P189 TESTING OF DIFFERENT MODIFICATIONS OF MULTIWAVE AVO-ANALYSIS BY MODEL DATA

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Summary

The paper presents results of comparative analysis of different wave combinations (PP+PS), (PP+SH), (PP+SV) as applied to inversion of AVO-response. Our approach is based on the combined inversion of a polynomial approximation for dependencies between reflection coefficients of compressional, shear and converted waves and incidence angles. Linearized problem has been considered. Accuracy and stability of inverse problem solution have been studied using numerical experiments for two-layered model. An iteration R-algorithm allowing to obtain stable non-biased estimators of elastic parameters of model has been used. It has been shown that the combination (PP+SV) is the best. It provides very high accuracy of inverse problem solution for noise level 50% (100%) for the PP (SV) waves. Stable non-biased estimators of elastic parameters using the (PP+PS) and (PP+SH) combinations can be obtained for comparatively low noise level - less then 25% (40%) for PP (PS and SH) waves accordingly. Simultaneously we consider the AVO-inversion problem for one thin layer by using (PP+PS) waves.

Introduction

In passing from the qualitative interpretation of AVO-data to the quantitative methods, which allows to determine the medium elastic parameters, the investigation of uniqueness and stability of this inverse problem solution is of present interest. In standard method AVO-inversion one wave mode (P-wave) is used and only one-two combinative parameters (wave resistance ρV_P and ratio Vs/Vp) can be determined stable (Ursin and Tjaland, 1992; Drufuca and Mazzotti, 1995). In one of our papers (Nefedkina, Kurdyukova, and Buzlukov, 1999) we apply inversion of AVO response with respect to compressional and converted PS-waves. This approach permits us to obtain stable estimates of three elastic parameters – Vp, Vs and ρ. The present work proposes the usage of compressional, converted and shear waves to increase the number of elastic parameters which can be determined reliably. Three different wave combinations have been considered: (PP+PS), (PP+SH) and (PP+SV). For practice the first combination is the most interesting because it allows us to increase the independent data volume using the same source. B. Ursin and his collaborators use the same approach to obtain AVO-attributes from multicomponent seismic data (Causse et al., 1998). It is known that most of the oil-gas collectors are the thin-layer objects. In this case the reflections are complicated by the wave interferention. In (Bakke and Ursin, 1998) thin-layering effect is taken into account by introducing the special corrections. In this paper we propose a new method of estimation of media parameters containing thin layer by multiwave AVO-data. The comparison of different modifications of multiwave AVO-inversion was carried out by model experiments.

Methodology

We consider a single horizontal reflector dividing the medium into two elastic isotropic half-spaces with parameters V_{P1}, V_{S1}, ρ_1 and V_{P2}, V_{S2}, ρ_2. For the case when difference between parameters of two elastic half-space is not high we can pass to relative variations of the parameters $\Delta V_P / V_P$, $\Delta V_S / V_S$, $\Delta\rho / \rho$, where $\Delta V_P = V_{P2} - V_{P1}$; $V_P = (V_{P1} + V_{P2})/2$; $\Delta V_S = V_{S2} - V_{S1}$; $V_S = (V_{S1} + V_{S2})/2$; $\Delta\rho = \rho_2 - \rho_1$; $\rho = (\rho_2 - \rho_1)/2$ and use the linearized equations for the reflection coefficients (Aki and Richards, 1980). These equations can be presented as a series of sin(i). Shuey made such presentation for the coefficient $R^{PP}(i)$ (Shuey, 1985)

$$R^{PP} \approx \frac{1}{2}\left(\frac{\Delta V_P}{V_P} + \frac{\Delta\rho}{\rho}\right) + \left\{\frac{1}{2}\frac{\Delta\rho}{\rho} - 4\gamma^2\left(\frac{1}{2}\frac{\Delta\rho}{\rho} + \frac{\Delta V_S}{V_S}\right)\right\}\sin^2 i + \frac{1}{2}\frac{\Delta V_P}{V_P}\frac{\sin^4 i}{1-\sin^2 i}$$

or $$R^{PP}(i) = r_0^{PP} + r_1^{PP}\sin^2 i + r_2^{PP}\sin^4 i + \ \ldots$$

Our presentation for coefficients $R^{PS}(i)$, $R^{SH}(i)$ and $R^{SV}(i)$ (Nefedkina, and Buzlukov, 1999; Nefedkina, Kurdyukova, et al., 1999) is

