19. *Reflections on the Tsunami of December 21, 1946.*

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1. Synopsis.

It is well known that, in the case of a tsunami, tide gauges show disturbances of sea surface for two days or more. These disturbances are not caused only by the waves which were propagated directly from the origin, but, with the exception of their initial part, also by such waves as are reflected from far distant continents or shallow water waves transmitted along the sea coast. They may include also secondary waves produced in the neighbourhood of tidal stations. The fact that the analysis of mareogram is far behind that of seismogram, is mainly due to the irregularities of the sea coast or to the great varieties of the boundary of reflection.

The authors have ascertained the existence of long-period waves in the tsunami which accompanied the Nankai Earthquake of 1946, and have detected a phase in them which seems to be due to the reflected waves from Guam Island.

2. Existence of Tsunami Waves having Long Periods.

The Nankai Earthquake of Dec. 21, 1946 (Origin time : 04 : 19. J.S.T. Epicentre: $\varphi=33°.0$ N, $\lambda=134°.8$ E, M=8.1[1]) inflicted much damage on the southern coast of Shikoku Island not only through the shock itself, but also through the accompanying tsunami.

Among the tide gauge records of this tsunami, those of Hachinohe, Mera, Itô and Uchiura were available. These records are shown in Fig. 1. They seem to have waves of long period superposed by the short period waves. At the oceanic trench or continental shelves, waves of large wave-length are more easily reflected and suffer less dissipation than waves of short wave-length. Therefore, the phases of reflection are, if there are any, more likely to be detected in the long period waves. In order to separate the waves of very long period from tide

1) H. KAWASUMI, *Bull. Earthq. Res. Inst.* **29** (1951), 481.

