ON THE BEHAVIOR OF CHILEAN TSUNAMI IN THE SETO INLAND SEA

BY

Haruo HIGUCHI

ABSTRACT

On 24 May, 1960, a great tsunami, the so-called Chilean Tsunami, attacked Japan. Its behavior in the Seto Inland Sea is investigated and compared with that of the tide.

1. Introduction

A tsunami, which was generated by the earthquake in Chile on 23 May, 1960, attacked our country on the following day. This tsunami was named "Chilean Tsunami" It propagated into the Seto Inland Sea, which is composed of six sea areas, and is 17,000 km^2 in area and 31 m in mean depth. It is connected with the Pacific Ocean and the Japan Sea through four straits, the total cross sectional area of which is about 1/10,000 of the sea area.

The behavior of Chilean Tsunami in this area was invertigated and compared with that of the tide.

2. On the records of the sea level

We investigated the damage caused by the Chilean Tsunami and compiled the records of the sea level on those eventful days at many tidal stations in western Japan. The investigated domain is shown in Fig. 1 by broken line. The records of tide gauges at 135 stations were collected, by using duplicating cameras. Among them, 61 are along the coast of the Pacific Ocean, 49 are of the Seto Inland Sea, and 25 are of the Japan Sea. The location of each tidal station, the data of which are used in this paper, is snown in Fig. 2 by numerals.

The sea levels on 24 and 25 May, 1960, at several representative stations are shown in Fig. 3a $\sim$ 3f. Fig. 3a is along the Pacific Coast, Fig. 3b $\sim$ 3e are along the Seto Inland Sea Coast, and Fig. 3f is along the Japan Sea Coast. These data were analysed.

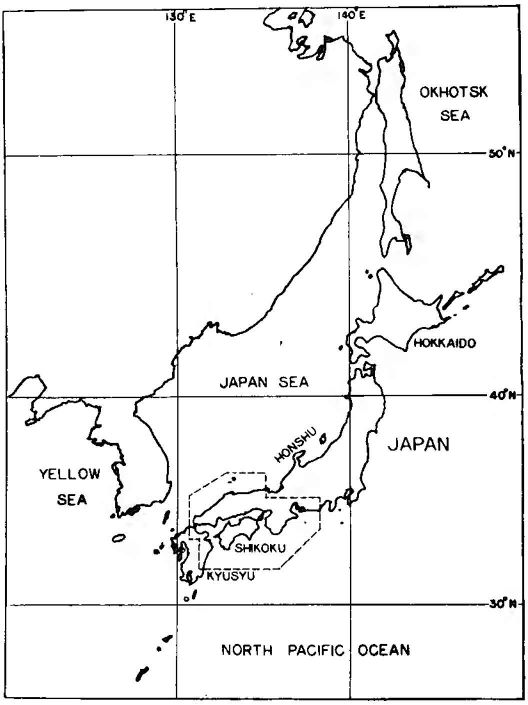


Fig. 1. Surveyed Area.

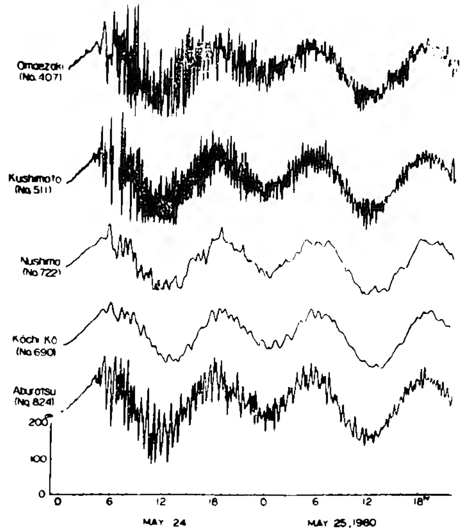


Fig. 3a. Sea level (along the Pacific Coast).

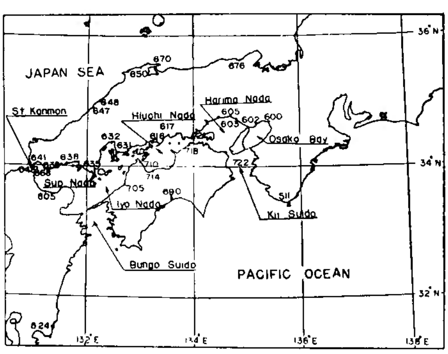


Fig. 2. Tidal Station.

