P146 REFRACTION AND CDP REFLECTION SHALLOW SEISMICS FOR DETECTION OF LOW AMPLITUDE FAULTS

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Abstract

The inversion of travel time curves of refracted waves by a method of homogeneous functions allows to compute seismic cross sections comparable with respect to resolution with cross sections obtained by a reflection CDP (Common Deep Point) method. The integration of seismic methods in a structure of a method of refracted waves and CDP method was applied for research of the rocky basis of Kursk Atomic Power Station (KAPS). The purpose of researches was detection of low amplitude faults. Sets of faults detected in CDP cross section and in cross section on the data of a method of refracted waves, obtained independently, practically have coincided. Such endorsement has made outcome by considerably more reliable. Processing and interpretation of refraction data was fulfilled by homogeneous function method. Integration of CDP method and of the refraction data interpreted by methods based on head wave theory did not allow solving this problem.

Introduction

Processing and the interpretation of the engineering seismic data in most cases are based on the theory of head waves (plus minus method and similar ones). In the basis of these methods exist the simplified opinions about geologic medium, as alternation of flat thick layers with constant velocity. The velocity from a layer to a layer should increase with the depth. This condition does not allow to obtain layers, in which velocity is less, than in overlying deposits. The construction of a cross section by these methods is difficult for automation, the interactive procedure can be applied only, as distinguishing of waves in the travel time curves and reference them to this or other seismic layer is non-formalizable operation. Method of homogeneous functions (Piip, 2001) is fully automatic method of the simple inversion of travel time curves of refracted waves into a 2-D velocity grid. By example of usage of this method for lithologic division of rocks, the determination of depth of boundaries of layers and condition of rocky block (allocation of faults) can be an experimental seismic works in Kursk region.

Method of homogeneous function of interpretation of refraction data.

The method is based on local approximating of real velocity distribution by homogeneous functions of two coordinates. These functions have no limitations with respect to values of gradient of velocity. Properties of homogeneous functions is adequate to properties of geological cross sections. It is known, that sedimentary layers are accumulated mainly in marine conditions and originally have horizontal bedding, hereinafter they are deformed, but the interfaces of layers remain approximately similar to each other. The contours of a homogeneous function are arbitrary curves, however they are similar curves, therefore the homogeneous functions are very convenient for the approximation of multilayer geologic mediums. In polar coordinates a homogeneous function is described by product of two functions of single coordinate: exponential function of radius and arbitrary function of a polar angle. The seismic model described by a homogeneous function, can include straight-line seismic boundaries and wave guides.
The algorithm of the inversion of travel time curves of refracted waves is based on following properties of a kinematics of waves in mediums with a homogeneous function of velocity.

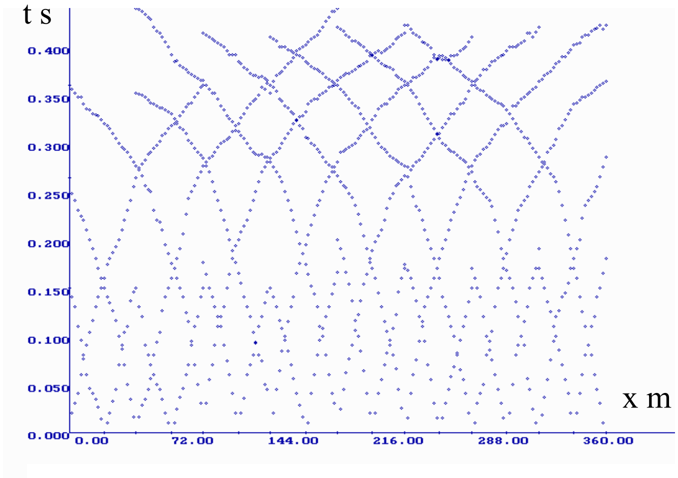

Fig. 1. Observed refraction travel time curves of first arrivals of S-waves along the profile.