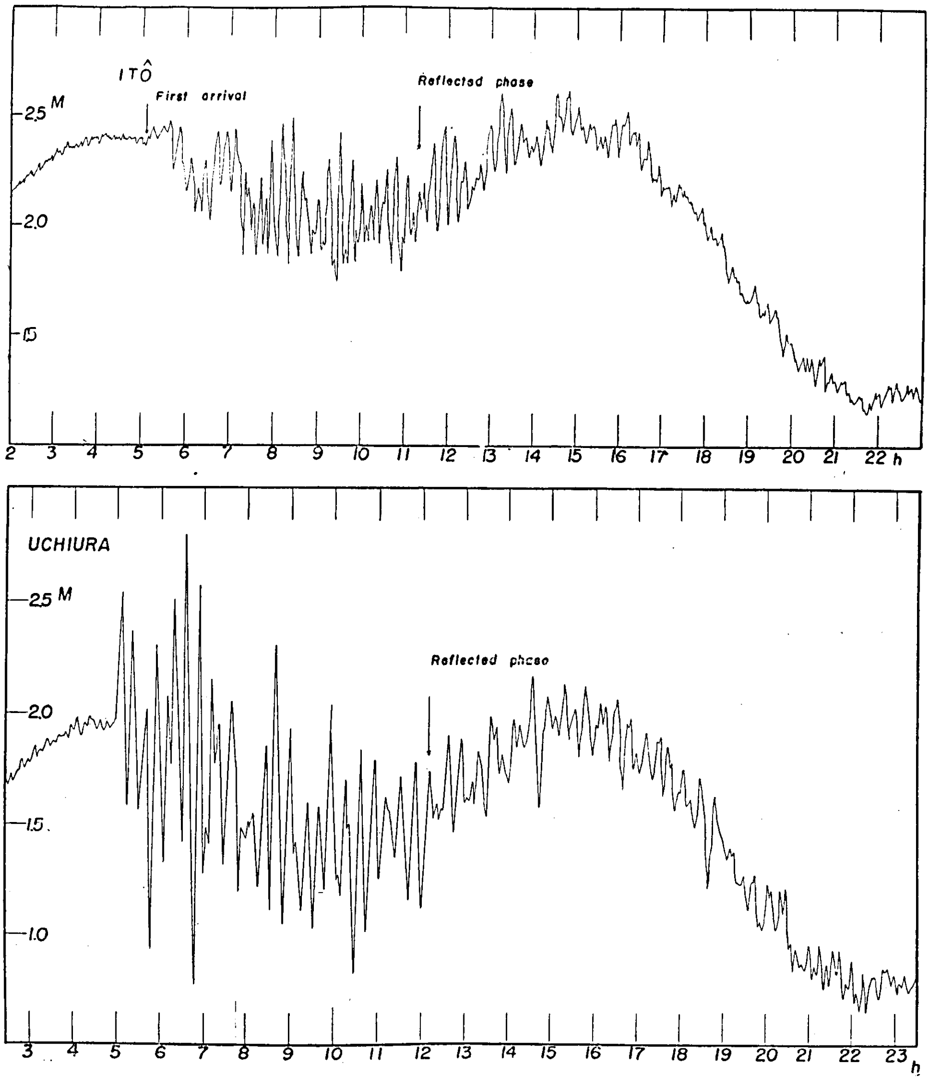

Fig. 1a.

and short period waves in the mareogram of four stations cited above, the tidal variation was at first eliminated by means of the tide curves predicted for the respective stations. Then by means of mechanical low-pass filter of torsion pendulum type[2], which was constructed by one of the authors for seismogram analyses, short period waves were taken away completely after repeating the filtration two or three times.

2) T. AKIMA, *Bull. Earthq. Res. Inst.* **30** (1952), 53.

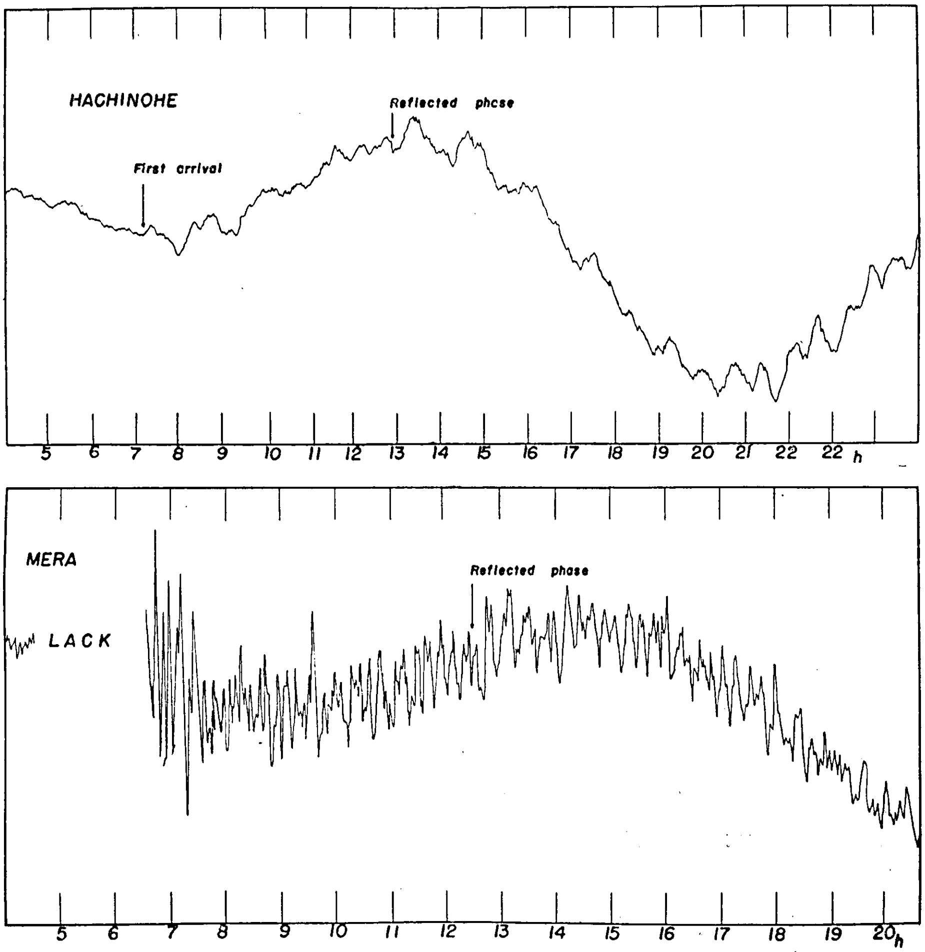

Fig. 1b.