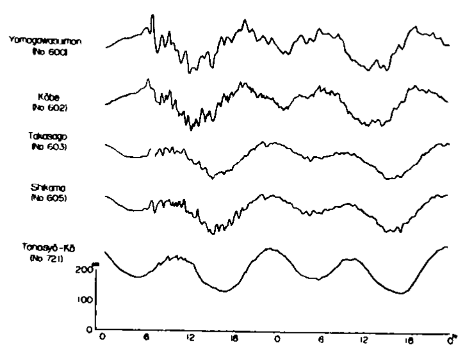


Fig. 3b. Sea level (along the Osaka Bay Coast and the Harima Nada Coast).

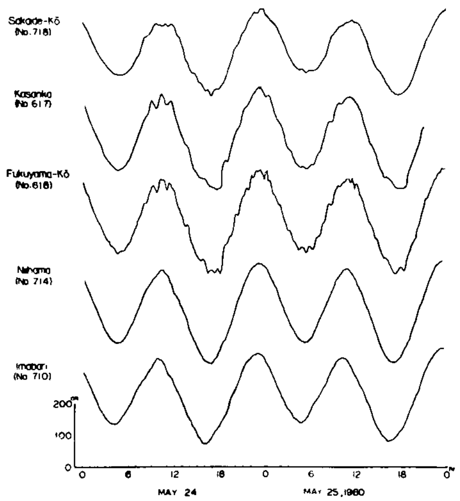


Fig. 3c Sea level (along the Hiuchi Nada Coast).

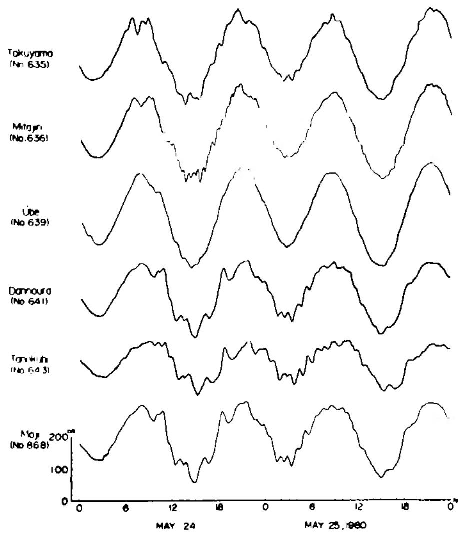


Fig. 3e Sea level (along the Suō Nada Coast).

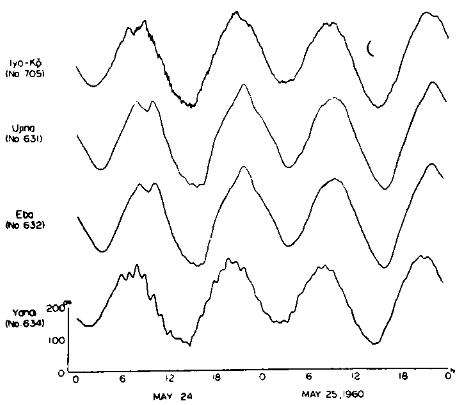


Fig. 3d Sea level (along the Iyo Nada Coast and the Aki Nada Coast).

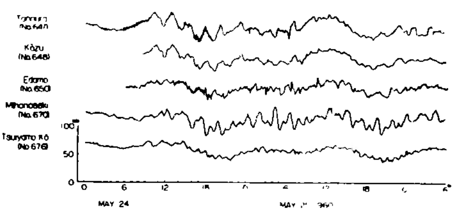


Fig. 3f Sea level (along the Japan Sea Coast).

3. On the results of the analysis

a) First undulation

Chilean Tsunami, which was generated by Chilean Earthquake occured at 4^h 11^m on 23 May, 1960 (the standard time in Japan), arrived in this domain at about 3^h00^m on the following day. The time when the first undulation occured, that is, when this tsunami arrived, is shown in Fig. 1 by numerals. The real line in the sea shows the co-arrival time. It is generally difficult to discriminate the arrival time on the record, therefore it may be decided subjectively by the reader. Consequently, the arrival time is not always exact, but the general tendency may be represented by this figure. From this figure it is clear that Chilean Tsunami progressed into the Seto Inland Sea through the Kii Suido at $1^{h}00^{m}$ and through the Bungo Suido at $4^{h}30^{m}$, and advanced along the nothern coast of Shikoku westward and eastward respectively, and met in the Hiuchi Nada at $7^{h}30^{m}$. The mean velocities of propagation are about 12 m/sec and 18 m/sec respectively. These velocities correspond with the propagation velocity of long wave in the mean water depths of 15 m and 33 m respectively. As the water in these seas are actually deeper than these values, it is considered that although the tsunami progresses faster in the broad sea area, it advances more slowly in the narrow sea area such as straits, and it seems to progress with such lower velocities in all.