For two reversed travel time curves non-linear transformations exist which continuously convert the direct travel time curve to the reversed one and vice versa. This fact has enabled us to develop an automatic procedure for the identification of waves refracted at different seismic boundaries. After the transformation and superposition of two reversed travel time curves the arithmetic mean from direct and reversed travel time curves is calculated. Simultaneously high-frequency noise is summed and is mutually decreasing.

In such media 2-D inverse problem can be converted into a 1-D inverse problem, when the velocity depends only on a polar angle. We compute unknown function of polar angle as step increasing function and therefore we obtain in cross section a set of seismic boundaries.

In the interpretation of a complex system of travel time curves some homogeneous function is calculated for each pair of reversed travel time curves selected from a system of observations, and then the outcomes incorporate in a common cross section by a method of a superposition. Each of pairs of travel time curves is processed independently provided that the velocity increases with the depth, thus we calculate a local velocity field. Simultaneously ray diagrams are calculated. Within the limits of any local velocity field the wave-guides are substituted by layers, with practically constant velocity. The extended zones of decreasing of velocity with depth can be only on the boundaries of local velocity fields. The processing using method of homogeneous functions is fully automatic procedure, is not required an initial model. The identification of waves in travel time curves from different sources is produced also automatically.

The method of homogeneous functions is basis for the software package "Godograf" intended for processing and interpretation of the data of refracted waves and computing of velocity grid

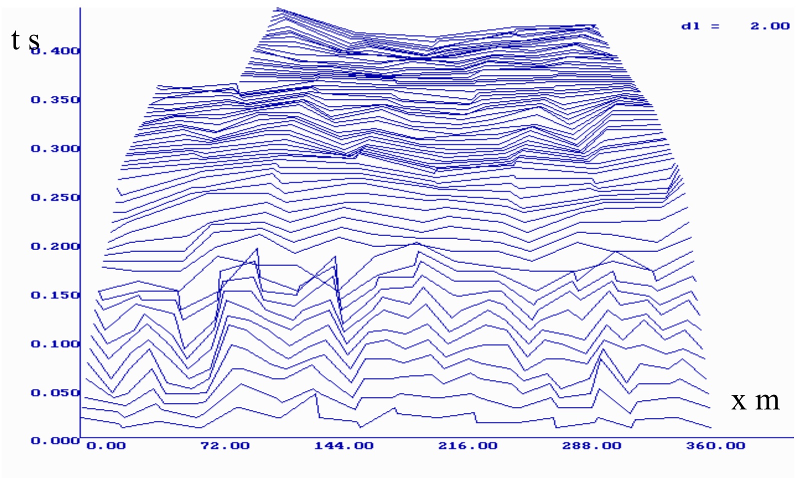

Fig. 2. Time section of equal offsets along the profile.

Seismic survey

The researches were produced by Institute "Gidroproekt" (Moscow) within the limits of arrangement of KAPS located about 500 km from Moscow in southwest direction. Along the profile by length of 360 m the refraction and CDP survey is fulfilled. In both cases the shear waves were generated and recorded. One well along the profile was available to calibrate and test seismic data and cross sections.

In region of observation a sedimentary sequence of several meters of alluvial deposits (marked by Q in fig. 4) followed by marls, alternated with clay marls, diatomites and opokas (K2st) (summary thickness is 15-20 m). True chalks of Cretaceous age (K2t-cn) (thickness 10-15 m) occur below.

At CDP works the interval between receivers was made 2 m, maximum offset was 58 m. Source gaps from first and last receivers were 12, 10, 8, 6, 4 and 2 m, further sources were located near each receiver.

CDP seismic section is shown in Fig. 4c. It represents the result of a depth migration. It was acquired using a velocity field derived from staking velocity analysis, borehole data and was successively updated by depth residual analysis on the common image gathers.