Fig. 2 shows the results of filtration. The obvious fact is that each record has waves of considerably long period, 80 minutes on the average, which appear as early as in the initial phase of the disturbances. A question is raised, however, whether these are propagated really from the origin or whether they are produced secondarily in the neighbourhood of the stations, i.e., in the bay in which the station lies, or at the continental shelves. To answer this question, an attempt was made to collate the records of two different tsunamis, of which the origins are near enough to each other so that the wave paths to a tidal station can be considered almost identical. The tsunami adopted here for this

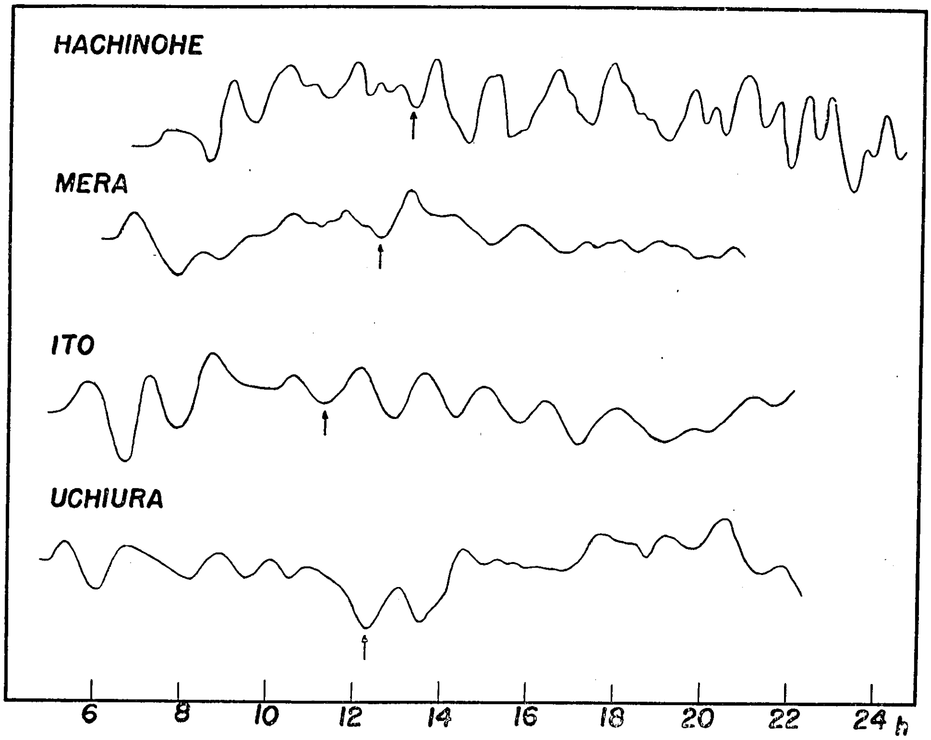

Fig. 2.

purpose is that which accompanied the Tônankai Earthquake of Dec. 7, 1944 (Epicentre: $\varphi=34°.0$ N, $\lambda=137°.1$ E, M=8.3[1]). Filtered records of this tsunami, however, show no waves of long period as in the case of the Nankai Earthquake. Therefore, one may conclude that the long period waves which accompanied the Nankai Earthquake tsunami are not of a local character, but generated at the origin of the tsunami.

3. On the Phase of Reflection.

The resemblance of the shape of filtered records shown in Fig. 2 is very conspicuous. Fig. 3. is the time-period and time-amplitude^2 curves for Itô and Hachinohe. The ordinates indicate the period of each wave (upward) and amplitude^2 (downward) respectively, while the abscissa is J.S.T. The wave periods were first measured from trough to trough and then, from crest to crest and so on. Usually near the origin of tsunami, the first wave is the largest of the train of disturbances, but at a considerable distance, it becomes smaller than the immediately succeeding waves.

