Near Surface 2007

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Joint Interpretation of P and SH Refraction Data

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SUMMARY

In this paper we propose the use of a fast kinematic refraction inversion method for P and SH arrivals for interpretation near surface structures. The basic aim for this method is that lateral changes both in layer thicknesses and propagation velocities in the media are described by adequately chosen functions expanded in series.With the method we can estimate the lateral changes of the P and S velocities and layer thicknesses. With the joint interpretation of both inversion results we can recognize in near surface structures the water table and low velocity contrast too. In the paper we show a practical example.

INTRODUCTION

In this paper we propose the use of a fast kinematic refraction inversion method for P and SH arrivals for interpretation near surface structures. With the method we can estimate the lateral changes of the P and S velocities and layer thicknesses. With the joint interpretation of both inversion results we can recognize in near surface structures the water table and low velocity contrast too.

In that case when the assumption can be accepted for the task encountered that lateral changes in layer thicknesses and P and S velocities (i.e. model parameters) of the studied 2D structure are continuous and these changes are not too rapid, there is a possibility to give these parameters as functions of the lateral coordinate.

This possibility has already been utilized earlier in seismics (Simmons and Bernitsas 1994, Shtivelman 1996). Applicability of functions in inversion of seismic surface waves, seismic refraction and geoelectric measured data along a profile has been proved (Dobróka 1997, Bernabini, Brizzolari and Cardarelli 1988, Zanzi 1990, Ormos et al. 1998, Nardis, Cardarelli and Dobróka 2005, Gyulai and Ormos 1999, Ormos 2000, 2002, 2004, Daragó and Ormos 2004, Dobróka and Ormos 2005, Ormos and Daragó 2005, Turai, Dobróka and Vass 2006). The use of functions realizes a joint inversion in case of different layer boundaries from different geophysical methods too (Gyulai, Ormos and Dresen 2000).

DESCRIPTION OF THE SEISMIC MODEL USING SERIES EXPANSION

The $p_i(x)$ physical and geometrical parameters of the model, i.e. layer thicknesses and velocities can be described in the form of series expansion as follows:

$$p_i(x) = \sum_{j=1}^{Ji} C_{ij} F_{ij}(x)$$

In the equation i indicate the layer parameters, J_i the number of elements of function describing the i^{th} parameter, $F_{ij}(x)$ the j^{th} basic function of the i^{th} parameter and C_{ij} the j^{th} expansion coefficient of the i^{th} parameter. In this paper we use trigonometrical basic functions. C_{ij}-s do not depend on the distance x along the profile and therefore they are suitable for determination (estimation) by inversion.

THE DIRECT PROBLEM

For solving the direct problem (ray-tracing) we assumed that the parameters of the structure might vary only slowly compared to the wave length in case of P and SH waves respectively, and the velocities abruptly change at the layer boundaries. Taking into consideration the wavelengths determined by the highest dominant frequencies attainable in investigation of near-surface structures and near-surface velocity conditions the above restrictions are acceptable from the viewpoint of application.

SOLUTION TO THE INVERSE PROBLEM

Based on the foregoing the inverse problem means estimation of the C_{ij} coefficients in the series describing the physical parameters from the observed first arrival time data, using other parameters of measurement (number and places of geophones and sources) and a priori information (number of layers). After solving the inverse problem calculation of the 2D model's physical parameters takes place from the estimated coefficients along the profile, at arbitrary point. The nonlinear task has been solved with a linearized, iterative method using the L_2 norm (LSQ). Application of this method allows determination of the reliability of the estimated coefficients, too, from this determination's reliability of the physical model parameters can also be calculated as a function of the distance along the profile. To characterize and qualification of the inversion results we propose several values to be used, however, all of them should simultaneously be taken into consideration. The relative data distance D in the data space is defined as follows:

$$D = \sqrt{\frac{1}{I}\sum_{i=1}^{I}\left(\frac{T_i^{(observed)} - T_i^{(calculated)}}{T_i^{(calculated)}}\right)^2}$$

(where $i = 1, \ldots, I$ denotes the number of time data).

