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SOURCE-MECHANISM OF THE CHILEAN EARTHQUAKE FROM SPECTRA OF LONG-PERIOD SURFACE WAVES

By

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Abstract

The Abuyama seismograms of the great Chilean Earthquake of May 22, 1960 were studied. Leng-peried Rayleigh waves R_3 and R_4 read, digitized, and Fourier-analyzed. The directivity function, defined by Ben-Menahem, was computed from amplitude ratio R_3/R_4. A fault of 1 200 km, with an azimuth of W80°S, and a rupture velccity of 3.5 km/sec gave the best fit to the result obtained by Press and others.

1. Introduction

The great Chilean Earthquake of May 22, 1960, gave many important informations for seismology. The long-period surface waves from this earthquake were also obtained from the Galitzin type seismographs at Abuyama Seismological Observatory of Kyoto University. The anlysis of seismograms of the great Chilean Earthquake have given the results for free oscillations of the earth and for the phase and group velocities of long-period surface waves.

Press, Ben-Menahem and Toksöz [1961] gave some preliminary results of determining fault parameters of earthquake focus, namely fault length and rupture velocity, from analysis of long-period surface waves. This study was also made using the Mongolian Earthquake of December 4, 1957, by Ben-Menahem and Toksöz [1962]. The theoretical bases for this method have been described by Ben-Menahem [1961]. He defined the directivity function under the basic assumption that the faulting process may be represented by a moving source. That function is equal to the ratio of spectral amplitudes of waves leaving the sourve in opposite directions and depends upon the fault length, the rupture velocity and the direction of the fault. This method is independent of the instrumental character, since we can use even- and odd-order surface waves recorded at the same station.

In this paper we made analysis of only R_3- and R_4-trains of the seismograms recorded at Abuyama Seismological Observatory. According to the results of Press et al. [1961], the Abuyama station is located in unfavorable position with respect to the fault, since it was located near the nodal lines of radiation pattern. Furthermore, the traveling distances of waves leaving the source in opposite directions are not very different each other, and so R_3- and R_4-trains cannot be separated perfectly. Thus we were interested in examining whether it is possible to determine the fault parameter using directivity function even under such unfavorable conditions.

2. Data and analysis

In analysis we used Rayleigh waves, and then we used the vertical component of Galitzin-type seismograph. Constants of this instrument are shown in Table 1 and the response curve of seismograph galvanometer system is shown in Fig. 1. This instrument has maximum sensitivity at about 10 sec., and at 100 sec. the response drops off 10^{-1} times less than the peak value. Consequently, because of the large

Table 1. Constants of Galitzin-type vertical seismograph

V_{max}	860	h_1	1.4
T_1 (sec.)	8.0	h_2	1.0
T_2 (sec.)	81.0	σ	0.1

V_{max}: Maximum magnification
T_1 : Period of pendulum
T_2 : Period of galvanometer
h_1 : Damping coefficient of pendulum
h_2 : Damping coefficient of galvanometer
σ : Coupling factor

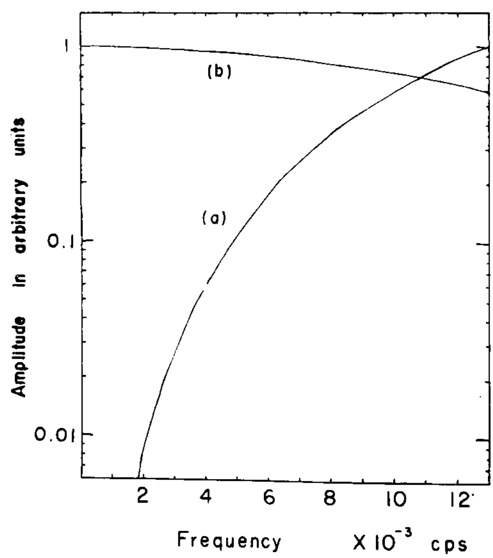

Fig. 1. (a) Response of seismograph-galvanometer system,
(b) Digital-filter response,

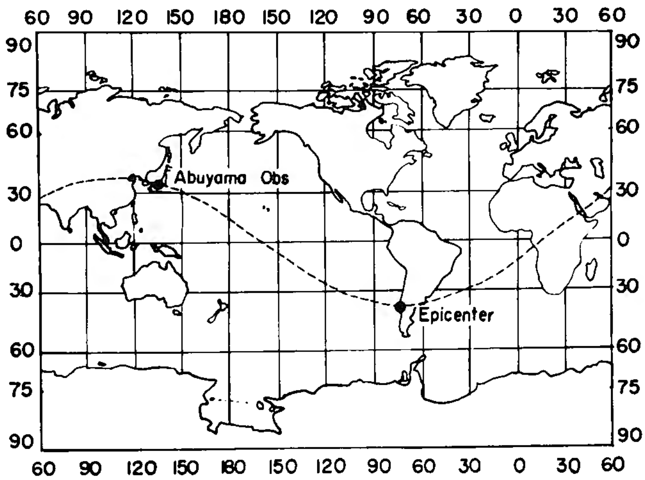

Fig. 2. Great-circle path of the Chilean Earthquake of May 22, 1960 from the epicenter to the Abuyama Observatory.

