Bulletin of the Earthquake
Research Institute
Vol. 47 (1969), pp. 523-537

22. *Study on Distant Tsunami along the Coast of Japan. Part 3, Tsunamis of Philippines and Indonesia Origin.*

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(Read Feb. 25, 1969.—Received March 31, 1969.)

Abstract

The tsunamis which were generated at E Luzon I. on Aug. 1, 1968 and off NE Celebes I. on Aug. 10, 1968, were observed along the Pacific coast of Japan. Wave amplitudes at Tosa-Shimizu and Kushimoto, both of which are located at the cape, are relatively high and amount to 20-30 cm with the period of 15 min.

Refraction diagrams of both tsunamis are drawn and the difference of the wave amplitude between SW Japan and NE Japan is investigated. The maximum wave group observed 3-6 hours after the initial wave front arrival can be explained by the effect of edge waves.

1. Introduction

Distant tsunamis generated in regions from the Kurile Islands to Alaska and of South America were studied in the previous papers (Hatori, 1965, 1968), with respect to the distributions of tsunami energy and refraction diagram along the coast of Japan. In this paper, the behavior of tsunamis generated in regions from the Philippines to Indonesia is discussed. One of the famous historical tsunamis generated in this region, was that on Aug. 26, 1883 accompanying the eruption of Krakatoa (6.7°S, 105.4°E) which was propagated across the Pacific Ocean and the Indian Ocean. Some abnormal tidal activities were felt on the Japanese coast, too (Imamura, 1945). The tsunami on Aug. 15, 1918 in the Celebes Sea, generated by an earthquake (Shallow, $M=8^1/_4$), was observed at the tide station in Japan (Imamura and Moria, 1939).

The tsunamigenic earthquake on Aug. 1, 1968 occurred at the east coast of Luzon I. (Philippines) and those of Aug. 10 and 14, near Celebes I. (Indonesia). According to the International Tsunami Information Center (Newsletter 1 (2), Sept. 1968, Honolulu, Hawaii), some parts at coastal areas in Celebes I. were damaged by Indonesian tsunamis. These tsunamis were observed with small amplitude at tide stations in Japan. Making use of tide gauge records of 31 stations, tsunami phenomena are investigated. Refraction diagrams starting from the epicenter

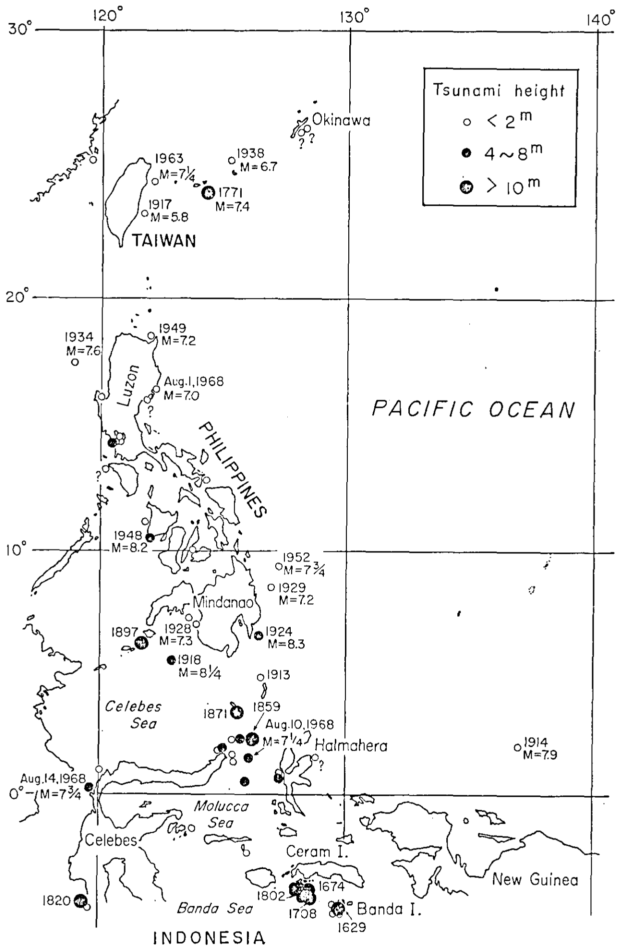

Fig. 1. Geographic distribution of epicenter of earthquakes accompanied by tsunamis (1627–1968).

at E Luzon I. and NE Celebes I. are drawn to investigate travel times and the distribution of tsunami energy along the coast of Japan. Existence of edge waves propagated along the continental shelf is discussed.

2. Historical tsunamis

According to the National Earthquake Information Center (Lander, ed., 1968), seismicity of the rigion from Taiwan to Indonesia in a year of 1967 is as follows: A seismic zone ($M<7$, $d=33$ km) lies from Taiwan to the west side of Luzon I., across between Luzon I. and Mindanao I. and tends to the east coast of Mindanao I. Depth of earthquakes in the region from south of Mindanao I. to Molucca Passage is relatively

Table 1. Tsunami on Aug. 15, 1918, as recorded by tide gauges. Wave originated near the earthquake epicenter (5.5°N, 123°E) in the Celebes Sea, at 12:18 (GMT), Aug. 15, 1918.

Tide station	Initial wave	Max. wave		
	Travel time	Double ampl.	Period	τ
	h m	cm	min	h m
Hososhima	4 06	13	20	11 30
Kushimoto	4 42	40	22	3 25

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

deep (d=71-300 km). Another zone lies from north of Celebes to New Guinea directed in E-W. Seismicity of Taiwan during the period from 1909 to 1958 was indicated by Hsu (1961) as follows: Relatively deep earthquake (40>d>100 km) occurred actively off the east coast of Taiwan. As for inland Taiwan, most earthquakes were very shallow (d<10 km) and were often accompanied by crustal deformation.

