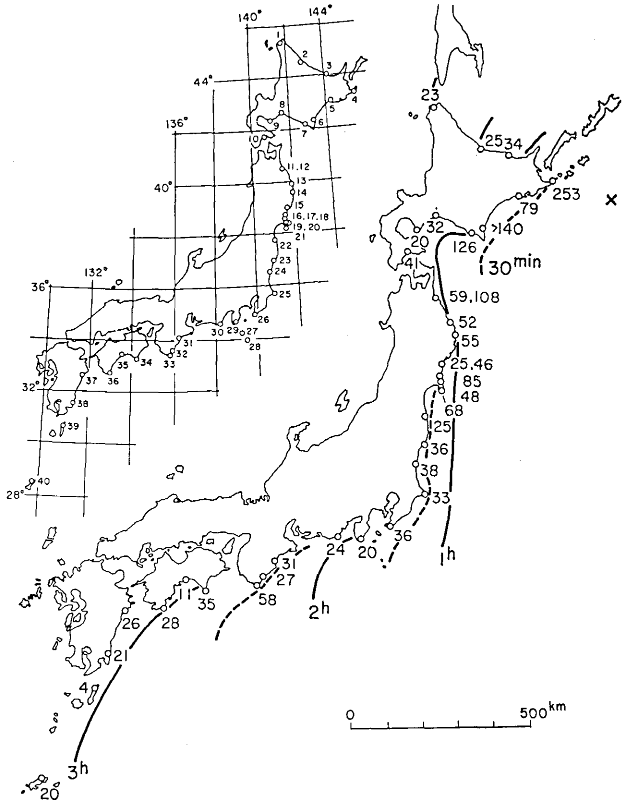


Fig. 1. Refraction diagram obtained from the arrival times of wave fronts and distribution of maximum wave-height (double amplitude, in cm). Upper figure: Distribution of tide stations, in which numerals correspond to the serial number in Table 1.

wave, in the region of Honshu the time interval between the arrival of the front and the maximum wave increases as the distance from the tsunami source increases. This fact has been explained as follows: The maximum wave group may be identified as edge waves propagated along a continental shelf with the minimum group velocity. In the cases of the 1958 Iturup and the 1963 Urup tsunamis, the ratios of the time interval of the arrival of the front and the maximum wave to the travel time of the initial wave were found to be 3.15 in Japan [HATORI and TAKAHASI, 1964]. For the present tsunami, this relation is approximately realized in northeastern Japan but is not clear in southwestern Japan.

The distributions of tsunami heights (above ordinary tide, cm) for the 1958 Iturup and 1963 Urup and present tsunamis are shown in Fig. 2. In the Hokkaido district, heights for the present tsunami are the largest but in the Sanriku district they are nearly the same. In the Hokkaido district, the travel-time of the present tsunami is 5 min smaller than that of the 1958 tsunami, indicating the nearer location of the wave source from Hokkaido. Fig. 3 shows the relation between the crest-height of the initial wave and the distance along the ray path from the margin of a tsunami source, where solid circles are for the present tsunami, open circles for the 1958 tsunami, and crosess for the 1963 tsunami. It can be seen that the tsunami magnitude of the present tsunami is nearly equal to that of the 1958 tsunami. At the position of 1000 km indicated by an arrow in Fig. 3, the abrupt change of wave height is observed. This location corresponds to the neighborhood of Boso Peninsula, in Central Japan, where the direction of the Japanese island Arc changes. The large decrease of height in southwestern Japan seems to be caused by the shadow effect of Boso Peninsula. At Izu-Oshima lying in the shadow side of Boso Peninsula, wave-heights are always very small for tsunamis generated in north-eastern Japan.