$$R^{PS} \approx -\sin i\left\{\frac{1}{2}\frac{\Delta\rho}{\rho} + 2\gamma\left(\frac{1}{2}\frac{\Delta\rho}{\rho} + \frac{\Delta V_S}{V_S}\right) - \left[\gamma(1+2\gamma)\left(\frac{1}{2}\frac{\Delta\rho}{\rho} + \frac{\Delta V_S}{V_S}\right) - \frac{\gamma^2}{4}\frac{\Delta\rho}{\rho}\right]\sin^2 i - \right.$$

$$\left. - \left[\gamma\left(\frac{1}{4} + \gamma^3\right)\left(\frac{1}{2}\frac{\Delta\rho}{\rho} + \frac{\Delta V_S}{V_S}\right) - \frac{3}{16}\gamma^4\frac{\Delta\rho}{\rho}\right]\sin^4 i + \ldots\right\}$$

or $$R^{PS}(i) = -\sin i\left(r_0^{PS} + r_1^{PS}\sin^2 i + r_2^{PS}\sin^4 i + \ \ldots\right)$$

$$R^{SH}(i) = -\frac{1}{2}\left(\frac{\Delta\rho}{\rho} + \frac{\Delta V_S}{V_S}\right) + \frac{1}{2}\frac{\Delta V_S}{V_S}\sin^2 i + \frac{1}{2}\frac{\Delta V_S}{V_S}\frac{\sin^4 i}{1-\sin^2 i}$$

or $$R^{SH}(i) = r_0^{SH} + r_1^{SH}\sin^2 i + r_2^{SH}\sin^4 i + \ \ldots$$

$$R^{SV}(i) = -\frac{1}{2}\left(\frac{\Delta\rho}{\rho} + \frac{\Delta V_S}{V_S}\right) + \left[4\left(\frac{\Delta V_S}{V_S} + \frac{1}{2}\frac{\Delta\rho}{\rho}\right) - \frac{1}{2}\frac{\Delta V_S}{V_S}\right]\sin^2 i - \frac{1}{2}\frac{\Delta V_S}{V_S}\sin^4 i + \ldots$$

or $$R^{SV}(i) = r_0^{SV} + r_1^{SV}\sin^2 i + r_2^{SV}\sin^4 i + \ldots$$

Coefficients of this series may be obtained by the method of least squares. They are connected with unknown variations of the medium parameters ($\Delta V_P/V_P$, $\Delta V_S/V_S$, $\Delta\rho/\rho$), therefore we can use them to obtain a solution. We can use different combinations of coefficients of approximating polynomials. To determine three unknowns $\Delta V_P/V_P$, $\Delta V_S/V_S$, $\Delta\rho/\rho$ we must have three equations. We shall use two first coefficients of approximating polynomials because they can be determined more exactly. Not all combinations of the coefficients are equivalent. For example, using coefficients ($r_0^{PP}, r_0^{PS}, r_1^{PP}$), ($r_0^{PP}, r_0^{SH}, r_1^{PP}$), ($r_0^{PP}, r_0^{SV}, r_1^{PP}$), ($r_0^{PP}, r_0^{SH}, r_0^{PS}$) or ($r_0^{PP}, r_0^{SV}, r_0^{PS}$) we shall obtain very unstable solution in the vicinity of the value γ =0.5 which is most typical for real media. As model experiments showed, the combinations of coefficients ($r_0^{PP}, r_0^{PS}, r_1^{PS}$), ($r_0^{PP}, r_0^{SH}, r_1^{SH}$) and ($r_0^{PP}, r_0^{SV}, r_1^{SV}$) give better accuracy for the parameters estimation.

