ON THE QUESTION OF THE PHYSICAL FOUNDATIONS AND EXPLORATION CAPABILITIES OF THE METHOD OF CONVERTED TRANSMITTED WAVES ACCORDING TO VERTICAL SEISMIC PROFILING DATA

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Abstract

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ON THE QUESTION OF THE PHYSICAL FOUNDATIONS AND EXPLORATION CAPABILITIES OF THE METHOD OF CONVERTED TRANSMITTED WAVES ACCORDING TO VERTICAL SEISMIC PROFILING DATA

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The application of the method of vertical seismic profiling has revealed great difficulties in the interpretation of seismic-exploration observation materials obtained by the method of converted transmitted waves, which in recent years has been widely introduced into the practice of seismic investigations. The development of this method is explained to a considerable degree by the difficulties existing in methods of regional investigations that use longitudinal waves—the CMP and DSS methods. In both methods, waves propagating mainly in directions close to horizontal are studied, and the possibilities of such observations are very limited.

In this respect, converted transmitted waves in principle have substantial advantages over longitudinal waves, since their propagation trajectory is close to vertical. In addition, joint processing of longitudinal and converted waves associated with one and the same boundary eliminates the need to study the nature and propagation trajectory of the longitudinal wave before its downward incidence on the conversion boundary. These and other fundamental advantages, formulated many years ago (see, for example, ([1]–[3])), explain the ever broader application of the converted-wave method. At present, the method of converted transmitted waves is used in seismic exploration ([3], [6], [8]), where the source of oscillations is an explosion, and in seismological investigations ([1], [2]), which use earthquakes; for this purpose, special apparatus of the "Zemlya" type has been developed and is being mass-produced ([7]).

The main stage of interpretation in the method of converted transmitted waves, as in all other methods of seismic investigations, is determining the nature of the recorded waves and, in particular, identifying waves on records of the vertical and horizontal components of oscillations that correspond to one and the same

boundary. At the same time, as experience shows, in processing materials there are often no sufficiently physically justified and reliable criteria for identifying P- and PS-waves.

In assessing the exploration capabilities of the method of converted transmitted waves, it was necessary to consider two principal questions: 1) the conditions for the formation of converted transmitted waves, 2) the conditions and possibilities for their isolation and tracing on surface seismograms.

The method of vertical seismic profiling (VSP), developed at the Institute of Physics of the Earth named after O. Yu. Schmidt of the Academy of Sciences of the USSR and based on observations at internal points of the medium ([4], [5]), proved to be the most effective way of studying the questions formulated above. Analysis of VSP materials, carried out in the seismic-exploration frequency range in regions differing in their structure, including special investigations conducted in 1966 in Volgograd Oblast, makes it possible to draw the following conclusions:

1. Intense converted transmitted waves are formed mainly at the sharpest interfaces, located, as a rule, in the upper part of the section. In different regions the depth of these interfaces is not the same and varies depending on the geological structure; however, it usually does not exceed 1000–1500 m.

2. The conditions for identifying and tracing converted transmitted waves are determined first of all by the structure of the upper part of the section, both in the shot area and in the receiver area.

a) Observations at great depths in the shot area have shown that inhomogeneities in the upper part of the section lead to the formation of a complex field of incident waves, which consists of a series of waves forming the initial part of the seismogram. In observations at large distances, these waves, one after another following the first, emerge at the ground surface along approximately the same trajectory.

b) In the receiver area, all waves incident from below form intense converted transmitted waves at sharp interfaces in the upper part of the section. In individual cases, even a single sharp interface in the upper part of the section, as experimental studies show, may prove sufficient to explain almost completely the record on the X-component. If there is not one but several interfaces, the number of waves increases correspondingly.

3. In most cases, all these waves form on surface seismograms of the horizontal component a complex interference wave field. Various types of multiple waves associated with the same interfaces in the upper part of the section may also play a substantial role in the formation of this complex field. As a result, in the absence of reliable criteria for their identification, it is practically impossible to distinguish in this complex field waves converted at deeper interfaces.

4. Under certain conditions, the horizontal components of longitudinal waves on a vertical profile may have sufficiently high intensity and may form, on the records of horizontal seismometers, dominant and well-traceable waves. In layers with high seismic-wave velocity, at relatively large emergence angles, the horizontal component of longitudinal waves may exceed the vertical component. Therefore the nature of the waves and the structure of the seismogram of the X-component cannot be understood without studying the nature of the waves recorded on the Z-component.

5. The criteria currently used in surface observations for identifying P- and P-waves—record form, delay time, polarization—do not make it possible to determine confidently the nature of converted waves. Therefore, even under comparatively not very complex seismic-geological conditions (for example, when there are only 2–3 conversion interfaces), the problem of interpretation may become practically ambiguous. This does not apply to the first wave, which can be interpreted with sufficient confidence. However, in most cases the first wave is associated with upper interfaces that are of no particular interest. The situation is further aggravated by the fact that, owing to the more or less fine layering of the medium and the comparatively low frequency of the recorded waves (5–10 Hz), converted transmitted waves are, as a rule, interference waves and are characterized by a complex record form.

The results listed above were obtained mainly by the VSP method in observations at depths down to 3000 m. The absence of boreholes penetrating deep interfaces in the Earth' s crust does not at present permit direct measurements to study the conditions of formation of converted transmitted waves at deep interfaces in the Earth' s crust and upper mantle. However, the results obtained by VSP make it possible to offer some suppositions on this question. It is known that the sharpness of interfaces, as a rule, decreases rapidly with depth. The sharpest interface in the Earth' s crust

is the Mohorovičić surface. For it, the jump in shear-wave velocities, on which the intensity of converted waves chiefly depends, is several times smaller than for boundaries in the sedimentary sequence, especially in its upper part. In practice, converted transmitted waves were confidently identified by us from boundaries for which the jump in shear-wave velocities was no less than 0.3–0.5.

The VSP data obtained for media with weak velocity differentiation show that at these boundaries intense converted waves in the seismic-exploration frequency range are not formed. Theoretical calculations confirm these experimental conclusions.

Thus, the results currently obtained from the experimental study of converted transmitted waves in the seismic-exploration frequency range by the VSP method, which agree with the data of theoretical calculations, cast doubt on the physical basis and exploration capabilities of the method of converted transmitted waves, primarily as applied to problems of studying boundaries

located at great depths under conditions where sharp boundaries are present in the upper part of the section. Special investigations are needed to study the conditions of formation and the physics of propagation of converted transmitted waves and to assess their exploration capabilities; without this, further expansion of seismic-exploration work by the method of converted transmitted waves under the indicated seismological conditions for the purpose of studying deep boundaries appears inadvisable.

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