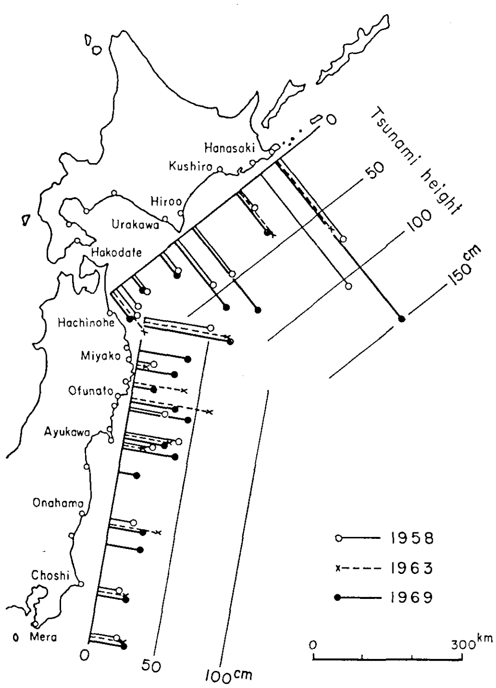


Fig. 2. Distributions of tsunami heights above ordinary tides for the 1958 Iturup, 1963 Urup and present tsunamis.

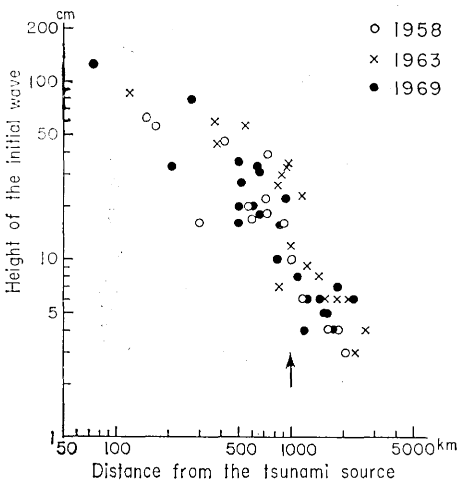


Fig. 3. Attenuation of crest-height of the initial wave for various tsunamis with distance from the tsunami source.

3. Estimation of tsunami source

Based on the arrival times of the initial motion at nine tsunami records, wave-fronts of an inverse refraction diagram are drawn at two minute intervals on the bathymetric charts. The estimated source area of tsunami is shown in Fig. 4 where the final wave front which started from the tide stations corresponds to the travel time, in minutes. Here, the initial wave recorded at Hanasaki clearly begins with a downward motion as shown in Fig. 9, but at Kushiro and Hiroo they are uncertain (Fig. 10). If the times of commencement of the crest are taken as the tsunami arrival, the final inverse wave fronts cannot be harmonized with other fronts determined from other stations. In Fig. 4, the senses, up and down,

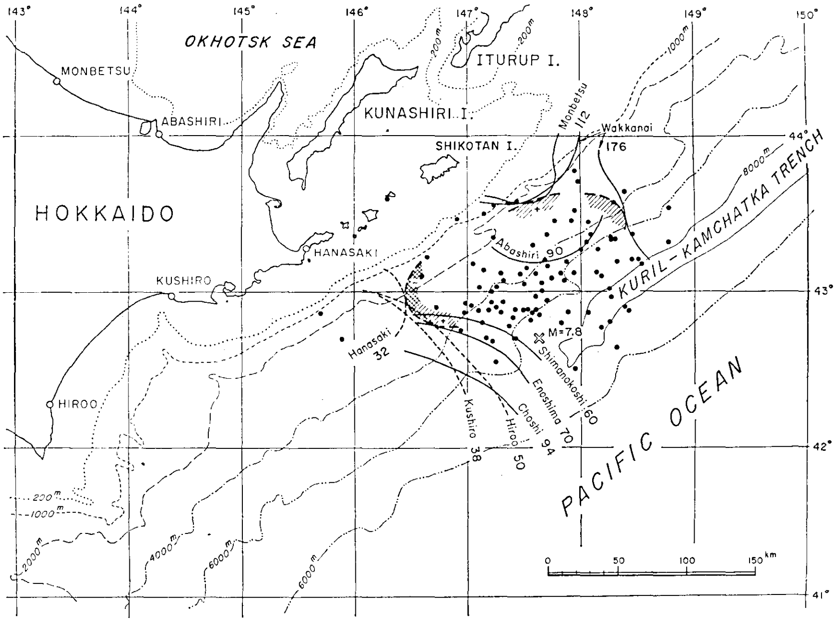


Fig. 4. Estimated generating area of the tsunami and the distribution of aftershocks. The last wave fronts are shown with the names of tide stations and travel times (min). The senses, up and down, of the initial motion of tsunami are indicated by solid and broken lines, respectively.

