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Abstract

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MICROSTRUCTURE OF THE TRAVEL-TIME CURVE OF THE LONGITUDINAL WAVE

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One of the principal sources of knowledge about the internal structure of the Earth is the travel-time curves of seismic waves. The method of constructing travel-time curves is based on combining and strongly smoothing data on the travel times of seismic waves for a large number of epicenters and observation points. In this process a number of details are inevitably lost, details that become very significant in interpretation connected with differentiation and repeated differentiation of the travel-time curve. Fundamentally new possibilities are provided by the use of comparatively small groups of stations of the LASA (USA) system: for a number of azimuths and epicentral distances the local slope angle of the travel-time curve can be measured directly, approximating the derivative of the travel-time curve with respect to epicentral distance. An interesting example of such an analysis for the wave P is described in the work of Chinnery and Toksöz (^{1}).

When interpreting observations of the type under discussion, specific difficulties arise. In particular, having data for a single group of stations, it is difficult to separate global effects, associated with features of the deep structure of the Earth, from local effects, which depend on large-scale horizontal inhomogeneity of the crust and mantle near the observation site. Another problem is connected with the nonuniform distribution of earthquake epicenters over the Earth' s surface; some important portions of the curve $dt/d\Delta$ in (^{1}) were constructed by interpolation, and their reliability is doubtful. These are only some of the reasons why, for the solution of contemporary geophysical problems, it is necessary to use many groups located in different regions of the globe.

Fig. 1. Location of seismic stations: *I* –Siberian network, *II* –Kirghiz network

To measure the derivative of the travel-time curve of the longitudinal wave

Figure 2. Observed values of $dt/d\Delta$ and smoothing curves. *I*—earthquakes recorded by seismic networks in the USSR (*a*—earthquakes of the Pacific belt, *b*—earthquakes of Europe and the North Atlantic), and earthquakes recorded by the LASA system from the azimuthal sector 300–320° according to Chinnery and Toksoz (1); the solid line is taken from Fig. 21; *c*—Chinnery-Toksoz, *d*—Jeffreys-Bullen.

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we used two regional networks of seismic stations, installed for the purpose of studying local seismicity in Siberia and Kirghizia. The extent of each of these systems (about 200 km) makes it possible to achieve a compromise between the degree of smoothing of the graph $dt/d\Delta$ and the level of random errors of measurement. The layout of the stations in both groups is shown in Fig. 1. The method for measuring $dt/d\Delta$ is based on approximating a segment of the travel-time curve as a function of epicentral distance by a straight line; the azimuth of the source and the angle of inclination of the straight line are determined so as to minimize the sum of the squares of the residuals of the arrival times of identical phases of the wave at the stations of the group. Distances from the earthquake epicenters to the center of the group are calculated from bulletin data.

In all, more than 200 earthquakes were processed, chiefly from the western part of the Pacific seismic belt, from Alaska in the north to New Zealand in the south. Most of the data were obtained for the Siberian group. For the Siberian group, no noticeable differences were found in the values of $dt/d\Delta$ obtained for earthquakes with identical Δ from Alaska, the Aleutian and Kuril Islands, Japan, the Philippines

Fig. 2. Observed values of $dt/d\Delta$ and smoothing curves. *I*—earthquakes recorded by seismic networks in the USSR (*a*—earthquakes of the Pacific belt, *b*—earthquakes of Europe and the North Atlantic), and earthquakes recorded by the LASA system from the azimuthal sector 300–320° according to Chinnery and Toksoz (1); the solid line is taken from Fig. 21; *c*—Chinnery-Toksoz, *d*—Jeffreys-Bullen.

and the islands of Indonesia. The differences in azimuths for these earthquakes reach 90° and more. The similarity of the results may mean, first, stability of the mantle velocity section in eastern Asia and, second, the absence of an azimuthal effect in the group records. In analyzing the Kyrgyz group data, good agreement was found between the measurement results for earthquakes with epicenters to the southeast of the group (the islands of Indonesia, the Philippines, etc.) and the data for the Siberian group. The results of measurements in the northeastern azimuth (the Kuril Islands—

a) for combination with all the remaining data it was necessary to increase it by 0.3 sec/deg. After this it proved possible to plot the results of measurements for both groups and all earthquakes of the Pacific belt on a single graph, with good internal agreement of all the data (Fig. 2 I).

The scatter of the points $dt/d\Delta$ is due to a number of causes. The main causes are the natural scatter of the arrival times of the wave at the stations of the array and errors in reading the time on the seismograms. The combined effect of these two factors produces random station residuals with an rms value of about 0.2-0.3 sec. Another important cause of the scatter of the values of $dt/d\Delta$ may be large-scale horizontal inhomogeneities of the mantle, confined to great depths on the path between the earthquake foci and the array. The nature of the various factors responsible for the scatter of the values of $dt/d\Delta$ is a subject for further investigation.