The error $\sigma_k(x)$ of the model's geometrical and physical parameters $p_k(x)$ along the profile can be calculated from the covariance of the estimated coefficients (COV_{jj}) and form the basic functions (F_{kij}) based on the principle of error propagation (Gyulai and Ormos 1999):

$$\sigma_k(x) = \frac{\sqrt{\sum_{i=1}^{J(k)}\sum_{j=1}^{J(k)}\left\{F_{kij}(x) * F_{kji}(x) \ * COV_{ij}\right\}}}{p_k(x)} * 100\% \qquad \bar{\sigma} = \sqrt{\frac{1}{K}\sum_{k=1}^{K}\sigma_k^2(x)}$$

where $J(k)$ is the number of coefficients in the series describing the k^{th} model parameter. To characterize the reliability of the inversion's results related to the whole model the mean estimation error $\bar{\sigma}$ is computed from the parameter's $\sigma_k(x)$.

APPLICATION TO P AND SH FIELD DATA

Refraction test measurements with P and SH waves were carried out on a sedimentary media near to a rivulet on the area of the University of Miskolc. The seismometers were deployed in both cases (vertical and horizontal) in a 40 m long profile section, with 1 m separation. Sources of energy were vertical hammer strikes to the P-waves measurements, and horizontal hammer strikes to a spiked lumber to the SH-waves altogether at 9 locations, at 6 meter intervals (Figures 1a, and 1b). The measurements were carried out with the seismograph ESS-03-24 (manufactured by ELGI Hungary). Total of 259 and 305 first arrival time data were picked for P and SH first breaks respectively with ReflexW (made by Sandmeier). The measured (and from the estimated model calculated) travel times are shown in Figure 2a and Figure 2b. The shape of the travel time curves might suggest a two layer model in both cases.

In the inversion trigonometric series were used. The layer thicknesses are described with one, the first velocity with seven, and the second velocities with three coefficients, for both models. We had altogether 11 unknown coefficients to estimate in both cases. After 50 iterations we get the models shown on Figure 3a for P-velocities and on 3b for S-velocities respectively.

The relative data distances D are 9.2% for P, and 7.1% for SH waves respectively. For the mean estimation error $\bar{\sigma}$ of the model parameter we got 4.2% in case of "P velocity model" and 12.2% for the for "S velocity model". The reason of the relative high value of $\bar{\sigma}$ on the second case is that the travel time curves are relative short in our example.

INTERPRETATION

The layer boundary obtained in about 2.7 m on Figure 3a is the water table in the weathered layer. Probably the second layer is invisible on the seismograms because of the low velocity contrast in P velocities between the water-filled weathered and the underlying layers.

The layer boundary obtained in about 7 m on Figure 3b is recognised as the boundary of the water-filled weathered and the underlying layers. In this case the water table as “boundary” do not visible because of the SH wave measurements. This result is confirmed by the result of the cone penetrating testing, which was carried out near to the test side.