Making use of the tsunami catalogue (Iida, *et al.*, 1967), epicenters of tsunamigenic earthquakes which occurred during the period from 1627 to 1968 are plotted in Fig. 1. Principal earthquakes are indicated with the year of occurrence and magnitude. It is most remarkable that the generating region of large tsunamis is the west side of the island arc rather than on the Pacific coast. There is little tsunami generation on north New Guinea. However, most tsunamis might have been overlooked owing to sparse population.

Inundation height for the tsunami of 1918 generated in the Celebes Sea was 7 m at SW Mindanao I. and double amplitude of 40 cm was recorded at Kushimoto. Table 1 shows the principal features of records given by Imamura and Moriya. From Fig. 1, the magnitude of earthquakes accompanied by tsunami is 7 or more. Historical tsunamis gave no effect to the Japanese coast because these tsunami origins were located in the west side of the island arc.

3. The Philippines and Indonesia tsunamis of Aug. 1968

Earthquake data reported by the U. S. Coast and Geodetic Survey are shown in Table 2. Figures 6 and 7 show the principal tide gauge records at the Japanese stations. On the records obtained by long-wave recorders at Miyagi-Enoshima and Isu-Oshima, the tsunamis on Aug. 1 and 10 were slightly observed (Figs. 8, 9). The tsunami on Aug. 14 generated at W Celebes I. is indefinite on the records (Fig. 10).

Table 2. List of earthquakes.

Dates and Time (GMT)	Epicenter	Depth km	*M*	Comment*
Aug. 1, 1968 20 : 19	16.5°N 122.2 E	36	7.0	No evidence of tsunami
Aug. 10, 1968 02 : 07	1.4 N 126.2 E	33	$7^1/_4$	Local tsunami; Huge waves swept coastal areas in the Donggala district of Celebes Is. Numerous deaths and much damage.
Aug. 14, 1968 22 : 14	0.2 N 119.8 E	23	$7^3/_4$	Island of Tuguan at north tip of Celebes Is. submerged and disappeared. Large local tsunami.

* after the International Tsunami Information Center.

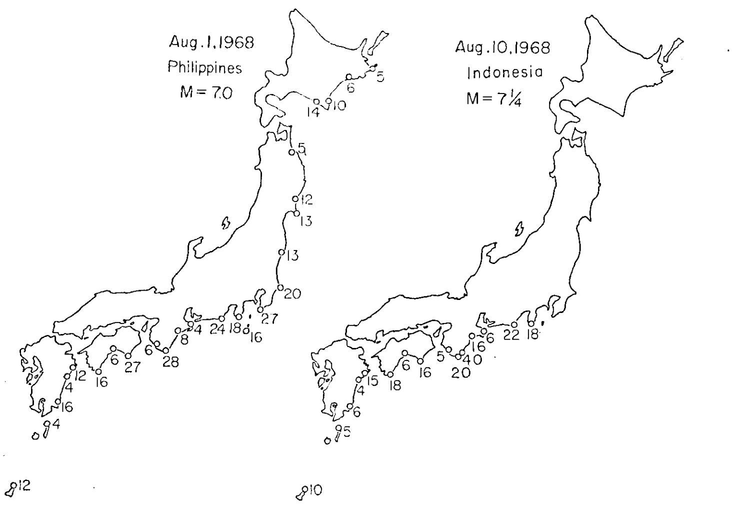

Fig. 2. Distribution of double amplitude of the maximum wave (cm) for the tsunamis of the Philippines and Indonesia.

Figure 2 shows the distributions of the maximum double amplitude along the Japanese coast for the tsunamis on Aug. 1 and 10, 1968. Wave amplitude at the cape is larger than other places due to the convergence of refracted waves and is 20-30 cm. Amplitudes at Kyushu and the South-West Islands are small, though these places are a relatively short distance from the tsunami origin. This behavior seems to be caused by the direction of incident waves. The details of each tsunami are as follows:

The Philippines tsunami on Aug. 1, 1968

The shape of an envelope of wave train for distant tsunamis usually

Table 3. The tsunami on Aug. 1, 1968, as recored by tide gauges. Wave originated near the earthquake epicenter (16.5°N, 122.2°E) at the east coast of Luzon I., at 20 : 19 (GMT), Aug. 1, 1968.

No.	Tide station	Initial wave						Max. wave		The 2nd highest wave	
		A			*B*						
		Travel time	Rise	Period	Travel time	Rise	Period	Double ampl.	τ	Double ampl.	τ
		h m	cm	min	h m	cm	min	cm	h m	cm	h m
1	Naze	2 23	3	10	3 57	6	14	12	2 16	10	3 40
2	Nishino-omote	2 28	2	16				4	2 28		
3	Aburatsu	2 54	4	20				16	6 30	10	2 20
4	Hososhima	3 10	3					4	2 40		
5	Totoro	?									
6	Kabae	3 06	6	20	3 06	6	20	12	5 33		
7	Tosa-Shimizu	3 06	3		3 49	10	20	16	2 50		
8	Kami-Kawaguchi	?									
9	Kochi	?						6			
10	Muroto	2 51	4	8	3 04	7	15	27	2 20	21	5 10
11	Kii-Sirahama	3 00	2		3 51	4	32	6	2 23		
12	Kushimoto	2 51	4	15	3 41	6	12	28	3 30	26	5 35
13	Urakami	3 01	3	10	4 03	7	15	12	2 56		
14	Owase	3 19	4	12	4 11	6	16	12	3 01		
15	Nagashima	?						8			
16	Toba	?						4			
17	Morosaki	?									
18	Omaezaki	3 33	4	12	4 41	6	10	24	3 28		
19	Uchiura	?									
20	Minami-Izu	3 16	4	8	4 11	4	8	18	5 45	16	2 30
21	Kozu I.	3 19	3	8	4 28	6	7	16	3 02		
22	Izu-Oshima	?									
23	Mera	3 38	4	16	4 36	5	18	27	3 06	14	6 23
24	Choshi	?						20			
25	Onahama	4 15	2	22	4 41	4	22	13	7 58	11	4 05
26	Ayukawa				5 49	5	8	13			
27	Enoshima	?									
28	Kesen'numa	?						12			
29	Hachinohe	?						5			
30	Urakawa	?						14			
31	Hiroo	?						10			
32	Kushiro	?						6			
33	Hanasaki	?						5			