Figure 2 I shows a smoothing curve of $dt/d\Delta$, constructed visually. It is interesting that earthquakes of Europe and the North Atlantic gave points lying above the averaging curve for earthquakes of the Pacific seismic belt. This may indicate lower velocities of longitudinal waves in the mantle of Europe and western Asia; additional data are needed to resolve this question. The averaging curve $dt/d\Delta$ has a very characteristic step-like form: against the background of a monotonic decrease in the values of $dt/d\Delta$ with increasing Δ, sections stand out where the curve goes much more steeply or much more gently than in adjacent sections. Sections of sharp change in $dt/d\Delta$ correspond to zones of sharp increase of the velocity of longitudinal waves with depth; they are confined to epicentral distances of 15-28°; 37-39°; 51-53°; 72-74°; the last three intervals correspond to depths (approximately) of 900; 1300; 1900 km. Let us note that in the sections of sharp change in the values of $dt/d\Delta$, in reality, discontinuities of the curve $dt/d\Delta$ are possible, corresponding to break points of the travel-time curve of first arrivals. This question needs additional investigation. Sections of weak change in $dt/d\Delta$ correspond to zones of weak increase of velocity with depth. If $dt/d\Delta$ does not change with distance, the existence of a low-velocity layer is possible. Sections of this type are confined to epicentral distances of 30-36°; 40-45°, and also, beginning from 92° and farther. They correspond to depths (approximately) of 800-900, 1000-1100, 2600-2900 km.

It is interesting to compare the obtained graph of $dt/d\Delta$ with the analogous graph obtained in (^{1}), and also with the analogous graph for the Jeffreys—Bullen travel-time curve (Fig. 2 II). Figure 2 II also shows the results given in (^{1}) of all measurements of $dt/d\Delta$ along the Aleutians—Japan profile, made with the aid of the LASA array. Our graph over the greater part of the region Δ from 25 to 80° lies below the Jeffreys—Bullen curve, which is in qualitative agreement with the latest data on travel times of longitudinal waves from nuclear explosions. Between our graph of $dt/d\Delta$ and the Chinnery—Toksöz graph there are differences, the nature of which requires clarification. In the region 50-

90° substantial differences in the shape of the two variants of the curve occur at $\Delta \sim$ 70-80° and at $\Delta \sim$ 50-57°, but the measurement results (^{1}) do not contradict, in these intervals, our variant of the curve. In the region 25-50° there is a statistically significant discrepancy between our data and the data of work (^{1}), reaching 0.3 sec/deg at $\Delta = 30°$, but the form of the curve chosen in (^{1}) in this interval is poorly supported by the measurement results.

The differences between the two variants of the curve $dt/d\Delta$ are especially noticeable when calculating $d^2t/d\Delta^2$ (Fig. 3). Our graph is much more jagged; the positions of maxima and minima of the two graphs do not coincide. It is interesting to compare the dependence of $d^2t/d\Delta^2$ on Δ with the dependence of the predominant

of the period of longitudinal waves on distance, obtained by Antonova and Khalturin $^{(2)}$, and the dependence of the displacement ratio in longitudinal and transverse waves, obtained by Vvedenskaya and Balakina $^{(3)}$. The corresponding graphs are shown in Fig. 3. The peaks of the curve $d^2t/d\Delta^2$ correlate rather well with the minima of the curve $T(\Delta)$. A noticeable correspondence is also found between our curve and the graph $u_P/u_{SH}(\Delta)$. The peaks of the curve $d^2t/d\Delta^2$ at 38, 52, and 73° correspond to the peaks of the curve u_P/u_{SH} at 39, 53, and 71°. Chinnery and Toksöz also point to the comparability of their results with those of Vvedenskaya and Balakina; however, in their interpretation the increase in the ratio u_P/u_{SH} is associated with zones of the mantle where the increase of the velocity of longitudinal waves with depth is slowed, or perhaps does not occur at all. In our interpretation it is more probable that the increase in the ratio u_P/u_{SH} and the decrease in the predominant period of oscillations in longitudinal waves are associated with zones of the mantle where there is a sharp increase in the velocity of longitudinal waves with depth. Further study of these relationships is of considerable independent interest.

Fig. 3. Comparison of the curves $d^2t/d\Delta^2$ (1—our results, 1*a*—according to Chinnery—Toksöz $^{(1)}$) with the curve u_P/u_{SH} (2) according to Vvedenskaya and Balakina $^{(3)}$, and with the curve of the predominant period of oscillations in longitudinal waves (3), according to Antonova and Khalturin $^{(2)}$.

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Note: Figure translations are in progress. See original paper for figures.