of the initial motion of tsunami are indicated by solid and broken lines, respectively. Tsunami waves which propagated into the Okhotsk Sea passing through both the Kunashiri and Iturup Straits are expected to arrive at Wakkanai at approximately the same time. The tsunami front which arrived at Abashiri and Monbetsu may have passed through the Kunashiri Straits, because the Nokke Straits (between Hokkaido and Kunashiri I.) is shallow.

The subsidence of the bottom may have occurred in the western part of the tsunami source, and the upheaval in the central part. On the other hand, FURUMOTO (1969) has suggested that the initial motion of the sea bottom was in the downward direction, based on the analysis of "the Rayleigh-acoustic waves" observed at Hawaii. Similar subsidence in a part of the tsunami source was inferred in the case of the 1968 Tokachi-oki earthquake [KAJIURA *et al*, 1968].

Making use of the seismological bulletin of JMA, the epicenters of the main shock and the aftershocks which occurred during August are plotted in Fig. 4. Most aftershocks occurred at the depth of 50~60 km and had magnitudes in the range of 4.2~5.2. It is seen that the estimated source area of tsunami approximately agrees with the aftershock area, and lies on the continental slope between 2000 m and 4000 m contour lines. It extends about 170 km in an elongated shape parallel to the bathymetric contour. According to the statistical formula [IIDA, 1958; HATORI, 1969], this source dimension is standard size for a shallow earthquake having magnitude $M=7.8$.

4. Oscillatory characteristics at some locations

Hachinohe

At Hachinohe Harbor, tide stations exist at Same and Minato, belonging to the Hachinohe Port Construction Bureau and Hachinohe Weather Station respectively. Fig. 5 is a map of Hachinohe Harbor where breakwaters indicated by thick lines did not exist before 1960. The depth inside the harbor is 5~10 m. As shown in Fig. 11, the record for the present tsunami observed at Minato shows a conspicuous "beat", and is different from the record at Same.

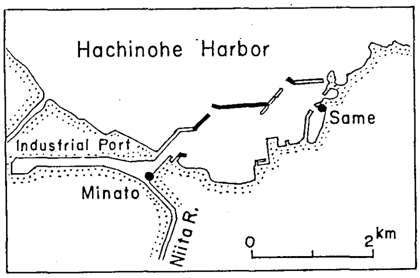


Fig. 5. Location of the tide stations in Hachinohe Harbor.

Several tsunamis were also observed at both stations. As shown in Table 2, the ratio of the tsunami height at Minato to that at Same

Table 2. Comparison of tsunami heights at Hachinohe-Minato and Same.

Tsunami	Tsunami height		Ratio of heights	Period	Remark
	Minato	Same	Minato/Same		
	m	m		min	
1952 Tokachi	1.2	2.0	0.60	10~30	KAJIURA (1969)
1958 Iturup	1.02*	0.68*	1.50	30~50	JMA (1959)
1960 Chile	3.6	4.3	0.84	40~60	KAJIURA (1969)
1968 Tokachi	2.3	3.7	0.62	10~30	〃
1969 E. Hokkaido	1.08*	0.59*	1.83	30~50	

* Double amplitude (m).

varies for different tsunamis. In the cases of the 1958 and present tsunamis, the tsunami heights at Minato are larger than those at Same. Although the harbor geometry protected by breakwaters is the same, the maximum height for the present tsunami is the 5th wave having an average period of 38 min at both stations, while for the 1968 Tokachi-oki tsunami, the maximum occurred for the 2nd crest with an average period of about 13 min. For longer period waves, the wave amplitude at Minato is larger than that at Same. According to a numerical experiment carried out by ITO *et al* [1969], the period band for the predominant amplifications of wave is 9~10 min at Same, and 22~45 min at the industrial port (Minato). The theoretical values agree, at least, qualitatively with observational results. Because of the different amplification caused by the harbor geometry, the tsunami height at Same is larger than that at Minato for tsunamis of near origin and vice versa for tsunamis of distance origin.