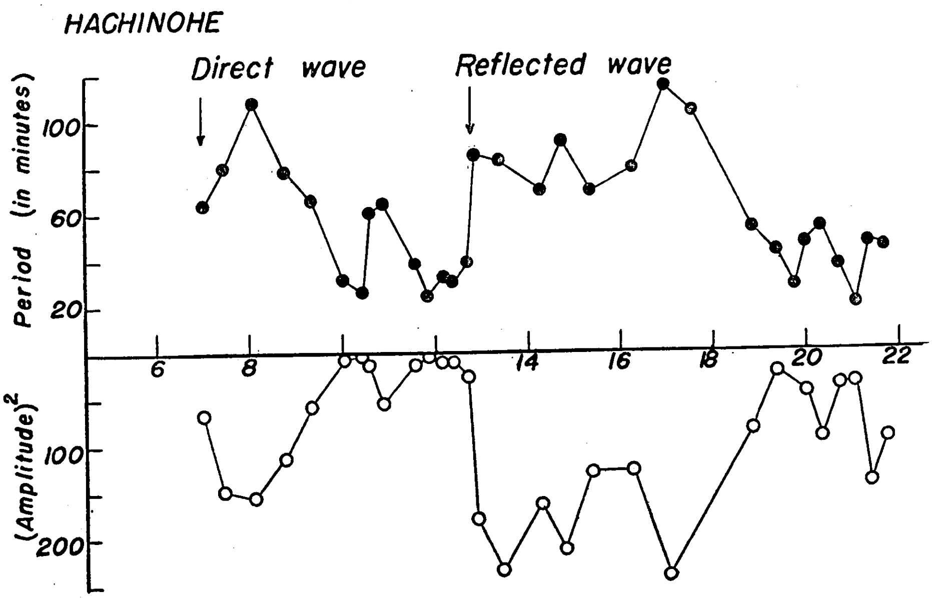
HACHINOHE
Direct wave
Reflected wave
Period (in minutes)
(Amplitude)^2
100
60
20
100
200
6
8
14
16
18
20
22

Fig. 3a.

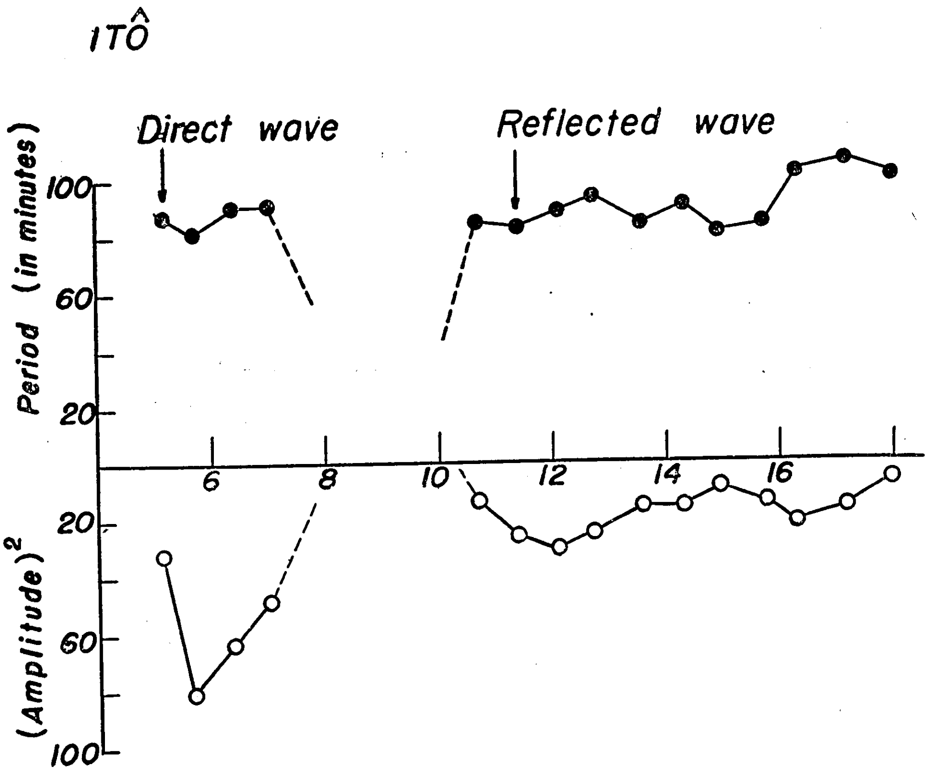
ITÔ
Direct wave
Reflected wave
Period (in minutes)
(Amplitude)^2
100
60
20
20
60
100
6
8
10
12
14
16