Thin layer reflection coefficients are represented as a superposition of plane waves reflected from the top and bottom of the layer. Only the single-reflected and single-converted waves are taken into account. The frequency characteristics of reflection coefficients depending on angle of incidence are shown in Fig. 1. The errors of approximation for model in Fig. 1 are less then 2 %. We investigate the AVO-inversion problem solution in two cases: if the thickness of layer is given, the solution is

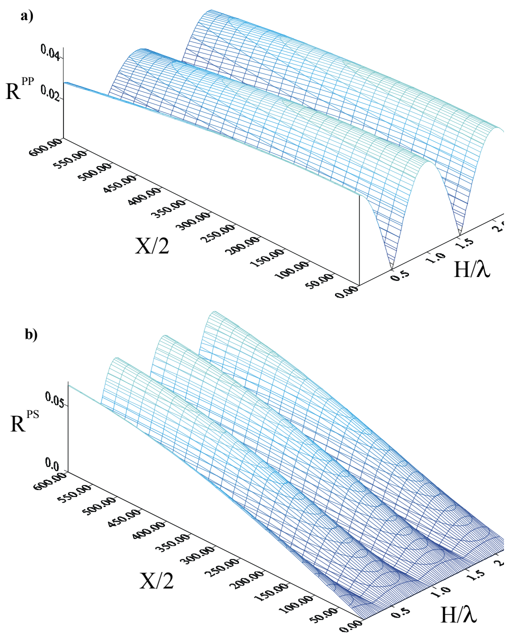

Figure 1. The reflection coefficients of PP-wave (a) and PS-wave (b) are shown. The model is with 5% contrasts of elastic parameters, layer thickness is equal 50m.

reduced to the inversion of overdetermined system of linear equations by the least squares method; if the thickness of layer is unknown, the solution is obtained using optimization.

In linearized problem the estimates of the medium parameters are displaced and unstable in the presence of random noise. The greatest instability is observed at square approximation R ($\sin^2$ i). Therefore, the solution refinement is necessary. As such procedure we considered an iteration process which we denoted as R-algorithm. The R-algorithm can be defined as follows:

$$\vec{\theta}^{(K+1)} = \vec{\theta}^{(0)} + (E - F^{-1}SG)\vec{\theta}^{(K)},$$

where $\vec{\theta} = (\Delta V_P / V_P, \Delta V_S / V_S, \Delta\rho / \rho)$, k is number of iteration, $\vec{\theta}^{(0)}$ is initial approach, *E* is unique operator, *G* is forward dynamic operator, *S* is approximation operator, F^{-1} is operator of inversion.

Model experiments

Numerical experiments were carried out on two-layer models with a horizontal interface and thin-layered models. We varied the next parameters: sign and value of contrast of elastic properties at the interface, range of incidence angles, level and properties of noise. For PS and SH (SV)–waves noise level was greater than 1.5 (2) times the noise level for PP-wave. For the models with a single reflector the testing has shown that the iteration procedure converges to the exact values of the parameters if the random noise is absent. The mean square deviations of the parameters estimators increase nearly linear with increasing level of noise. This is shown in Figure 2. The wave combination (PP+SV) provides the most accuracy of estimation of parameters among the methods that use two waves. The results for two wave combinations (PP+PS) and (PP+SH) are similar. Deviations of estimates of medium parameters for these methods are approximately equal and greater than 5 times the deviations for (PP+SV)-method. They do not exceed limiting values for this model (10%) if the noise level is less then 25%. The estimation accuracy of Vs is greater than 2 times the estimation accuracy of Vp and ρ. The results of solution of the inverse problem for the different wave combinations for the gas deposit model are shown in Figure 3. The parameters of the second layer V_{P2}, V_{S2}, ρ_2 are determined when the parameters of the first layer V_{P1}, V_{S1}, ρ_1 are known. Each point is the mean of 20 values. A universal means and the mean square deviations were calculated for 100 different sets of random noise. The mean square deviations of the estimators of parameters for noise level of 20% are less then 5-7% with respect to all modifications.