Ofunato

Although in other places in the Sanriku district, the wave heights and periods are almost the same for the 1963 Urup tsunami and the present tsunami, at Ofunato the former tsunami is about 1.5 times higher than the present one (Fig. 2). The difference of tsunami height at Ofunato seems to be caused by the effect of a tsunami breakwater constructed in March, 1967. According to the theoretical result [FUKUCHI and ITO, 1966] in the case of no breakwater, this height ratio was expected to be about 3.5. Also, in the present tsunami, the ratio of wave amplitudes at Ofunato (the head of bay) to that at Nagasaki (the mouth of bay) is about 1.8 as compared with 1.0 for the numerical model.

Miyagi-Enoshima

It was pointed out that the earlier part of the records for the 1958 and 1963 tsunamis observed at Enoshima are very similar in shape [HATORI and TAKAHASI, 1964]. Fig. 6 shows a record of the present

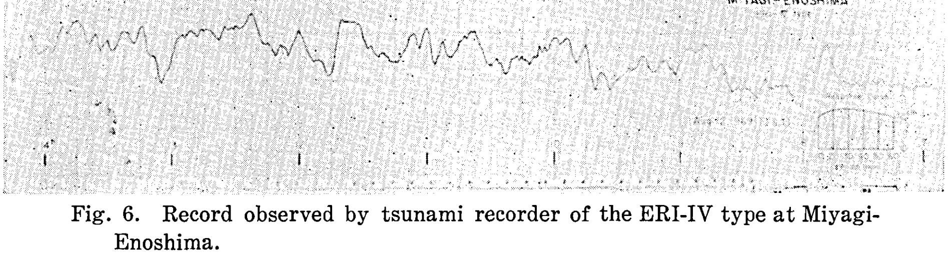


Fig. 6. Record observed by tsunami recorder of the ERI-IV type at Miyagi-Enoshima.

tsunami obtained by the long-wave recorder of the ERI type at Enoshima. This wave form is apparently similar to those of the above mentioned tsunamis. Power spectra of three tsunamis calculated by Tukey's method are shown in Fig. 7. The conditions of analysis are as follows: Time length of the record is 6.5 hours including the initial wave with sampling at every 2.5 minutes interval. The total number of data points is 157 and the lag is 72. The spectra are corrected with respect to sensitivity and oscillatory characteristics of the instrument. As seen in Fig. 7, the spectra have a predominant peak in the range of period of 60~90 min and a small peak at the period of 30 min. Averaged spectrum of back-ground noise at Miyagi-Enoshima (AIDA, 1967) is shown in a lower part of Fig. 7. The spectral amplitude at the longer period part over

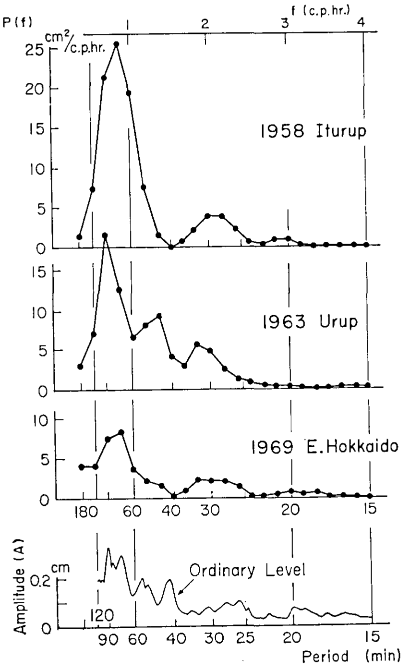


Fig. 7. Power spectra for various tsunamis analyzed from the records at Enoshima. Lower figure: Average spectrum of back-ground noise at Enoshima at ordinary time (after I. Aida).