First arrivals of very fine quality were obtained. System of observed refraction travel time curves is shown in Fig. 1. Green lines in Fig. 4c represent the seismic boundaries computed by method of head wave. Refractive boundaries obtained by this method insufficiently in detail are corresponding to the disturbed reflective seismic boundaries especially inside of middle part of the cross section (Fig. 4c). Travel time curves of refraction waves were processed also by homogeneous function method. Beforehand the time section of equal offset was computed with goal of imaging of geological structure that is mapped at this time section and to interpolate travel time curves. Fig. 2 is showing this cross section. It includes 3-4 layers differing by apparent velocity (which is inversely proportional to distance between contours) and by form of contours. Interpolated travel time curves used for inversion by homogeneous function method are shown in Fig. 3. We see that more detailed system observation was computed using interpolation.

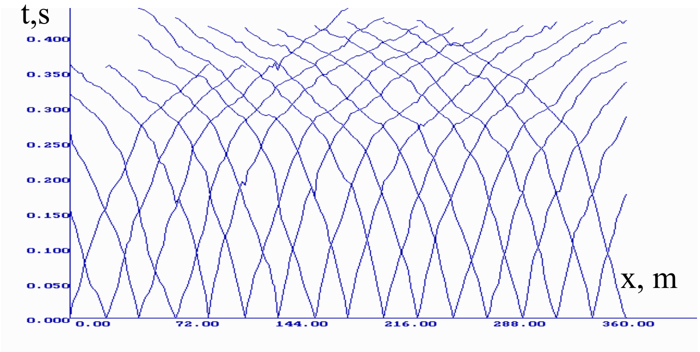

Fig. 3.Interpolated refraction travel time curves along the profile.

The final section was computed as velocity grid with cell size 1.5 m x 0.6 m, so the maximum expected accuracy in vertical direction was no better then 0.6 m. This section is represented in two views (Fig.4a and 4b). Section in Fig. 4 (a) is shadow of first vertical derivative of velocity grid with velocity grid with 50m contour levels (thin black lines). Velocity grid with 25 m contour levels and seismic boundaries (red dash lines) are shown in Fig. 4b. It is known that sedimentary deposits are thinly layered. In section in Fig. 4a the thin layers are mapped. Macro layers also are tracked; they are differed by predominating thickness of thin layers. Boundaries of macro layers are shown in Fig. 4b by red dash lines. The boundaries are consistent with the stratigraphic information obtained from the well. Layer of clay marls with velocities of 400-600 m/s and thickness of 15-20 meters is subdivided into two sub layers: lower sub layer is characterized by rather low velocity gradient and decreasing values of velocity. This sub layer is distinguished also on the CDP section, where practically there are not reflections. It speaks that the bottom of clay marls is more uniform, than upper part of the layer.

In Fig. 4d the CDP section and velocity grid with 40 m contour levels (thin black lines) are shown. The CDP section and velocity grid match very well. They are consistent in following parameters.1) 40m/s contour levels are coincide in average with one period of the reflections 2) high amplitude blocks in CDP section practically everywhere are limited by faults tracked in velocity grid. 3) Inclination of contour levels coincides with inclination of reflections. Clearly, a perfect correspondence between two different parameters cannot be expected, but the general trends seem to be consistent.

Conclusion

The integration of CDP works and refraction data interpreted by homogeneous function method is able to produce reliable detection of low amplitude faults. That was main goal of the seismic investigations.

References

1. Piip V.B. 2D inversion of refraction travel time curves using homogeneous functions. // Geophys. Prosp. 2001. Vol. 49, p. 461-482.