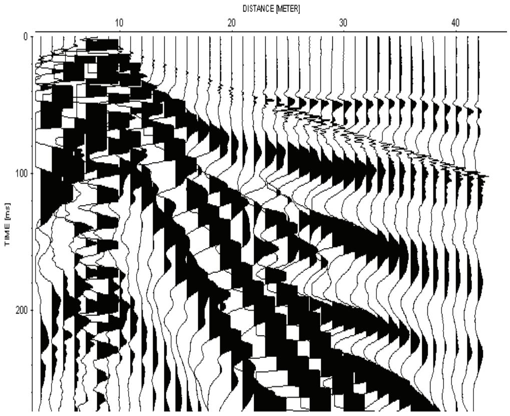

Figure 1a: Example seismogram for P-waves

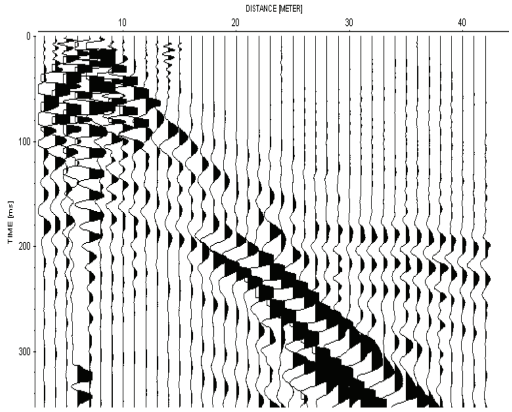

Figure 1b: Example seismogram for SH-waves

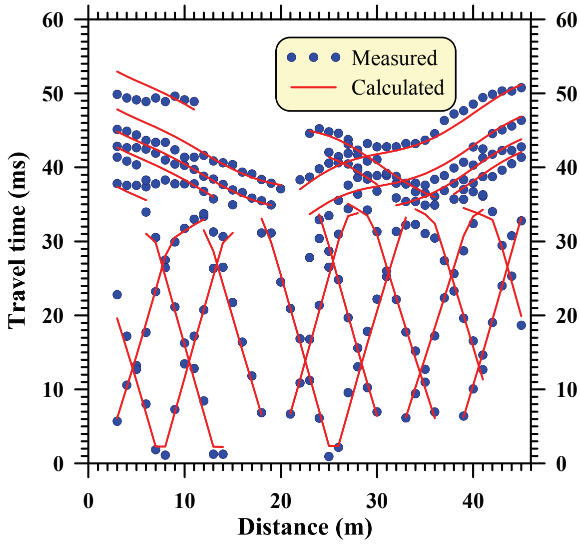

Figure 2a: Measured and calculated first breaks for P-waves

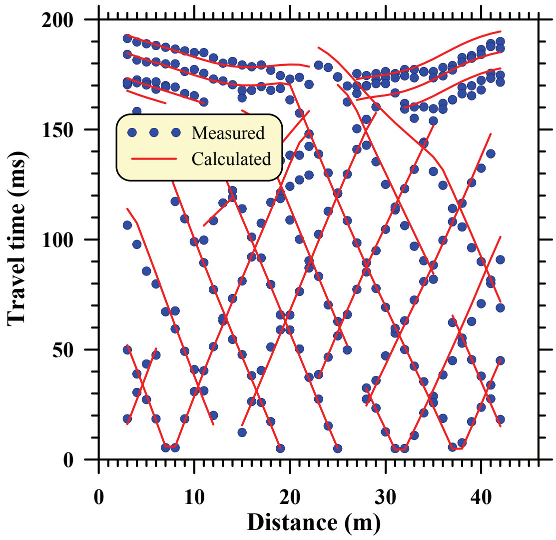

Figure 2b: Measured and calculated first breaks for SH-waves

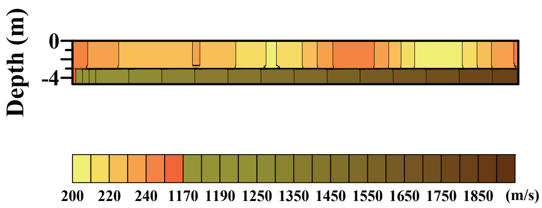

Figure 3a: Estimated model with P-velocities

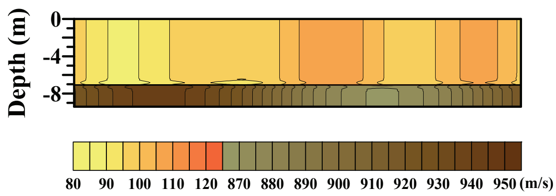

Figure 3b: Estimated model with SH-velocities

SUMMARY, CONCLUSIONS

For P and SH filed refraction data we used a fast kinematic refraction inversion method for interpretation near surface structures. We estimated the lateral changes of the P and S velocities and layer thicknesses. With the joint interpretation of both inversion results we recognized in near surface structures the water table and low velocity contrast too.

ACKNOWLEDGEMENTS

The authors express their thanks to the Hungarian Scientific Research Fund (OTKA T037842 and T062416) for the support of the research.

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