A: Wave front is indefinite. Wave front is determined with the aid of the refraction diagram. *B*: Evident wave commences. τ: Time interval between the arrival of front (*A*) and the maximum wave or the 2nd highest wave.

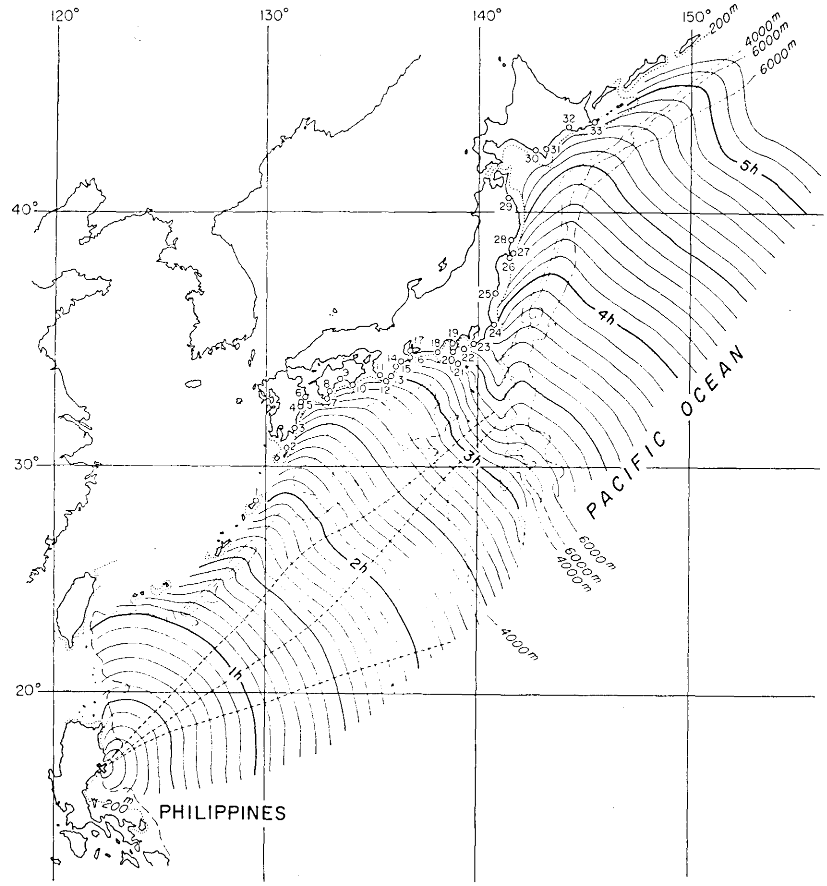

Fig. 3. Refraction diagram of the Philippines Tsunami of Aug. 1, 1968 (time interval: 5 minutes). Numeral at the tide station is the serial number in Table 3.

observed in Japan, is a spindle type. It is difficult to judge the wave front arrival in the present case from the records because of too small amplitude. In Table 3, the waves of symbol *A* are read from the records with the aid of the refraction diagram and those of symbol *B* are a comment of relatively evident arrival. τ denotes time interval between front arrival (*A* wave) and the maximum or the 2nd highest wave. The locations of each station are shown with numeral in Fig. 3 corresponding to the serial number in Table 3.

The tsunami source being assumed at 16.5°N, 122.2°E, wave fronts are drawn at 5 minutes intervals in Fig. 3. The travel times of wave front are 2 h 30 m-3 h 00 m at the coast of Kyushu-Shikoku and 3 h-4 h in Kinki-Kanto districts. As shown in Fig. 3, wave rays start from the tsunami source in the direction of each 10 degrees increment, and conspicuous divergence is observed in NE Japan. The observed amplitudes in this region are the ordinary level of daily wave activities. In cases of the tsunamis of the 1944 Tonankai and the 1946 Nankaido, the wave-height in NE Japan is conspicuously small. These behaviors seem to be caused by the effect of direction of the island arc.

The Indonesia tsunami on Aug. 10, 1968

The summaries of principal features of records at various stations are given in Table 4. The maximum wave-height at Urakami was 40 cm, arrived at 9 hours after the initial wave front. Travel time of the initial wave with the period of 15 min is about 5 hours in SW Japan.

Table 4. Tsunami on Aug. 10, 1968, as recorded by tide gauges. Wave originated near the earthquake epicenter (1.4°N, 126.2°E) off NE. Celebes I., at 02:07 (GMT), Aug. 10, 1968.