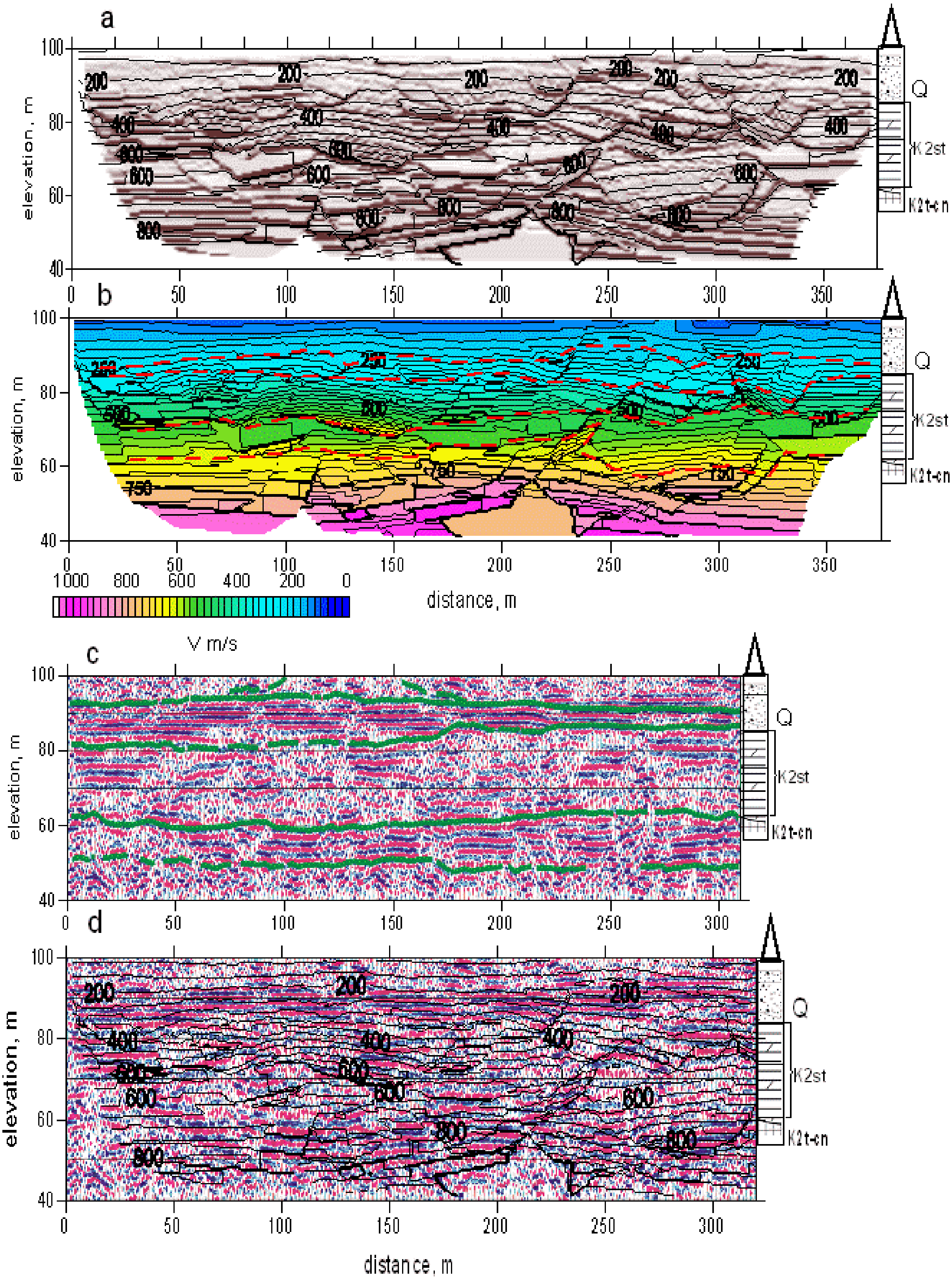

Fig. 4. Shadow of first vertical derivative of velocity grid with velocity grid with 50m contour levels (thin black lines) (a); velocity grid with 25 m contour levels and seismic boundaries (red dash lines) (b); migrated CDP seismic section with refractive boundaries obtained by plus-minus method (green lines) (c); migrated CDP section and velocity grid with 40 m contour levels (d). On the right the lithology on borehole data is shown.