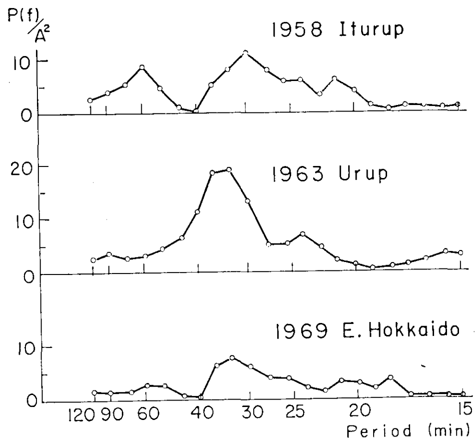
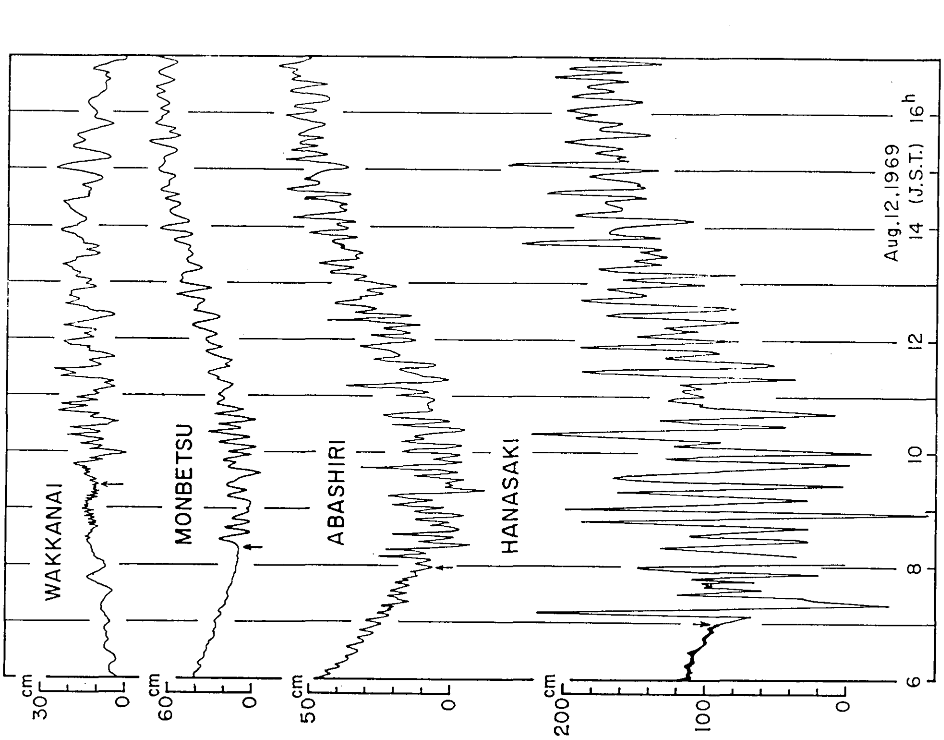


Fig. 8. Power spectral ratio of various tsunamis to the back-ground noise at Enoshima.

40 min is conspicuously larger than that at the shorter period part and, roughly speaking, this spectrum may be considered as the response spectrum of the shelf. Fig. 8 shows the power amplitude ratios of the tsunami spectrum to the noise spectrum. There is a small peak at the period of 32 min for the present tsunami, while for the 1958 tsunami,



F g. 9. Tide gauge records of tsunami.