Tide station	Initial wave			Max. wave		The 2nd highest wave		Remark
	Travel time	Rise	Period	Double ampl.	τ	Double ampl.	τ	
	h m	cm	min	cm	h m	cm	h m	
Naze	?			10				
Nishino-omote	?			5				
Aburatsu	4 33?	3	18	6	4 03	6	7 10	
Hososhima	?			4				
Kabae	5 03	7	16	15	3 55			
Tosa-Shimizu	4 58	7	15	18	3 42	12	8 00	
Kochi	?			6				
Muroto	4 55	6	14	16	3 30			Swell 30 cm
Kii-Shirahama	?			5				
Kushimoto	4 55	6	15	20	4 03	18	7 16	
Urakami	5 05	10	18	40	9 00			
Owase	5 21	10	14	22	5 13			
Nagashima	5 33	6	30	16	3 16			
Toba	?			6				
Omaezaki	?			22				
Minami-Izu	?			18				
Mera	?							Swell 40 cm
Choshi	?							〃 35 cm
Ayukawa	?							〃 30 cm
Urakawa	?							〃 30 cm
Kushiro	?							〃 25 cm

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

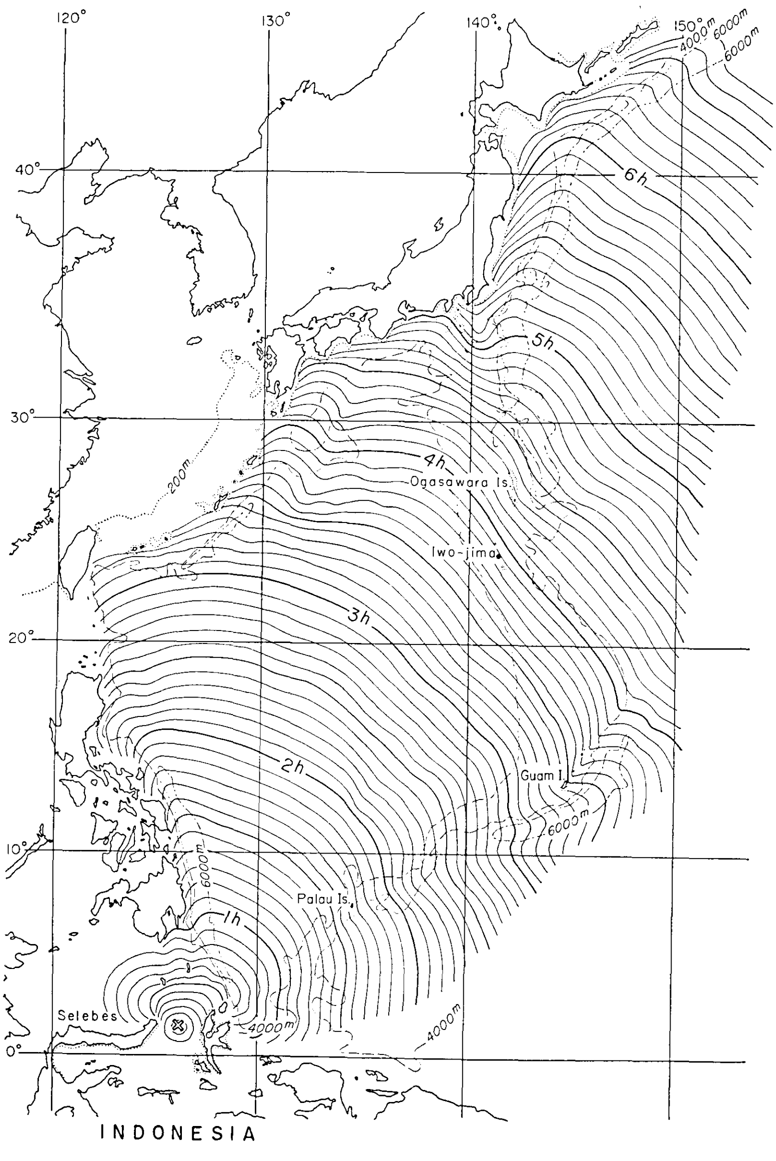

Fig. 4. Refraction diagram of the Indonesia Tsunami of Aug. 10, 1968 (time interval: 5 minutes).

In NE Japan, the waves of tsunami were masked by a storm surge due to Typhoon No. 7. In those days, a temporary observation of tide had been made at Iwo-jima, Ogasawara Is. (Fig. 4) by the authors. From the record of a portable tide gauge (magnification: 1/26, paper speed: 11 mm/hour), the tsunami could not be found.

Figure 4 shows a refraction diagram and the wave fronts are drawn starting from the assumed tsunami source at 1.4°N, 126.2°E, at 5 minutes intervals. The travel times of the final weve front agree well with the observed values. The direction of the wave fronts for the Indonesia tsunami is different from that of the Philippine tsunami and is parallel to the coast of SW Japan.

4. Edge wave

In case of distant tsunamis, the maximum wave has often been observed several hours after the initial wave. This phenomenon has been explained by means of a theory and model experiment, *i. e.* the maximum wave group may be identified as edge waves propagated along a continental shelf with the minimum group velocity. In cases of the Kamchatka and Iturup tsunomis, the ratio of the time interval of the arrival of the front and the maximum wave to that of the occurrence of the earthquake and the initial wave arrival were found to be 3.15 from tide guage records in Japan (Hatori and Takahasi, 1964).