Fig. 3b.

As to be seen in Fig. 3, both the period and the amplitude continue to decrease for the first several hours at every station, then quite suddenly they increase by a conciderable amount. This phase appears six or seven hours after the first arrival of tsunami. The first arrival of the direct wave is 07 : 15 at Hachinohe and 05 : 09 at Itô, while the arrival time of the phase in question is 12 : 51 and 11 : 19 respectively.

As there was no remarkable after-shock observed at the corresponding time, this phase can not be another tsunami generated by an aftershock and propagated directly from the origin. It must be a wave which was reflected at some distant coast or islands, and which travelled back through the Pacific Ocean.

4. Determination of the Boundary of Reflection.

In order to determine the boundary of reflection, wave fronts were drawn at intervals of five minutes by Huygens' Principle, assuming that the velocity of propagation of tsunami is $\sqrt{gh}$, where g is the accelaration of gravity and h the depth of the ocean. The starting points were the origin (O), Hachinohe (H) and Itô (I), as is shown in Fig. 4. Time interval between the origin time of the earthquake and the arrival time of the reflected phase at Itô is just 7 hours. Therefore, if the points of intersection of the wave fronts from (O) with those from (I) wherein the sum of the respective travel time is 7 hours are found, the line drawn through these points will be the probable boundary of reflection. The open circles in Fig. 4 are the point of intersection in the case of Itô found in this way and the solid circles are those of Hachinohe.

Though the two boundaries of reflection thus obtained must coincide or at least intersect with each other, in reality they neither coincide nor intersect, which is probably due to the time error produced in the area of shallow water near the coast. In such cases we took the mean of the two lines, the probable boundary of reflection thus obtained lying at Guam Island or Mariana trench. If the reflection happens to occur at an oceanic trench, the phase of the reflected wave must be reversed. But as the reversal of phase is not distinguishable in our case, the most probable boundary of reflection of this tsunami is Guam Island and its surrounding reef.

Theoretically, the amplitude of the reflected waves must be considerably smaller than the direct waves. At Hachinohe, the reflected waves are larger than the direct waves. The problem whether this is