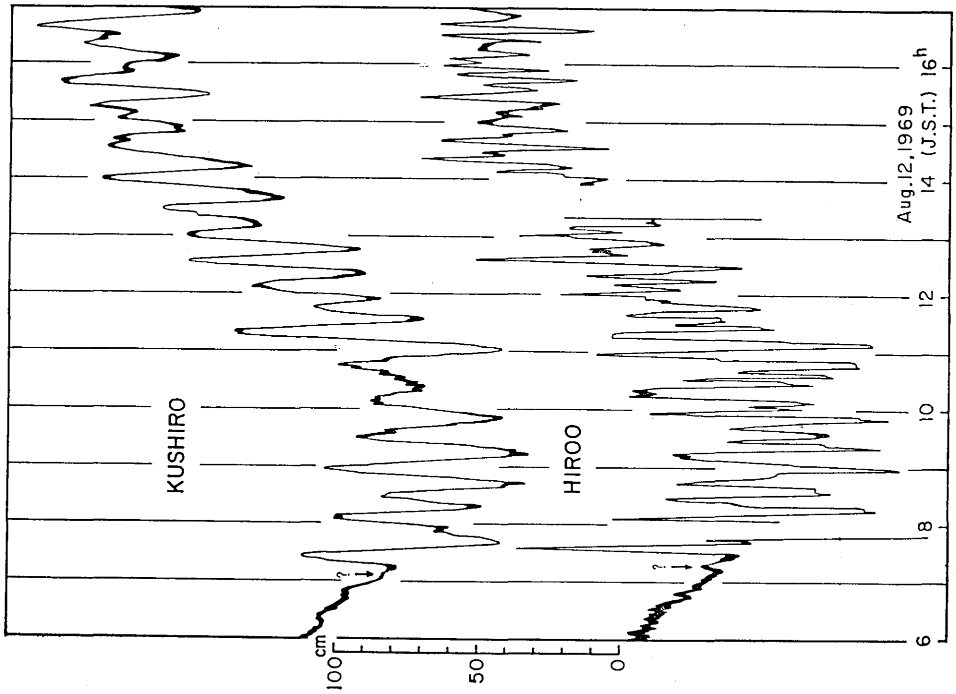


Fig. 10. Tide gauge records of tsunami.

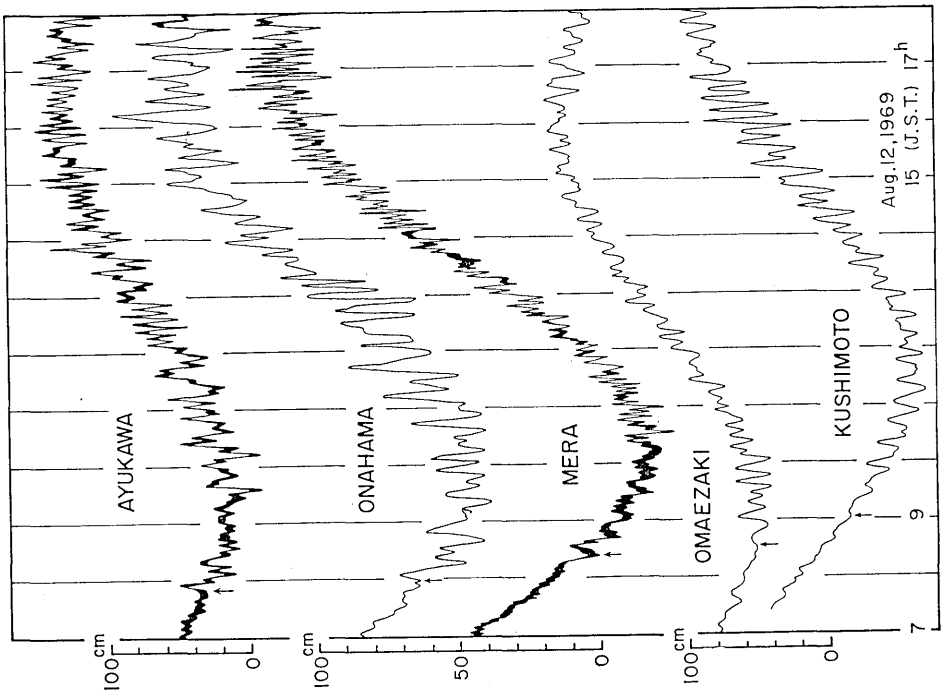


Fig. 12. Tide gauge records of tsunami.