For the present tsunamis, these relations are shown in Fig. 5 where the solid circles are the maximum wave, open circles the 2nd highest wave. The profile of shelf is assumed step-type and the time interval between the earthquake occurrence and the wave front arrival is t_0, that of the maximum wave t. The ratio α of the time interval for each wave is

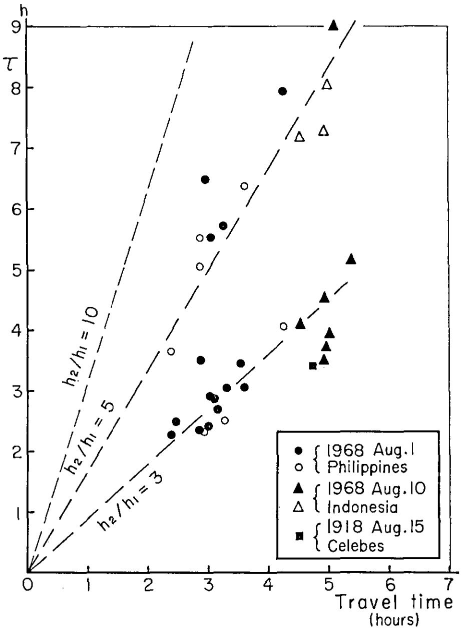

Fig. 5. The relation between travel time of the initial wave front and the time interval between arrival of front and large wave. Closed circle: the maximum wave, open circle: the 2nd highest wave.

$$\alpha = \frac{t-t_0}{t_0}$$

$$= \frac{c_2}{c_m} - 1$$

$$= \frac{1}{c'_m}\left(\frac{c_2}{c_1}\right) - 1$$

where c_1 is long-wave velocity on a shelf, c_2 that of outer sea, $c_m(=c'_m c_1)$ the minimum group velocity. Let h_1, h_2 be the depth of shelf and that of outer sea, respectively. The ratio α is expressed as

$$\alpha=\frac{1}{c'_m}\left(\frac{h_2}{h_1}\right)^{1/2}-1.$$

The factors were given by Satô (1951) as follows: $c'_m=0.8431$ at $h_2/h_1=5$ and $c'_m=0.9140$ at $h_2/h_1=3$. These factors are put in the above equation. The ratio can be obtained as follows:

$$\alpha=1.65 \text{ at } h_2/h_1=5\ ,$$
$$\alpha=0.9 \text{ at } h_2/h_1=3\ .$$

The ratio of water depth are shown as a parameter in Fig. 5. In case of the Kamchatka and Iturup tsunamis, the observed values were explained by the parameter of $h_2/h_1=10$. It is interesting that the shape of wave envelopes for distant tsunamis propagated from the north and from the south of Japan is classified by the different topography of the sea bottom.

5. Conclusion

Historical tsunamis generated in Philippines and Indonesia are located inside these island arcs. Therfore, the effect of tsunami has been small for the Japanese coast. For the Philippines and Indonesia tsunamis, the wave-height in NE Japan is smaller than that in SW Japan. This behavior seems to be caused by the effect of direction of the island arc rather than the increase of distance from the tsunami origin. The maximum wave was observed at 3-6 hours after the initial wave front arrival. This wave is explained by the wave-train with the minimum group velocity of edge wave.

Acknowledgment

The author wishes to express his hearty thanks to the Japan Meteorological Agency, Hydrographic Office, Geographical Survey Institute and Prefectural Offices for putting their tide gauge records to author's disposal. His thanks are also due to Prof. K. Kajiura for his guidance.

