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Ultrasonic Modelling of a Moving Source

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Abstract. An ultrasonic model experiment simulating a finite moving source in a plate is described.

The source consisted of five identical piezoelectric transducers, which were triggered one after another to form a delay-line. The "rupture velocity" was kept constant.

The directivity, as introduced by Ben-Menahem, was computed and a good agreement was found between the observations and theoretical predictions. Some differences result from the fact that a discrete number of single sources have been used instead of a continuous moving source, as required by theory.

Key words: Moving source – Model seismology – Directivity.

Introduction

In order to use seismic model experiments as an aid in the study of earthquake phenomena, it is desirable to simulate the effect of fracture upon the generation of seismic waves. This can be achieved by modelling a moving source. Thereby no restrictions exist in principle with respect to the complexity of the structure employed.

The effect of the moving source upon the spectrum of seismic surface and body waves was investigated by Ben-Menahem (1961, 1962 resp.). He showed that the spectrum is modulated by a function depending on fracture velocity and fracture length. The theoretical method was successfully applied to earthquake data and was also tested by an ultrasonic model experiment (Press et al., 1961). In this experiment the receiver instead of the source was moved, making use of the theorem of reciprocity. For practical purpose, however, it seems more suitable to model a moving source directly. This can be done in a number of different

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ways. It has been possible for us to model a P-wave source which moved unilaterally with constant "fracture velocity". In the same way Schick and Schneider (1964) used a set of three shearing transducers to study the generation of a head wave, but no quantitative treatment with respect to Ben-Menahem's formulas was presented.

The source, which will be described in the following chapter, has the advantage of being reproducible. This can hardly be achieved by modelling real fractures as has been done by Mansinha (1964) and Savage and Hasegawa (1965), among others.

The 2-Dimensional Ultrasonic Model

There are several different possibilities of modelling the seismic effect of a propagating fault in a plate model:

a) One could generate a moving crack, which has the disadvantage of being non-reproducible. This, therefore, was not suitable for our purpose.

b) A dilational wave in a rod, attached to the plate's surface, will act as a continuous source of elastic waves in the plate at the area of contact. This has been suggested by Koenig (1974, personal communication). The angle between the rod and the plate will control the propagation velocity of the source, which is equivalent to the fracture velocity v_F. Velocity control is best obtained in the

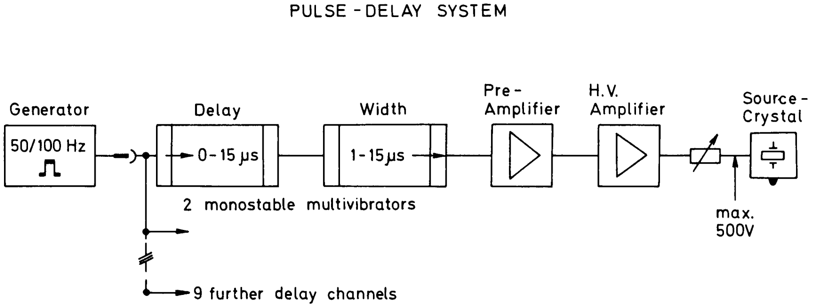

Fig. 1. Schematic diagram of the apparatus used (after Behle et al., 1975)

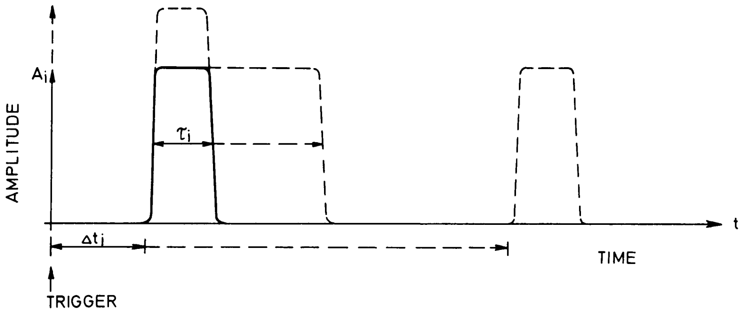

Fig. 2. Schematic representation of the variables of the delaying-system

case of plane wave propagation in the rod. This proved, however, difficult to achieve.

c) A sequence of n sources distributed in the plate and triggered successively with a time-delay $\Delta t_i = (i-1) \cdot \Delta t$, $(i=1, \dots n)$ can also be used for the purpose. This method has also been suggested by Press et al. (1961) and represents an experimental approximation to the theoretical concept of Ben Menahem. We have made use of this method with five equivalent sources.

A delaying system has been developed by R. Herber and R. Nortmann[1], which can be used to trigger up to 10 sources (Fig. 1). It has been built in the electronics laboratory of the Institute of Geophysics, University of Hamburg.

Each channel consists of two monostable multivibrators. The first one sets the start at the time Δt_i, whereas the second one controls the duration τ_i of a rectangular voltage pulse of variable amplitude (Fig. 2). The time-settings Δt_i and τ_i can be continuously varied between 0 and 15 µsec and are reproducible with an accuracy of ± 0.5 µsec. The amplitude A_i of the pulse can be chosen between 0 and 500 Volt (see also Behle et al., 1975).