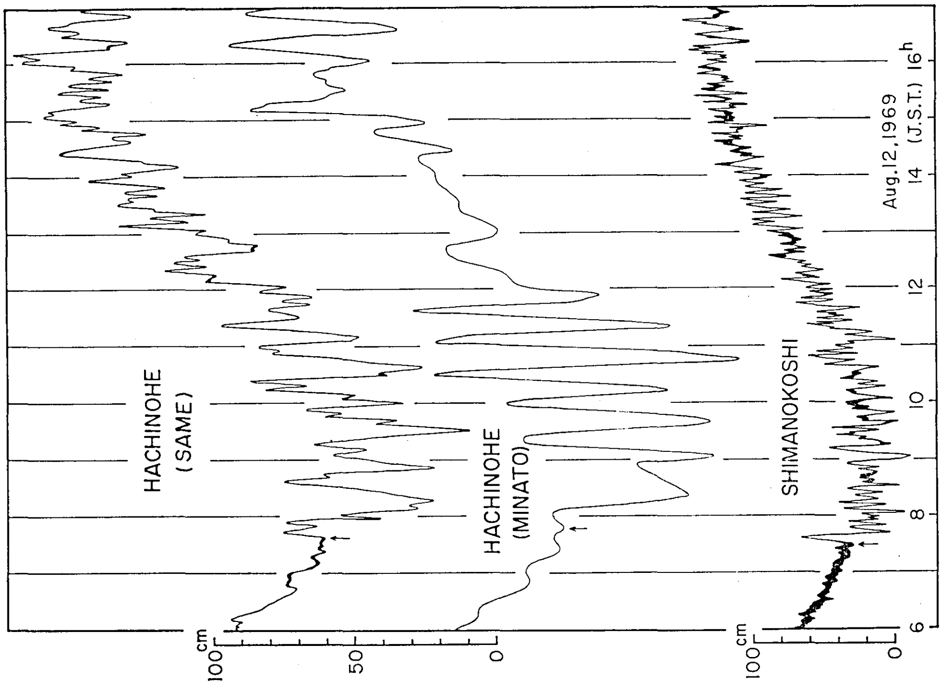


Fig. 11. Tide gauge records of tsunami.

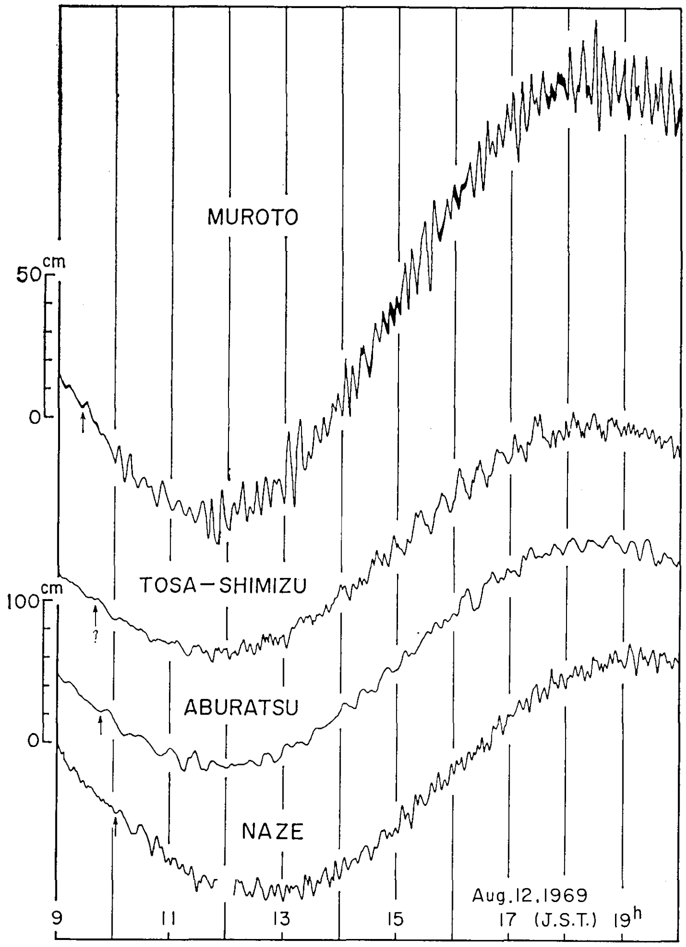


Fig. 13. Tide gauge records of tsunami.

another peak is found at the period of 60 min. These peaks may have corresponded to the predominant period of the tsunamis incident on the shelf near Miyagi-Enoshima.