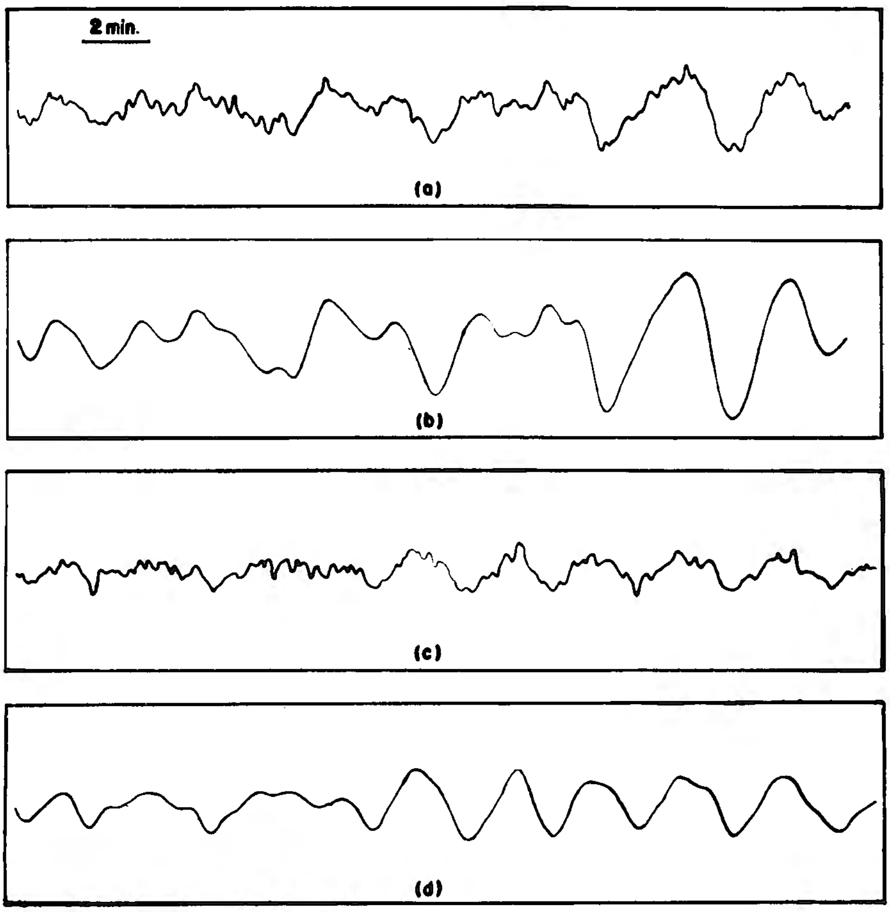

Fig. 3. Traced records.
(a) R_3-original (b) R_3-filtered (c) R_4-original (d) R_4-filtered

high-frequency components and the light traces, it was impossible to follow the R_1- and R_2-trains. However, R_3 and R_4 could be traced clearly.

The great circle path from the epicenter to the station is shown in Fig. 2. The epicentral distance was 17,400 km and the travelled distances of R_3- and R_4-trains were 57,400 km and 62,600 km, respectively. The difference of these values was not so sufficient as to separate these trains clearly. Therefore, we were afraid that the beginning of R_4-train may be superposed on the end of R_3-trains. We, therefore, preferred to asign a group-velocity window in order to determine R_3 and R_4 wave trains. We cut the R_3-train with the minimum group velocity of R_3 which corresponds to the latest group arrival of the Airy phase. And at the same time we assumed that the latest group arrival of R_3 corresponds to the onset of R_4-train. Thus we chose the range of 3.86 km/sec$\sim$3.50 km/sec for the group velocity, which corresponds to a period range of about 80$\sim$300 sec. The separated (unfiltered) records of R_3 and R_4 are shown in Figs. 3-(a) and (c). Each wave train was digitized at 3/2 sec. intervals. In the beginning the linear trend of zero line was removed from the data with the least square method. Before the Fourier analysis the data were filtered with a 39-