In the experimental setup the delaying system is used to pulse 5 piezo-electric transducers of PZT ceramics (Vernitron Ltd., England) of outer diameter 6.5 mm. We chose tubes with approximately isotropic radiation of mainly P-waves, thus simplifying the experimental conditions. The tubes are put into a homogeneous aluminium plate, centres 7.5 mm apart, forming a line (Fig. 3). The fracture length $L_0 = 30$ mm is defined by the distance between the centres of the outermost tubes. The crystals are triggered to simulate a constant fracture velocity $v_F = 2.9$ mm/µsec. This corresponds to approximately half the velocity of the longitudinal plate wave in aluminium.

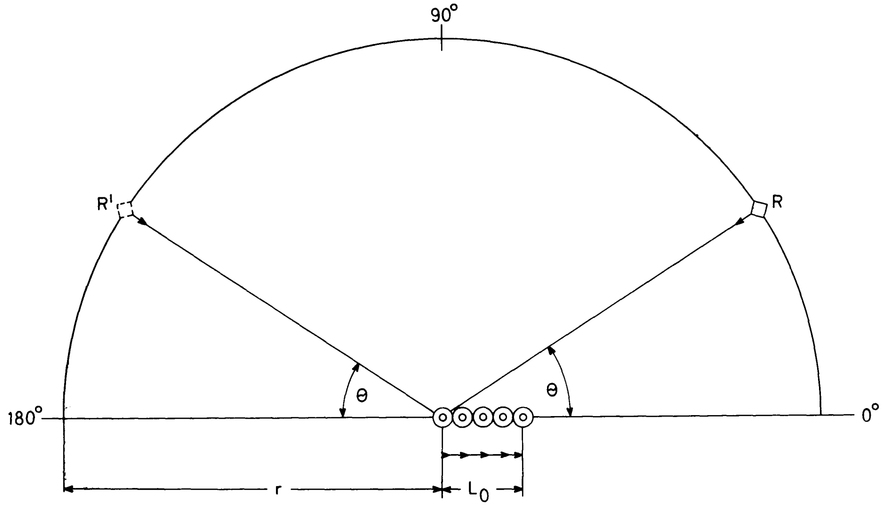

Fig. 3. Corresponding pairs of seismograms were picked up at positions R and R'

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[1] R. Herber und R. Nortmann, Institut für Geophysik, Bundesstr. 55, D-2000 Hamburg 13

A multimorph transducer was used to record the radial component of motion. Thus we only consider the longitudinal plate wave P which is analoguous to the dilatational wave in the three-dimensional case. If excited individually, the crystals yielded at any point of observation signals identical in shape for all practical purposes. Diffraction at neighbouring crystals has little influence on the results (Rohde, 1975) and shall not be discussed here. Recordings were made at 10° intervals along a half-circle with a radius of $r=35$ cm around the source (Fig. 3).

The effect of source propagation will be significant only, if the fracture length L_0 is at least of the order of the dominant seismic wave length. The duration t of the fracture should be at least of the order of the dominant signal period T. Both conditions are approximately fulfilled in the experiment, as $L_0=30\,mm$, $\lambda\approx 36$ mm, $t\approx 10\,\mu$s, $T\approx 7\,\mu$s.

Results

Seismograms were recorded on magnetic tape, digitized and processed on the CDC 1700 computer of our Institute. The recording device has been described by Koenig (1969).

The vector directivity D of the P-wave signals was computed according to Ben Menahem's method (1962). For this purpose we used corresponding pairs of observations at R and R' (see Fig. 3) which are symmetrically placed with respect to the source. Figure 4 shows the values of the *directivity function* $|D|$, computed