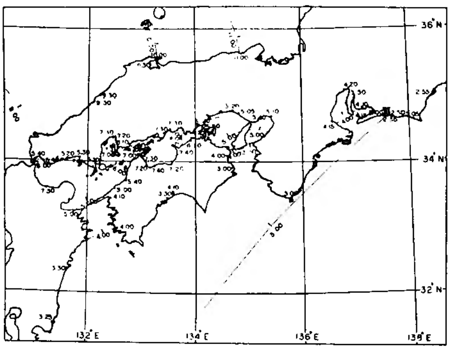


Fig. 4 Arrival time of Chilean Tsunami (the standard time in Japan).

b) Periodgram

The periodgrams for 4 stations along the pacific Coast, 20 stations along the Seto Inland Sea Coast, and 5 stations along the Japan Sea Coast are shown in Fig. 5a ~ 5f. The abscissa of these figures is the period of the oscillation in minutes and the ordinate is the amplitude in cm.

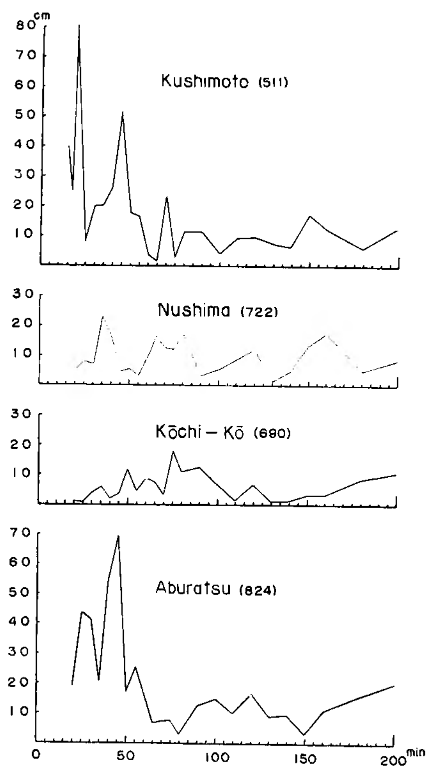


Fig. 5a Periodgram (along the Pacific Coast).

Fig. 5a shows the periodgram along the Pacific Coast. From this figure it is clear that the ocsillations of the period 20, 45, 70, 80, 120, and 150 minutes predominated at Kushimoto (511), which faces the open sea, and they turned into those of 35, 80, 120, and 160 minutes at Nushima (722), inner part of the Kii Suido. Especially, the oscillations of shorter period damped strongly. It is considered that the periodgram at Kōchi-Kō (690) does not represent the character of Chilean Tsunami in the open sea, where the tide gauge is set at the inner part of the small-mouthed bay, therefore we take no notice of it. The oscillation of the period of 25, 45, 100 and 120 minutes predominated at Aburatsu (824). The curve at Aburatsu bears some resemblance to that at Kushimoto. The common period, 25 and 45 minutes, at Kushimoto and Aburatsu may be the predominating periods in the open sea near the Pacific Coast of western Japan.

Fig. 5b shows the periodgram along the coast of the Osaka Bay and the Harima Nada. The curves at Yomogawasuimon (600) and Kōbe (602) are considerably different from each other in shorter period, although these two stations are situated in the same bay. The amplitude of the oscillation in the Harima Nada was generally small in comparison with in the Osaka Bay, and the oscillation of 65 and 110 minutes somewhat predominated.