5. Conclusion

The present earthquake occurred about 140 km off Shikotan Island, the tsunami source being the nearest from Hokkaido from among the three tsunamis which occurred in this neighborhood. About 30 min after the occurrence of the main shock, the wave front of tsunami was observed at the coast of eastern Hokkaido, the maximum height in this region occurring at the first or the second wave. At Hanasaki located near the tsunami source, the double amplitude of 2.5 m was recorded by a tide gauge, and is the largest in the tsunamis generated in this region. However, tsunami energy of the present tsunami seems to be equal to that of the 1958 Iturup tsunami, taking account of the distance from the wave source.

The initial wave observed at the coasts of the Okhotsk Sea and north-eastern Japan was with an upward motion. However, the commencement of the initial wave at Hanasaki is clearly in a downward direction, suggesting the existence of the subsidence somewhere in the western part of the tsunami source area. The estimated source area is located on the continental shelf, roughly agreeing with the area of aftershock activity, extending about 170 km parallel to the Kuril Arc. From the power spectral analysis of records obtained at Miyagi-Enoshima corrected for the shelf response, a small peak was found at the period of 32 min, which may be the predominant period of tsunami incident on the shelf near Miyagi-Enoshima.

Acknowledgement

The author wishes to express his hearty thanks to the Japan Meteorological Agency, Hydrographic Office, District Port Construction Bureau, Hokkaido Development Bureau, Prefectural Office, and Faculty of Science, Tohoku University for putting their tide gauge records at his disposal. His thanks are also due to Prof. K. Kajiura for his valuable advice and for the assistance of Mr. M. Koyama in making the drawings. The computation of spectrum was made at the Computer Center, Tokyo University.

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24. 1969 年 8 月北海道東方沖地震による津波

地震研究所 羽 鳥 徳 太 郎

1969 年 8 月 12 日 6 時 28 分 (JST), 北海道色丹島沖の地震に伴ない津波が発生した. 気象庁の地震月報によると, 震央は 42°42′N, 147°37′E, 深さ 30 km, 地震のマグニチュードは $M=7.8$ である. この津波は, 本震が起った約 30 分以後から各地の検潮所で観測された. 津波の第 1 波は, 本州とオホーツク海に面した北海道沿岸では押し波で始まつた. しかし, 波源に近い花咲では明瞭な引き波が記録され, 波源域の 1 部分が沈降したことを暗示している. 各地の津波の到達時間をもとにして作図した逆伝播図によると, 津波の波源域は色丹島沖合の水深 2000～4000 m の陸棚斜面上にあつて, 等深線に沿つて伸び, その大きさは約 170 km と推定される. この程度の規模を持つ浅い地震に対して, この推定値は統計的に標準の大きさである. なお, 推定波源は余震域とほぼ合致した位置にある.

以上のように今回の津波は, 最近南千島で起きた津波より波源が北海道に近接し, この付近の沿岸では 第 1～2 波が最も高く, 全振幅は 1.5 m 以上もあつた. しかし, 波源からの距離を考慮にいれると, 今回の津波は 1958 年のエトロフ沖津波と同程度の規模とみなされる.

宮城江ノ島で津波計によつて観測した今回の津波と, 1958 年, 1963 年のエトロフ沖津波とでは, 長周期部分の波形はかなり似ている. 初動を含めた 6.5 時間分の記録について周期分析を行なつたところ, 3 個のスペクトルは 60～90 分の周期に優勢なピークと, 30 分付近に小さなピークが見られた. これら津波スペクトルと, 平常時の観測から得られたノイズのスペクトルとの振幅比を較べたとき, その様子は津波によつて違つている. 今回の津波では 20 分の周期に小さなピークが認められた. 江ノ島付近の陸棚へは, この部分の周期を持つた津波が入射したと思われる.