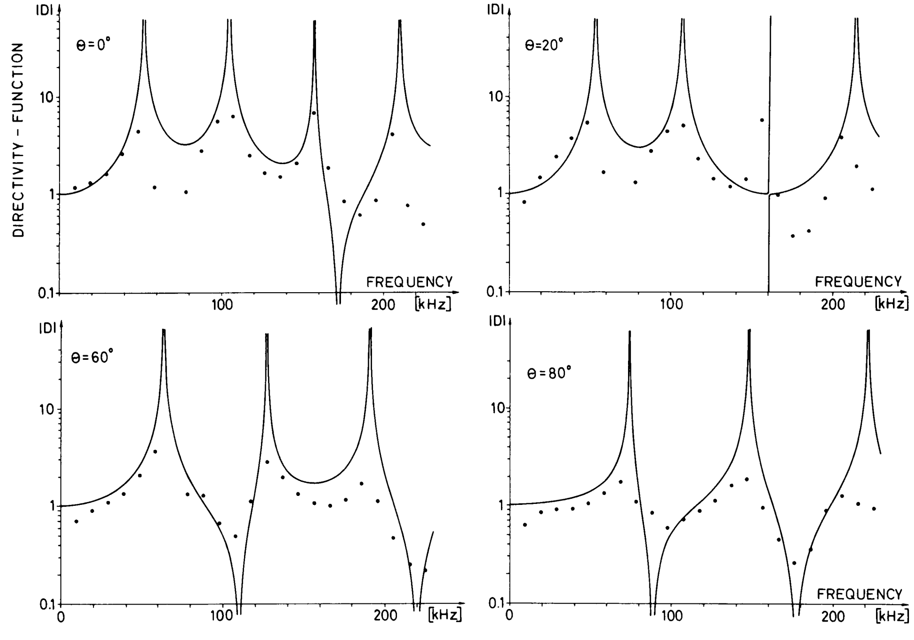

Fig. 4. The experimental (points) and theoretical (solid lines) directivity functions for some angles θ

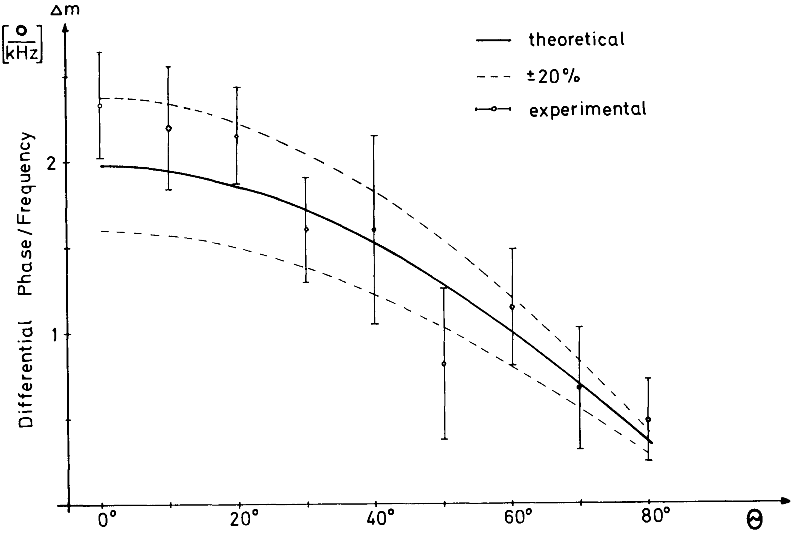

Fig. 5. The slope of the differential phase versus angle θ

from the experimental data for certain angles θ, along with the best possible matching curve obtained from Ben Menahem's formula.

The parameters of this best fitting curve are: fracture velocity $v_F = 2.9$ mm/μsec and fracture length $L_0' = 37$ mm. This best fit fracture length differs from the value of $L_0 = 30$ mm (see Fig. 3) by $+25\% \pm 3\%$. This holds for all values of θ. The value of L_0' happens to be nearly equal, however, to the distance of 37.5 mm between the outer edges of the source. Thus, it would seem natural to define this distance rather than L_0 as the fracture length. That this is not true will be discussed below. The *phase of D*, called the differential phase, with respect to angle θ, should be a straight line through the origin. The slope of this line is proportional to the rupture length L_0. We have approximated our phase spectra by best line fits and calculated the difference between the average phase slopes of a corresponding pair of observations. This difference is shown as a function of θ in Figure 5. For comparison, the theoretical slope of the phase difference corresponding to the true fault length of 30 mm is plotted. The fracture length computed from the phase slopes differs from the true value of L_0 by $\pm 20\%$ or more.

Discussion

The results can be summarized as follows:

1. The directivity as determined from the experimental data is in significant qualitative agreement with the computed directivity as expected from the theoretical concept of a finite moving source.

2. The deviation of actual fracture parameters from those computed from the experimental data using the formulas of Ben-Menahem (1962) is about 25%.

The reason for this deviation is that the experimental conditions differ from the theoretical assumptions of Ben-Menahem (1962). In the experiment we used a number of single sources whereas theoretically there should be a continuous distribution of sources. This causes the main part of the deviation in the directivity function, as has been shown by Rohde (1975), who also adapted the theory of Ben-Menahem (1962) to the actual conditions of the experiment. He showed that, distributing an increasing number of sources along L_0, the best fit fracture length L'_0 approaches the value of L_0. (The above mentioned agreement of $L'_0 = 37$ mm and the distance between the outer edges of the source coincidentally results from the special circular shape of the transducers together with their arrangement.)

Limited frequency resolution and anisotropy of radiation from the transducers are considered to be further sources of error. Besides, another condition which is required by theory, viz. $L_0/r \ll 1$ could not be entirely fulfilled in our experiment.

It is for these reasons that an accuracy of not better than $\pm 3\%$ could be achieved for the parameters L_0 and v_F, calculated from the experimental results.

Conclusions

The above results are an encouraging step towards modelling a more realistic mechanism of earthquake focus. This could be done with the help of shearing transducers, varying the fracture velocity along the fault and proceeding from uni- to bi-lateral fault models.

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