Fig. 5c shows the behavior in the Hiuchi Nada. At Sakaide-Kō (718) the amplitude is generally small and the curve bears some resemblance to that at Tonosyo-Kō (721) in the Harima Nada. At Kasaoka (617) and Fukuyama-Kō (618), which face the Hiuchi Nada, the curves are considerably different from the preceding two, and the ocsillations of the period of 40, 70, 100, and 120 minutes predominated. At Niihama (714) the general form of the curve resembles those of Kasaoka and

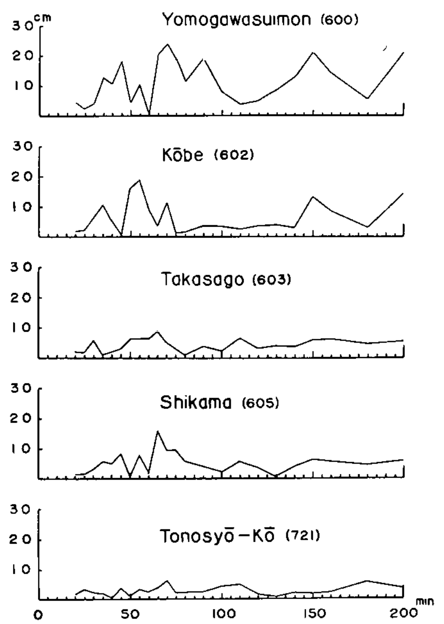


Fig. 5b. Periodgram (along the Osaka Bay Coast and the Harima Nada Coast).

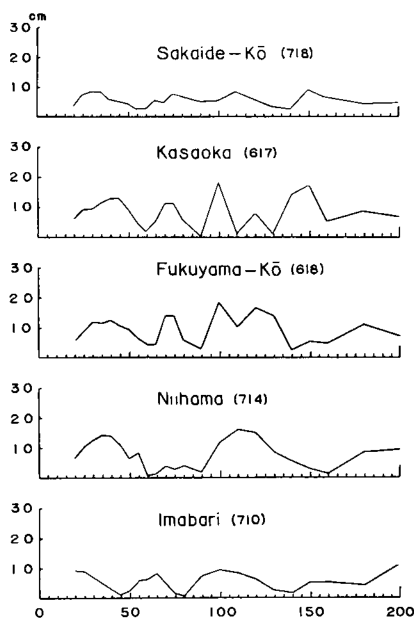


Fig. 5c. Periodgram (along the Hiuchi Nada Coast).

Fukuyama-Kō, but the oscillation of the period of 65 ~ 70 minutes is comparatively slight.

Fig. 5d is of the Aki Nada and the Iyo Nada. The curves at Iyo-Kō (705) and Ujina (631) resemble each other. The curve at Imbari (710) in Fig. 5c is similar to these two with the exception of the period of 140 minutes. The curves at these three stations are generally smooth. The curve at Yanai (634) is considerably different from the preceding three. In the Suō Nada the curves are complex again, which means that the oscillations of various periods co-exist in this sea area. The curve changes its form gradually from eastern part to western part, that is, from Tokuyama (635) to Mitajiri (636) and from here to Ube (639). At the former two, the oscillations of the period of 40, 60, 90 and 120 minutes predominate. but at Ube 40 and 60 minutes only predominate, and those of 90 and 120 minutes cannot be found. At Nakatsu (805), the curve differs considerably from these three, and the oscillation of a shorter period is large, and that of 110 minutes predominates.

The lower three curves in Fig. 5e show the behavior at both sides of the strait of Kanmon. Here the oscillation of the period of 150 ~ 160 minutes predominated. This oscillation is seen at Ube and Mitajiri.

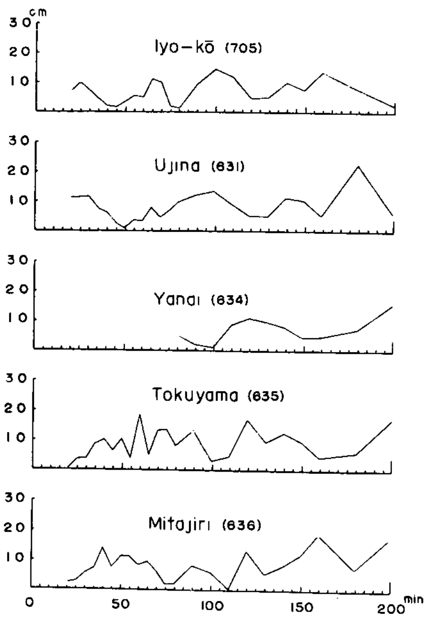
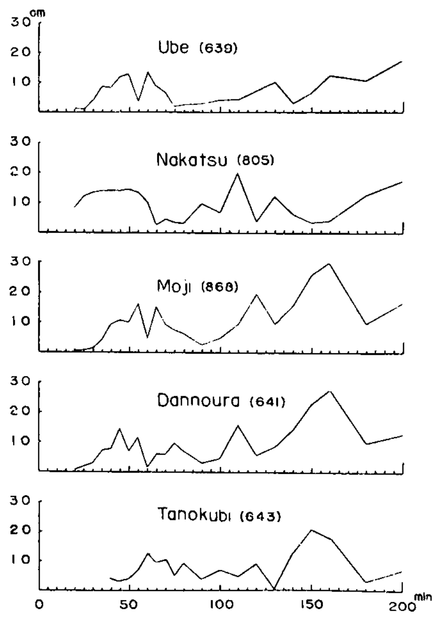


