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Abstract

Full Text

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On the Question of Amplitude Curves of Longitudinal Seismic Waves

(Presented by Academician E. K. Fedorov, February 13, 1962)

1. Amplitude curves of body seismic waves (the dependence of amplitude on epicentral distance) are essentially necessary for determining the magnitude of earthquakes. In addition, it is of interest to ascertain whether these curves can be used to refine the velocity section of the Earth, since the determination of velocities from the travel-time curve is often unreliable. This applies first of all to the upper part of the Earth's mantle, the velocity section of which is still a subject of discussion: different authors propose versions of sections that differ considerably from one another ⁽¹⁻³⁾. This is explained by the fact that the curvature of the travel-time curve of the first arrivals is very small in the interval of epicentral distances $\Delta = 5-15^\circ$ and increases sharply near the distance $\Delta = 20^\circ$. Some investigators suppose that a loop of the travel-time curve is present here. Therefore the Herglotz-Wiechert method is not applicable to these parts of the travel-time curve (not to mention possible waveguides), and the dependence of velocity on depth is determined by a fitting method (the corresponding theoretical travel-time curves must coincide with the experimental one within the limits of observational error). At these same epicentral distances a large scatter is found on the experimental amplitude curves, and they are averaged for the Earth with great difficulty ⁽⁴⁾. In selecting the velocity section, the dynamic data are not taken into account directly.

In the present work an attempt has been made to clarify the influence of the velocity section on the dynamics of waves arriving in the first arrivals. Calculations were carried out for 5 variants of sections of the Earth's mantle: the sections of Gutenberg ⁽¹⁾ (variants 1 and 2), Jeffreys ⁽³⁾ (variant 3), and Lehmann ⁽²⁾ (variant 4). In addition, variant 5 was added, in which the velocity is almost constant down to a depth of 240 km and thereafter coincides with variant 1. Data on the sections considered (depths h and velocities v corresponding to these depths) are collected in Table 1.

Table 1

Variant 1	Variant 1	Variant 2	Variant 2	Variant 3	Variant 3	Variant 4	Variant 4	Variant 5	Variant 5
h	v	h	v	h	v	h	v	h	v

Fig. 1. Examples of seismograms in the vicinity of the first arrivals for variants 4 and 3

Figure 1: Fig. 1. Examples of seismograms in the vicinity of the first arrivals for variants 4 and 3

Variant 1	Variant 1	Variant 2	Variant 2	Variant 3	Variant 3	Variant 4	Variant 4	Variant 5	Variant 5
0	6.2	0	6.2	0	6.2	0	6.2	0	6.2
40	7.0-8.1	40	7.0-8.1	40	7.0-7.75	35	7.0-8.0	40	7.0-8.1
76	7.8	50	8.19	230	8.32	55	8.12	240	8.15
159	7.8	94	7.85	550	9.88	220	8.12-8.4	600	10.0
600	10.0	172	7.85			600	10.22		
		600	10.0						

In the interval between the layer boundaries indicated in the table, for each variant the velocity was approximated by Bullen' s law

$$v^{(i)}(r) = v_0^{(i)} \left(\frac{r}{r_0^{(i)}} \right)^{-k_i} .$$

- The hodograph of the direct wave that has passed through the shell has an initial point. In the case of variants 2-5, the hodographs of waves reflected once from below, from the Mohorovičić surface, have the very same initial point. In the neighborhood of this point there always exists a region where the delay time of multiply reflected waves relative to the arrival time of the direct wave is considerably less than their predominant period T . In this region a single interference oscillation is recorded, which may be called the "head" wave formed at the Mohorovičić boundary. The usual ray formulas for calculating its field are inapplicable, and its properties depend essentially on T . Ray formulas can be applied only beginning at sufficiently large distances, where the first arrival is formed by several waves with a small multiplicity of reflections.

Fig. 1. Examples of seismograms in the vicinity of the first arrivals for variants 4 and 3

In the present work the computations were carried out by ray formulas (zero approximation) (7). In all variants, the hodographs and intensities of the direct, once-, twice-, and three-times-reflected waves were calculated. It turned out that the hodographs of the first arrivals for all variants are close to one another within the error of observation. The total field $u(t, \Delta)$ in the vicinity of the first arrivals was obtained by superposition of the fields of the individual waves.