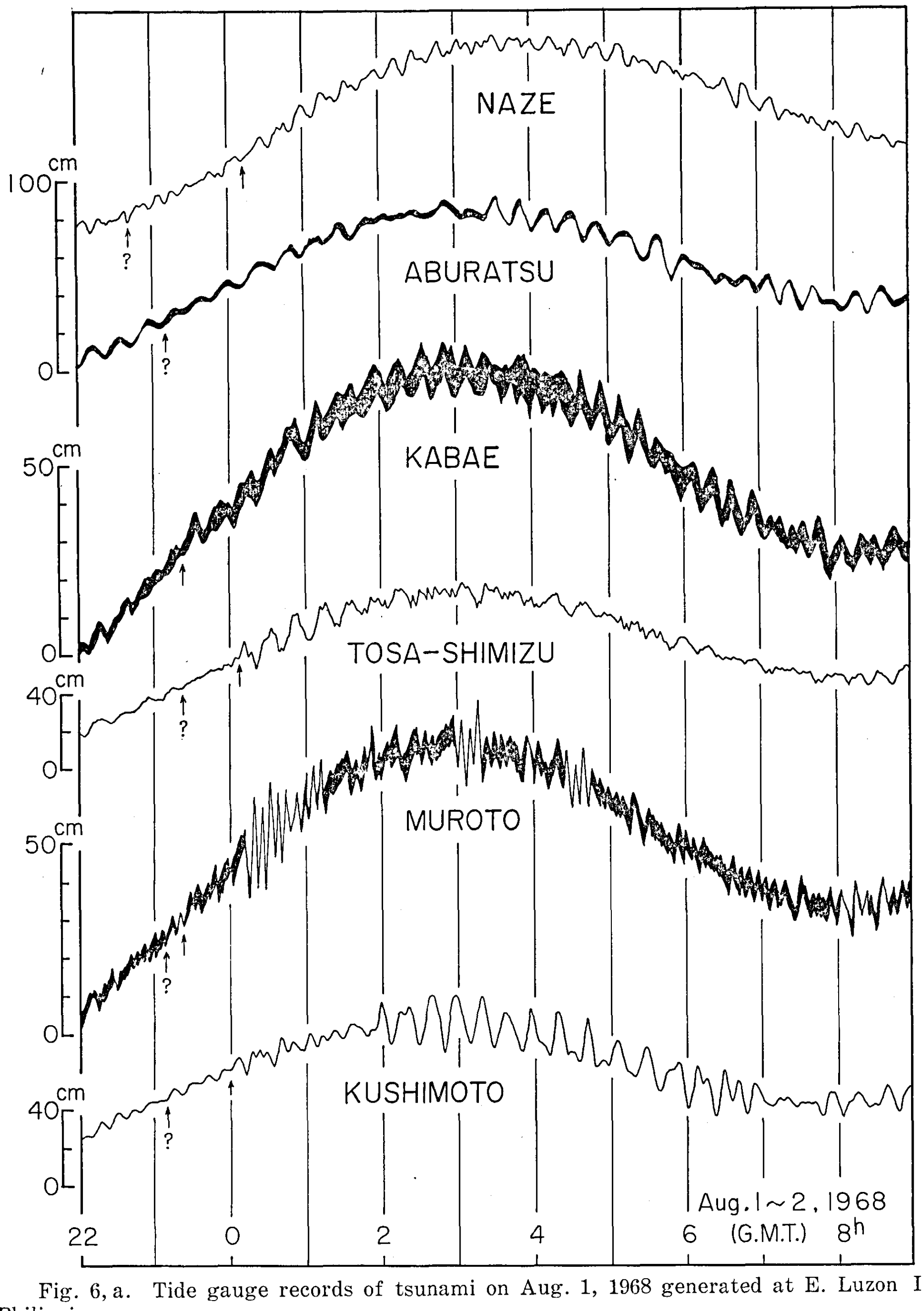

Fig. 6, a. Tide gauge records of tsunami on Aug. 1, 1968 generated at E. Luzon I., Philippines.

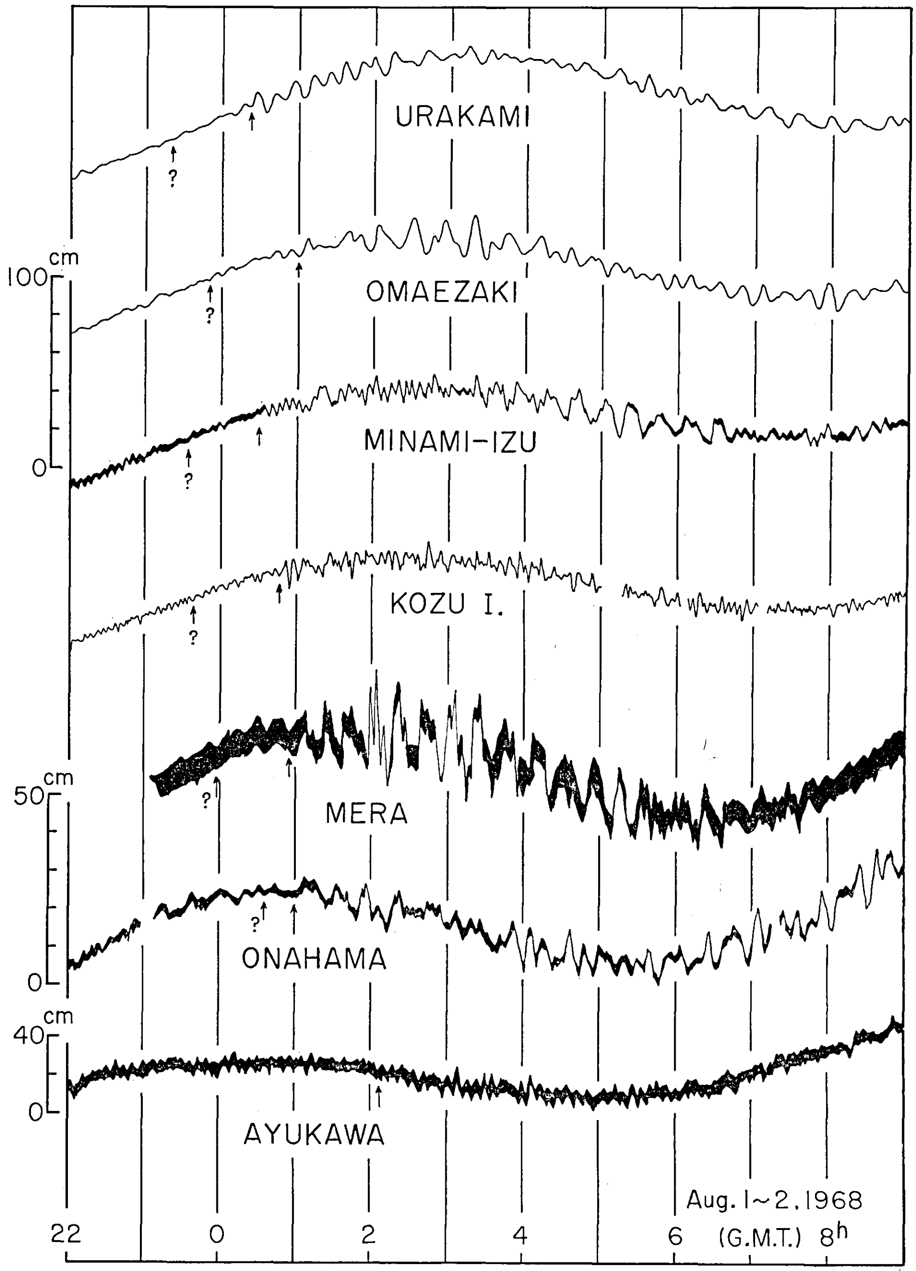

Fig. 6, b. Tide gauge records of tsunami on Aug. 1, 1968 generated at E. Luzon I., Philippines.