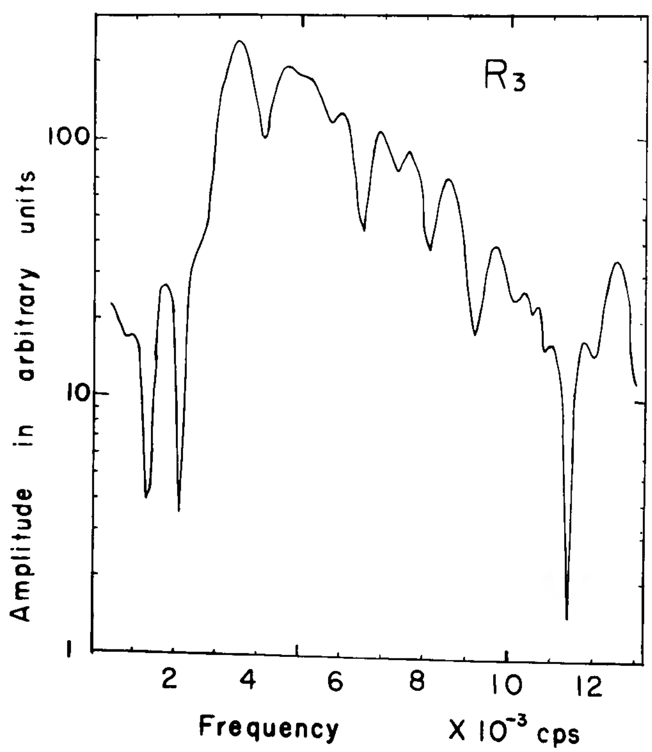

Fig. 4. R_3 amplitude spectrum.

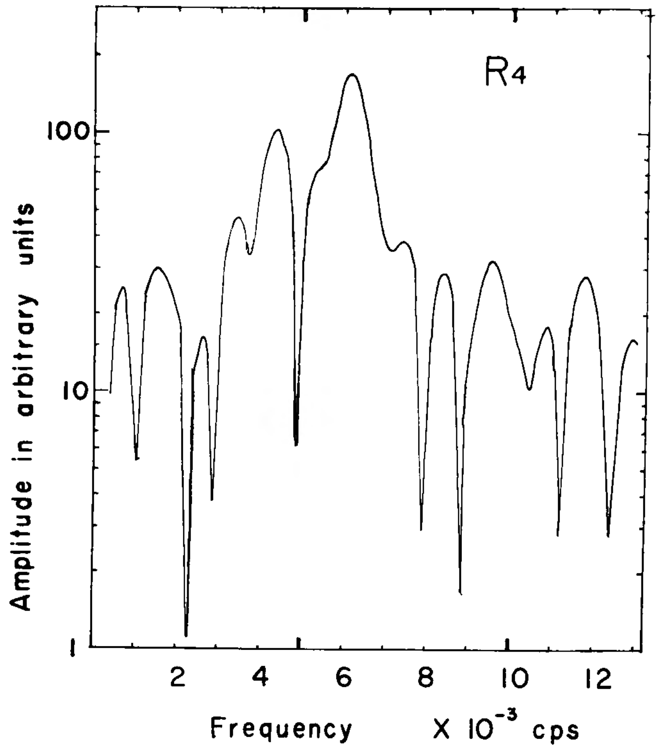

Fig. 5. R_4 amplitude spectrum.

coefficient triangular low-pass digital filter. The response of the filter is shown in Fig. 1. The filtered records of R_3 and R_4 are shown in Figs. 3-(b) and (d). In Fourier analysis the data at 6 sec. intervals were analysed using the Filon's method (Filon, [1928-1929]). The amplitude spectra from the filtered R_3 and R_4 are given in Figs. 4 and 5.

3. Directivity function

Ben-Menahem [1961] defined the directivity function in order to express the effect of the source finiteness on radiation of seismic waves from finite sources. The directivity function is equal to the ratio of spectral amplitudes of waves leaving the source in opposite directions when the oscillators move along the fault. Theoretically this function is given by

$$D = \left| \frac{(C/V+\cos\theta)[\sin \pi b/\lambda(C/V-\cos\theta)]}{(C/V-\cos\theta)[\sin \pi b/\lambda(C/V+\cos\theta)]} \right|$$

where

b: fault length, V: rupture velocity, θ: angle between the fault line and the great circle from the fault to the recording station, C: the phase velocity, λ: the wave length.