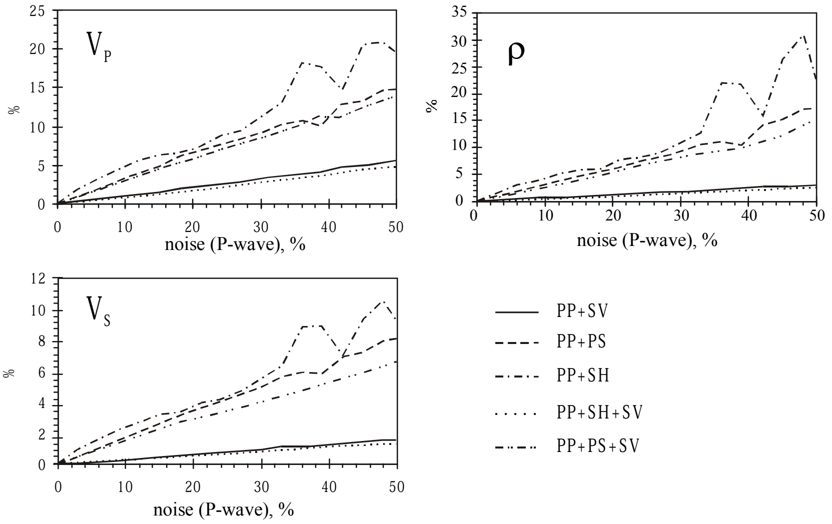

Figure 2. The mean-square deviations of estimates of elastic parameters for the model with positive 10% contrast of the elastic parameters at the interface obtained by means of different methods data are shown. Linear approximation R ($\sin^2 i$); range of incidence angles i=0-40^0 (for SV-waves i=0-27^0).

Conclusion

Complexing of waves of different modes for AVO-inversion permits reliable determination of three elastic parameters of the medium Vp, Vs, ρ. Every combination of two waves with the different polarization allows to increase accuracy and stability of inverse problem solution essentially in comparison with compressional waves. Comparative analysis of different methods has shown that the combination (PP+SV) is the best. It provides very high accuracy of inverse problem solution for noise level less then 50% (100%) for the compressional (shear) waves. Accuracy of estimation of parameters using the (PP+PS) and (PP+SH) combinations are approximately equal. Stable non-biased estimators of elastic parameters can be obtained for comparatively low noise level - less then 20-25% (40%) for compressional (converted and shear) waves. Complexing of waves of three modes (PP+PS+SV) or (PP+SH+SV) could increase the accuracy of parameters estimation by 1-2% in comparison with wave combinations of two modes (PP+PS) or (PP+SV). The determination of thin layer parameters using (PP+PS)-waves is reliable if the spectrum width is ~100 Hz for the layer 2-3 meters and 50 Hz for the layer 5 meters. The ways suggested broaden the capabilities of seismic methods to determine rock petrophysical characteristics (Poisson's ratio, Young's modulus) and to compute the medium stress tensor and to estimate perspectives for fluid-saturation of the reservoir.

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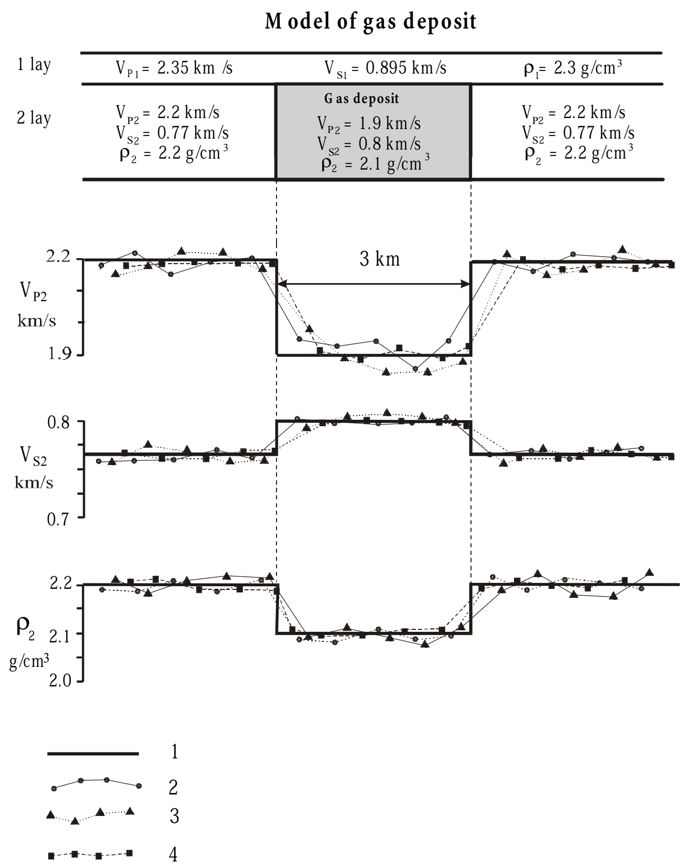

Figure 3. The results of inversion by means of different methods data for model of gas deposit are shown. Noise level is 20% (P-wave); linear approximation is used. 1 –exact values of elastic parameters, 2 – estimates of parameters with respect to (PP+PS)-waves, 3 - estimates of parameters with respect to (PP+SH)-waves, 4 - estimates of parameters with respect to (PP+SV)-waves.