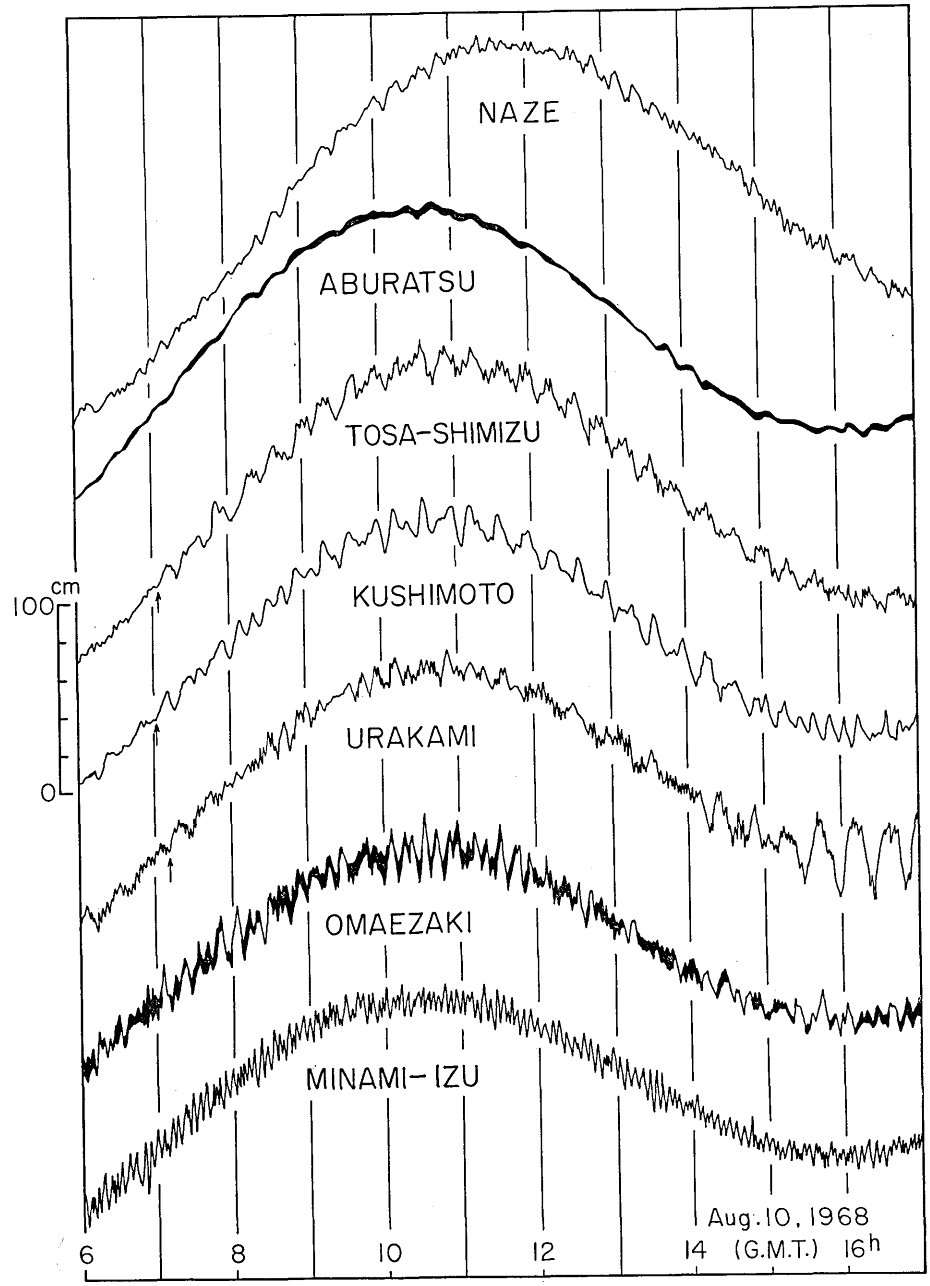

Fig. 7. Tide gauge records of tsunami on Aug. 10, 1968 generated off NE. Celebes I., Indonesia.

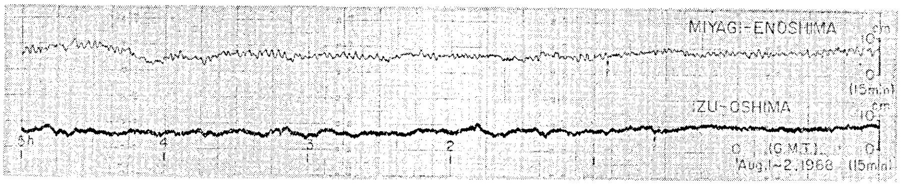

Fig. 8. Feature of long-wave records for the Philippines Tsunami of Aug. 1, 1968, at Miyagi-Enoshima and Izu-Oshima.

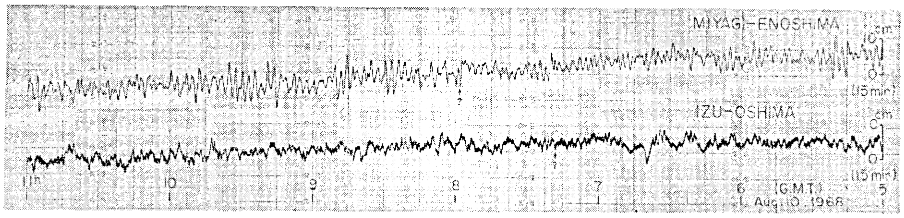

Fig. 9. Feature of long-wave records for the Indonesia Tsunami of Aug. 10, 1968, at Miyagi-Enoshima and Izu-Oshima.