The numerator of the ratio corresponds to waves leaving the source in the direction of rupture. The experimental directivity was obtained from the ratio of the amplitude spectra of R_3 and R_4. In Fig. 6-(a) we show the result of $R_3(\omega)/R_4(\omega)$. The theoretical curve which was calculated by giving appropriate values for V, b and θ is compared with the experimental curve. The calculations were made for about 50 sets of the values of V, b and θ. But only two examples of those are shown in Figs. 6-

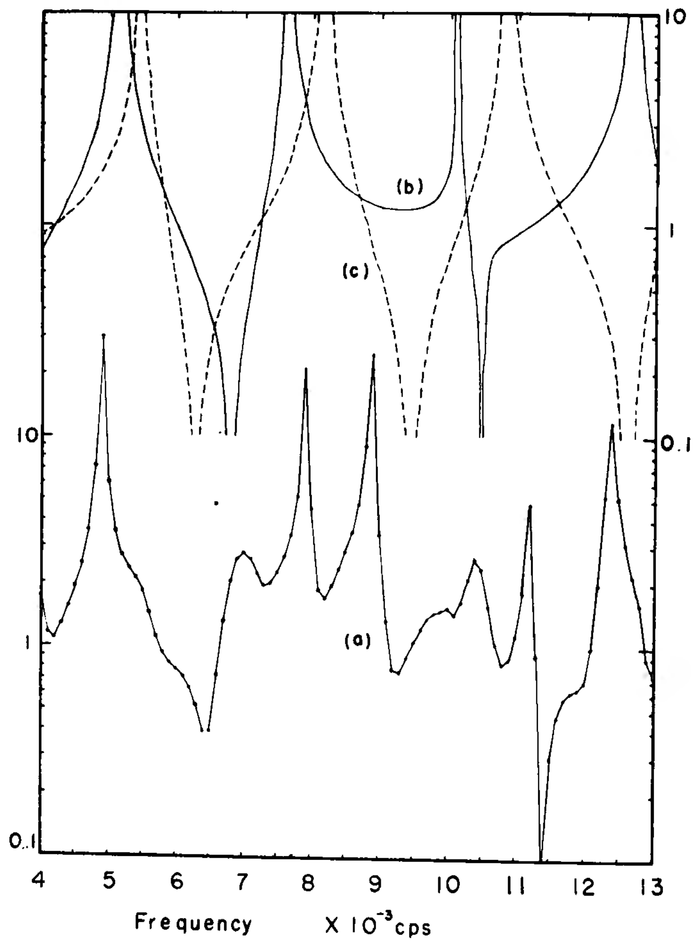

Fig. 6. Directivity functions.
(a) Experimental
(b) Theoretical, V=3.5 km/s, b=1,200 km, θ=80°
(c) Theoretical, V=3.5 km/s, b=1,200 km, θ=85°

(b) and (c). Of course, these values are not able to be determined uniquely. But, since the curve varies in differnt way with each of V, b and θ, it is possible to obtain the best fitted values for V, b and θ by the trial and error method. In this case the best curve for the experimental data was obtained with $b=1{,}200$ km, $V=3.5$ km/sec and $\theta=80°$. These results agree well with the values given by Press et al. [1961]. They obtained the fault length of 800~1,400 km range and rupture velocity close to shear waves in crustal rock, using three methods. On closer examination, however, there are some discrepancies between the theoretical curve and the observation. And at the frequency of about 9×10^{-3} cps, there is a peak in the observed directivity, but not in the theoretical curve. At present, however, it is impossible to interpret these discrepancies clearly. Though the spectra of R_3 and R_4 should be corrected for the effect of absorption, we took no account of it. For such effect may be considered to be small, since the path difference of R_3 and R_4 is not so large, and further the absorption coefficient is hard to regard as constant through the medium of path. Nothing that these fault parameters have not been able to be determined so sharply, as was indicated by Press et al. [1961], we can consider our results to be reasonable.

4. Conclusion

We obtain the directivity function of the Chilean earthquake from the record of the Abuyama Seism. Obs. The results of fault parameters of $b=1{,}200$ km, $V=3.5$ km/sec, and $\theta=80°$ are good agreement with the results from Press et al. [1961] and

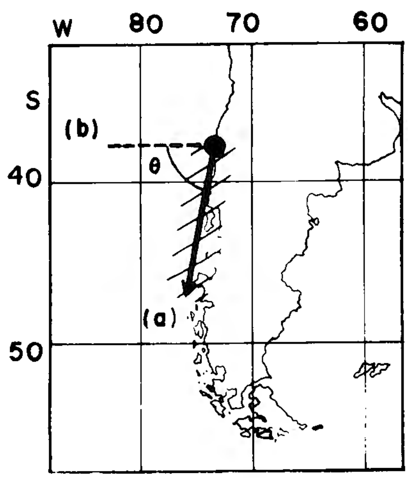

Fig. 7. Fault direction of the Chilean Earthquake of May 22, 1960, deduced from the directivity function ($V=3.5$ km/s, $b=1{,}200$ km, $\theta=80°$).
(a) Direction of fault
(b) Direction of the Abuyama Seism. Obs.

from the phase shift of free oscillation of the earth (Benioff et al., [1961]). Considering the type of the radiation pattern and the partial superposition of R_3 and R_4, Abuyama Obs. is not located in favorable position. But we found the directivity was fairly well determined. Hence we consider that this method is useful owing to the less effect of the condition of station so far as we use the surface waves.

Acknowledgements

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