Fig. 5d. Periodgram (along the Iyo Nada Coast, the Aki Nada Coast, and the Suō Nada Coast).



Fig, 5e. Periodgram (along the Suō Nada Coast and the strait of Kanmon).

Generally, the periodgrams of Chilean Tsunami show similar forms in each sea area of the central part of the Seto Inland Sea respectively, for example, the Harima Nada, the Hiuchi Nada, and the Aki Nade, but those in the eastern part, the Osaka Bay, and in the western part, the Suo Nada, do not show similar forms.

With respect to the coast of the Japan Sea, the amplitude is generally small as shown in Fig. 5f, and the periodgrams resemble each other with the exception of that at Mihonoseki (670). In this sea area, the period of the predominant oscillation is generally longer than in the Seto Inland Sea, which is 150 $\sim$ 160 minutes, and coincides with that of the strait of Kanmon. At Mihonoseki, the oscillations of the periods of 75, 130 and 160 minutes predominated.

c) Predominant period

The distribution of period and the amplitude of the predominant oscillation in the Seto Inland Sea are shown in Fig. 6. The numeral shows the period in minutes and that in the parenthesis shows the amplitude in cm. Although it seems that the predominant period has various values at each station, it may be roughly said that it is longer in the western part than in the eastern part. That may due to the dimention of the sea area.

To clarify the validity of this view, the period of main probable seiche is calculated. When the length of the sea is L, the mean water depth is h, and the gravity acceleration is g, the period of fundamental oscillation of the lake is represented by $T=2L/\sqrt{gh}$. Because of the uncertainty in deciding the length and mean water depth of the sea, the actual value cannot be determined. The

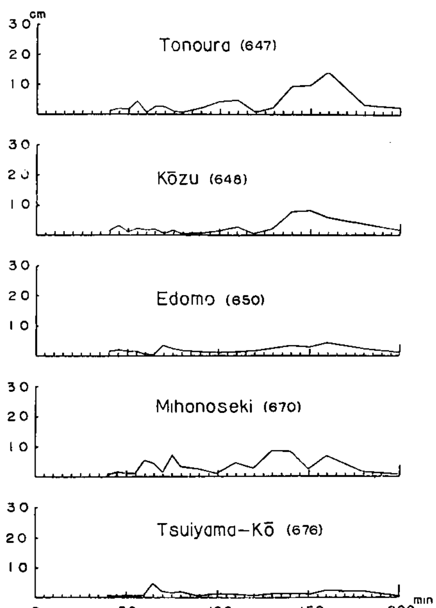


Fig. 5f. Periodgram (along the Japan Sea Coast).

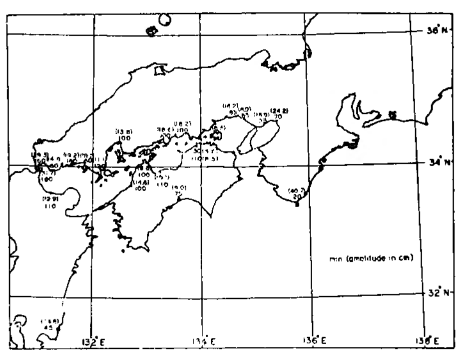


Fig. 6. The period and the amplitude of the predominant oscillation of Chilean Tsunami.