Fig. 2

Figure 2: Fig. 2

The lower boundary of the epicentral distances considered was chosen so that the group of first arrivals, for a period $T = 1$ sec, would be formed by no more than 4 waves. In addition, wave fields were not determined in the shadow or penumbra regions (in variant 1 for $\Delta < 15^\circ.6$, in variant 2 for $9^\circ < \Delta < 16^\circ.5$) and at angular points of the hodograph loops (in variant 1 at $\Delta = 15^\circ.6$, in variant 2 at $\Delta = 16^\circ.5$, in variant 5 at $\Delta = 18^\circ.6$). Examples of the seismograms obtained are shown in Fig. 1 (the shape of the pulse chosen at the source is shown in the upper left corner).

3. From the calculated curves $u(t, \Delta)$, dependences were constructed of

$$\log \frac{A^*(\Delta)}{T},$$

where $A^*(\Delta)$ is the maximum amplitude in the group of oscillations in the first arrivals (within 4 sec from the onset of oscillations) (Fig. 2). On the same figure is plotted the curve obtained by Gutenberg⁽⁶⁾ by averaging data for earthquakes over the entire Earth. Gutenberg's curve is shifted along the ordinate axis in such a way that it coincides with the theoretically calculated curves at epicentral distances $\Delta > 24^\circ$, since, as is clear from a comparison of the theoretical curves, the curves for different sections agree well at $\Delta > 21-24^\circ$ and differ strongly at Δ from 6 to 18° .

4. From Fig. 2 it is evident that regional differences in the structure of the shell may correspond to sharp differences in the amplitude curves at $\Delta < 21^\circ$ (and indeed, it is precisely at these Δ that a very strong scatter of experimental points is observed). Consequently, one cannot use an averaged amplitude curve either for determining magnitudes, or still less for determining the section. Nevertheless, comparison of the experimental and theoretical curves apparently shows that, down to depths of 200 km, sections of the Gutenberg and Lehmann type, in which the velocity does not increase with depth, are closer to reality. This conclusion will not change when absorption is taken into account,

which will give only a monotonic and, apparently, insignificant decrease of the theoretical curves with distance Δ . Incidentally, when determining absorption, the variety of laws governing the change in the intensity of elastic waves with distance is not taken into account.

Fig. 2. Dependence of $\log \frac{A^*}{T}$ on epicentral distance. 1–5 for the theoretically calculated variants 1–5; 6—curve averaged over the whole Earth from earthquake data; 7—difference between the curve for nuclear explosions and the standard curve.

5. For $\Delta < 21^\circ$, the error in computing magnitude by means of Gutenberg's curve averaged for the whole Earth may reach 1.0 on the scale of unified magnitudes m , owing to small regional features of the upper part of the mantle that are barely noticeable on the hodograph. This, apparently, may explain the fact that the magnitudes for nuclear explosions (North America), computed by American authors ⁽⁵⁾, turned out to be underestimated. Yu. V. Riznichenko ⁽⁸⁾ noted that the underestimation

magnitudes occurred because of the interval of epicentral distances $15\text{--}23^\circ$, i.e., precisely where the amplitude curves are unstable. In Fig. 2 the difference, given in ⁽⁸⁾, between the amplitude curve for nuclear explosions and the standard calibration curve is plotted (the zero level for it is shown in Fig. 2 by a dotted line). This difference is of the same order as the scatter of the amplitude curves, so that Gutenberg's averaged scale can be used as the standard calibration curve for computing magnitudes only beginning with distances at least greater than 21° .

In order to establish the dependence of the amplitude curves on frequency, computations of $\log \frac{A^*(\Delta)}{T}$ were made for periods T equal to 0.5, 1, and 2 sec. for variant 4. It was found that these curves depend only weakly on the period.

Summarizing all that has been said, one may arrive at the following conclusions:

1. The dynamic characteristics of longitudinal waves in the interval $\Delta < 15^\circ$ depend on the parameters of the mantle considerably more strongly than do the kinematic characteristics (the root-mean-square deviations of the hodographs from one another for the sections considered do not exceed 3 sec.). It follows from this that, when choosing variants of the section, it is necessary to take the wave dynamics into account.
2. Since the observations make it possible to suppose that there are regional differences in the structure of the upper part of the mantle, in the interval of Δ under consideration it is inadvisable to average amplitude curves over the whole Earth, and it is necessary to construct them separately for each region. In particular, it was not possible to determine the magnitudes of the American nuclear explosions from the observations in this interval using the averaged curve, as was done in ⁽⁵⁾.

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