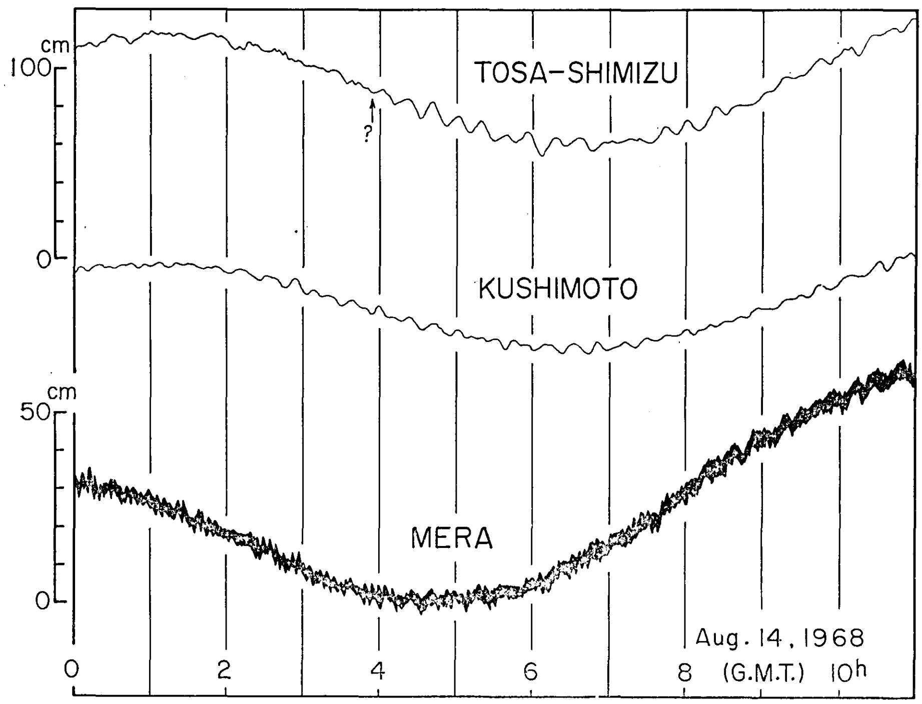

Fig. 10. Tide gauge records of tsunami on Aug. 14, 1968 generated at NW. Celebes I., Indonesia.

References

1) HATORI. T., and R. TAKAHASI, 1964, On the Iturup Tsunami of Oct. 13, 1963, as observed along the coast of Japan, *Bull. Earthq. Res. Inst.*, **42**, 543-554.

2) HATORI, T., 1965, Study on distant tsunamis along the coast of Japan. Part 1, Distribution of tsunami energy and travel time, *Bull. Earthq. Res. Inst.*, **43**, 499-508.

3) HATORI, T., 1968, Study on distant tsunamis along the coast of Japan. Part 2, Tsunamis of South American origin, *Bull. Earthq. Res. Inst.* **46**, 345-359.

4) HSU, M. T., 1961, Seismicity of Taiwan (Formosa), *Bull. Earthq. Res. Inst.*, **39**, 831-847.

5) IIDA, K., COX, D. C. and G. PARARAS-CARAYANNIS, Preliminary catalog of tsunamis occurring in the Pacific Ocean, *Hawaii Inst. Geoph., Hawaii Univ., Data Report No.* **5** HIG-67-10, Aug. 1967.

6) IMAMURA, A., and M. MORIYA, 1939, Mareographic observations of tsunami in Japan during the period from 1894 to 1924, *J. Astr. Geophs. Japan.* **17**, 119-140.

7) IMAMURA, A., 1945, On the tsunami accompanying the eruption of Krakatoa (in Japanese), *Zisin*, **18**, 24-26.

8) LANDER, J. F., editor, 1968, Seismological notes, *Bull. Seism. Soc. Amer.*, **58**, 1175-1182.

9) SATÔ, Y., 1951, Study on surface wave I, Velocity of Love-waves, *Bull. Earthq. Res. Inst.* **29**, 1-12.

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22. 日本太平洋沿岸における遠地津波

第3報　フィリピン，インドネシアの津波について

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フィリピン，インドネシア海域で起きた歴史津波のうち，日本沿岸では，有名な 1883 年 8 月クラカトア火山の噴火による津波が認められた．また 1918 年 8 月セレベス海で起きた津波では，串本において 40 cm の波高が観測されている．同海域で起きた津波を伴なった地震の規模 M は大体 7 以上で，その多くは島弧の西側にあって，日本に対する津波の影響は比較的小さかった．

1968 年 8 月には 3 個，津波を伴なった地震が起り，1 日のルソン島東岸の地震 (M=7.0) と 10 日のセレベス島北東沖の地震 ($M=7^1/_4$) による津波は，日本各地では検潮儀によって観測された．14 日のセレベス西岸の地震 ($M=7^3/_4$) による津波は，日本の記録からは認められなかった．なお 2 個のセレベス津波では，現地付近で津波による被害が報告されている．

8 月 1 日と 10 日の津波は，土佐清水や串本のような岬の地点で 20-30 cm の全振幅となり，他の地域よりも波高が大きく，屈折波の収斂による効果がみられた．東北日本，九州と南西諸島では，四国—近畿地方の波高と較べて，波源からの距離の割に波高は小さい．両津波の伝播図によると，これは日本列島の島弧の向きによって，津波が斜めに入射する効果と考えられる．

カムチャッカ，エトロフ津波のような遠地津波では，日本各地の記録の波形は紡錘形であった．いいかえると第 1 波を観測してから数時間後に最大振幅が現われ，今回の津波も同様な形で観測された．これは大陸棚を伝わるエッヂ波の効果と言われている．記録から第 1 波の伝播時間と第 1 波から大きな波までの時間を読みとり，これらの関係を調べると 2 群に分れた．陸棚を階段形の単純モデルで取扱ったとき．水深比 h_2/h_1 (h_1: 陸棚上の水深，h_2: 外海の水深) をパラメーターとして示すと，今回の津波は $h_2/h_1=5$ と 3 となり，カムチャッカ，エトロフ津波では $h_2/h_1=10$ で表わせた．このように，東北日本と西南日本とでの海底地形の違いが，波形の面からも区別されて興味深い．