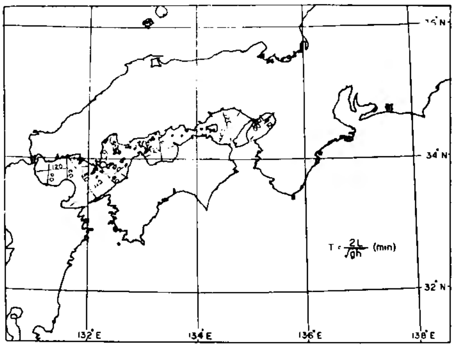


Fig. 7. The period of seiche.

result of the calculation is shown in Fig. 7. As compared with Fig. 6, the period of the seiche coincides with that of the predominated oscillation in some cases, but it dose not coincide in other cases. Therefore it is difficult to explain the predominant period simply by this point of view.

d) Comparison with the tide

The behavior of Chilean Tsunami in this area is compared with that of the tide. Among the many tidal constituents, the semi-diurnal tide (M_2) is chosen because of the importance. Although it may be rash to compare the tide with the tsunami because the tide is not a pure gravity wave, it can be presumed that they have something in common in the sense of the oscillation of the water level of long period. The lag ($K°$) of the semi-diurnal tide is shown in Fig. 8. The numeral in this figure shows the degree, and the line is the co-tidal line. The period of M_2 is about 12 hours, so that 30° corresponds to about 1 hour. As compared with Fig. 4, it is found that the semi-diurnal tide progresses through the Kii Suido and through the Bungo Suido, and meet in the Hiuchi Nada, the same as Chilean Tsunami. The time of travel is about 4 hours for the former and about 3 hours for the latter, which are both longer than those of the tsunami.

The amplitude of M_2 is shown in Fig. 9. From this figure it is found that the amplitude becomes large in a regular manner from the Kii Suido and the Bungo Suido to the inner part of the sea, the Hiuchi Nada and the Suō Nada. Therefore, it may be said that the distribution of the amplitude of the semi-diurnal tide is rather more systematic than that of Chilean Tsunami.

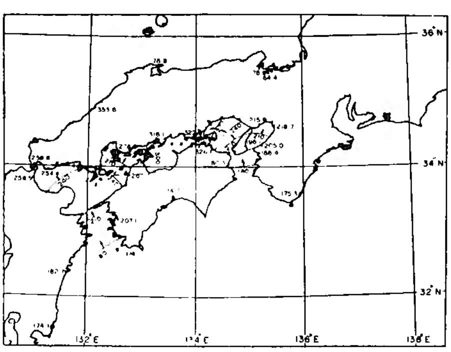


Fig. 8 Lag (K) of M_2 constituent in degree.

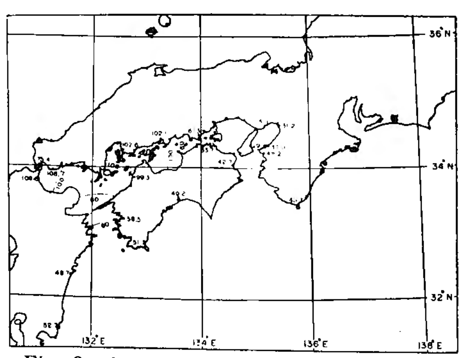


Fig. 9 Amplitude of M_2 constituent in cm.

4. Conclusion

Chilean Tsunami in the Seto Inland Sea was investigated by analysing the records of the sea level at that time, and was compared with the semi-diurnal tide M_2. As to the result, it becomes to be clear that:

1. Chilean Tsunami first progressed through the Kii Suido to the Seto Inland Sea, and then about half an hour later it went through the Bungo Suido, and advanced westward and eastward respectively along the northern coast of Shikoku, and at last met in the Hiuchi Nada three and half hours later. This relation is similar in the case of the semi-diurnal tide, but the time of travel is about half an hour longer than that of the tsunami.

2. There are the typical periodgrams in the Harima Nada, the Hiuchi Nada, and the Iyo Nada respectively, but there is no such periodgram in the Osaka Bay and in the Suō Nada.

3. The predominant period is generally longer in the western part of the Seto Inland Sea.

4. The predominant period does not always coincide with that of the seiche calculated with the use of the mean depth.

5. Although the distribution of the amplitude of M_2 is in a regular manner, that of Chilean Tsunami is not so in both cases of the same period and the predominant period.

Acknowledgement

The author wishes to thank Prof. Shōitirō Hayami, Geophysical Institute, Kyoto University, for his kind guidance.

He is also grateful to those who willingly offered the data and who painstakingly compiled them.