12. On the T Phase of Seismic Waves Observed in Japan

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Introduction

In these years, M. Ewing, F. Press, L. Don Leet, and many other authors investigated the T phase of the seismic waves and drew the attention of seismologists. The T phases were observed from seismograms obtained at various seismological stations in U.S.A. and Canada, which record the earthquakes that occurred in the Pacific and Atlantic region, particularly the Dominican earthquakes.

The authors studied the seismograms of the Japanese seismological stations and found the T phases, especially clearly in the seismograms recorded by Ishimoto's seismograph installed at Torishima Island (30° 29' N, 140° 18' E). Among many T phases observed, that of the Yoshino earthquake of July 18, 1952 made us surprise by its extraordinary predominance, in spite of its epicenter being located in an inland of Kii Peninsula.

In this paper, all the observational data of T phase obtained up to the present by the Japanese seismological network are shown and the investigation into the mechanism of transmission of T waves are done using these data.

§ 1. Observational Data of T Phase

Some typical examples of seismograms in which T phases were observed are shown in Fig. 1. As is seen in the figure, the T phase arrives about four times later than the S does after the incidence of P, and is characterized by its rapid oscillation even though the amplitude is very small when observed by a seismograph of rather long period*. In some cases, it is noticed that T wave begins with small oscillation and after several or tens of seconds is followed by a train of larger waves. These two phases are tentatively called as T₁ and T₂, respectively.

In Table I are tabulated the data of T phases observed at Torishima, Shionomisaki and some other stations, and in Table II, the maximum amplitudes of P, S and T phases observed at Torishima in order to show the relative magnitude of these phases.

*) Wiechert's seismographs (T=3-6 sec. V=70-90) are generally used in the Japanese seismological stations.
§ 2. Natures of the T Phase

Ewing and others concluded that the T phase is propagated across the ocean as compressional waves in the water. They obtained $1.49 \pm 0.2\text{ km/sec.}$ as the mean velocity of that phase by the observations of...
27 circumpacific shocks, which agrees well with the value 1.48 km/sec. obtained by SOFAR observation by Anderson.

In the adjacent sea of Japan, the depth of the axis of sound channel and the velocity are 800–1000 m and 1.47–1.48 km/sec. respectively in the southern sea, and 400–700 m and 1.46–1.47 km/sec. respectively in the northern sea, as is seen in Fig. 2.

In Fig. 3, a travel time curve of 1.47 km/sec. is drawn to show the general tendency of observed travel times of T phases. As is seen in the figure, the time of arrival of T phases are in most cases earlier than that expected by the curve, especially in the case of deep-seated earthquakes. This shows that the T phase travels through land and shallow water paths which are not negligibly small compared with that through ocean.

As stated before, the T phase observed in Yoshino earthquake is particularly noticeable and the topography near the epicenter is illustrated in Fig. 4. It seems that the SV waves sent from the hypocenter, 70 km in depth, emerged at the continental slope which lies at a distance from the epicenter comparable to the depth of hypocenter, and generated sound waves in the water. The sound waves thus raised will travel through the ocean water along the sound channel without any considerable attenuation. The travel time thus calculated, taking into consideration the land and shallow water paths near the station, closely agrees with that of T phase observed.

As for the T phase of the earthquake (No. 16), quite a similar interpretation is applicable. In this case the epicenter of the earthquake is located in the neighborhood of the Ryukyu Islands and its focal depth is 240 km, and the continental slope lies in the sea east to the islands at a distance of about 260 km from the epicenter.
Thus, also in case of other earthquakes the observed travel times of $T_2$ are generally in good coincidence with those calculated by the same consideration as mentioned above.

On the other hand, the amplitude of the $T_1$ phase is generally very small and its accurate time of arrival difficult to obtain. It is supposed, however, by the travel time of $T_1$ phase that this phase is first sent from the focus as P or SV wave and arrives at a place of sea bottom about 2-3 times the focal depth from the epicenter, and becomes the sound wave through the water. In short, the elastic wave path of $T_1$ phase is 2-3 times longer as compared with that of $T_2$ phase. The difference between the two arrival times $T_1$ and $T_2$ is nearly proportional to the focal depth of each earthquake as is seen in Table I. It is not, however, able to give adequate explanation at present why it has come to be so.

It is worthy of our notice that the arrival times of $T$ phases observed in the cases of earthquakes (Nos. 17 and 18) occurred in the Japan Sea are too late to be regarded as ordinary $T$ phases. Considering from the arrival times of these $T$ phases, they seem to be reflected waves, being reflected at the continental border as shown in Fig. 2.
§ 3. Discussion

It is rather difficult to get an accurate value of propagating velocity of T wave through the sea water in this investigation, because the land and shallow water paths are not definitely determined in respective cases. But it seems to the authors that the T wave is generated at the ocean bottom by the SV (and P) wave emitted from the focus and that the existence of the steep slope of the sea bottom plays an important part. Of course, the sound wave through the sea water must be raised strongly at some place of the oceanic basin, and most favourable in case the depth agrees with that of the axis of sound channel. This condition will be well fulfilled when the steep slope exists at a distance of approximately the depth of focus from

Fig. 2. Paths of T phases

Depth of the sound channel axis and the velocity there are as follows:

(a) 350 m, 1454 m/sec. (b) 200, 1451 (c) 370, 1464 (d) 500, 1473 (e) 650, 1472 (f) 850, 1477 (g) 800, 1470 (h) 803, 1473 (i) 1000, 1480 (j) 1000, 1476
the epicenter. For reference, in Table III is shown the energy which goes into the water across unit area at the surface of sea bottom by the incidence of P and SV wave, taking the whole energy of each wave sent from the focus as unity.

We can see from the table that the sound wave in water is produced most efficiently in the epicentral region by the incidence of P and at a place where the epicentral distance is comparable to the focal depth by SV.
Fig. 4. The Yoshino earthquake and the topography of its epicentral region

Table III. Energy of sound wave raised in the water by the incidence of seismic waves ($10^{-4}$ km$^{-2}$)

- $h$: Focal depth
- $\Delta$: Epicentral distance

<table>
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<tr>
<th>$\Delta$ km</th>
<th>Incident P 80 km</th>
<th>Incident P 200 km</th>
<th>Incident SV 80 km</th>
<th>Incident SV 200 km</th>
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<tr>
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By the way, the present investigation shows that the observation of T phase cannot give us a valid standard for tidal wave warning.

§ 4. Acknowledgment

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References

3) "The Results of Marine Meteorological and Oceanographical Observations, 1949 and 1950" published by Central Meteorological Observatory, Tokyo.