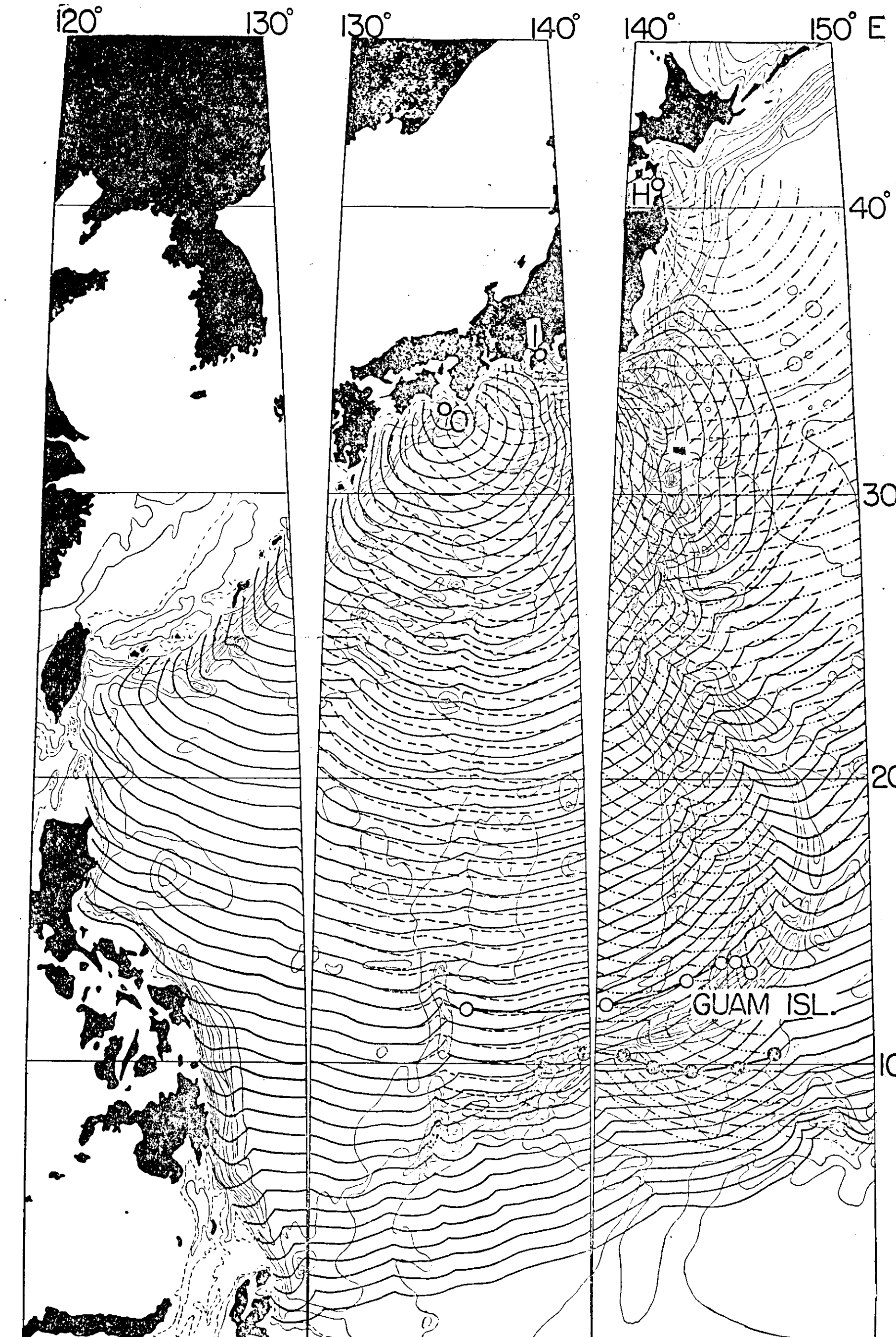

Fig. 4. Path of the tsunami waves of the Nankai Earthquake, Dec. 21, 1946.

due to the diminution of the direct waves transmitting through the sea ridges of Izu Islands or due to some other mechanism still remains unsolved.

Further studies on other later phases of reflection, period increase, dispersion or dissipation of energy of tsunami must be pursued in future.

5. Acknowledgment.

The authors wish to express their appreciation to Prof. R. Takahasi for his valuable suggestions and encouragements throughout this work.

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19. 南海地震に伴つた津浪の反射

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津浪の検潮記録の解析，特に位相の發見に就いて，地震記象のそれに比べて著しく遅れてゐるのは，反射境界面が複雑である事，又海岸の形が不規則であつて，海岸附近で二次的に生成される波が澤山ある事などの爲めである．

著者等は南海地震に伴つた津浪の 4 箇所の検潮記録から，低域濾波器を用いて短週期の波を取り去つて見たら，平均 80 分位の非常に長週期の波が殘る事が判つた．それが，地震後七時間位して，振巾・週期共に大きくなつてゐる位相に目を付けて，その位相が Guam 島附近から反射して來た反射位相であらうと云ふ事を作圖に依り結論した．