Phase spectrum applied to pinch out zones analysis

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Abstract

We are going to discuss the possibility of using the phase spectrum of seismic signals for analysis of pinch out zones in thin layer reservoirs. The results presented show by analysis of the phase spectrums help to determine more accurately the pinch out point, reducing the domain of uncertainty. These results were obtained by using synthetic and real data. The synthetic data was obtained for signals having frequencies similar to real ones.

Introduction

There have been few studies performed on the phase spectrum in practical geophysics, and the number of publications about this topic is very limited; although in the phase component of signal spectrum there is more information than in its amplitude component, usually studied in the dynamics analysis of real seismic data. In addition, the amplitude spectrum represents mostly the integral characteristics; at the same time the phase spectrum deals mostly with information about differential characteristics of media. Often in the results of seismic data processing the signals are reduced to spectrum with minimum phase even, more frequently, to spectrum with zero phase. So, the information about the phase spectrum of the observed signal is lost or significantly distorted. Probably because it is connected with the traditional orientation of real data processing on time characteristics of signal, and with the complexity of joint processing of a large set of phase spectrums. The focus on the phase spectrum can be renewed during dynamics analysis of complex objects of the wave field and in connection with the solution of the inverse dynamic problems for thin layer objects. It is a well-known fact that even for one thin layer it is impossible to fully reconstruct the elastic parameters using only the amplitude characteristics of spectrum of the reflected signal. In this report we shall consider some aspects related to a more precise definition of the pinching-out point of a layer by analyzing the phase spectrum.

The basic obstacle in processing and interpretation of the phase component of spectrum is a low noise stability of its estimates, obtained by real seismograms. Application of some accumulating procedures, even for such simple procedures as the summation of the phase spectrums of two signals having different time arrivals, requires serious attention to the uniqueness of their definition. Such a problem can become more serious one when we try to perform joint processing or analysis of a large set of phase components. At the same time the guarantee of the uniqueness of phase spectrum definition for each of the traces permits us, even in complex models of the wave field, to obtain consistent estimates of unknown parameters, see Goldin, 1976, and Mitrofanov, 1986. Below we consider some questions of uniqueness of the phase component definition and some of its statistical aspects. Simple criteria to ensure such uniqueness have been created.

Method

During the processing of the phase spectrums of real seismograms, when the corresponding values are obtained for fixed values of the frequency, it is very important to study their joint frequency distribution function, which allows us to construct stable procedures of continuation of the phase component and guarantees conformality of the spectral transformation, and of all another procedures, which will be constructed on its basis; for example, procedures of the linear estimation of the phase spectrum parameters. Such an investigation was made by Mitrofanov, 1979, where the corresponding formula for the joint frequency distribution function $g(\varphi_l, \varphi_m)$ was introduced; in addition φ_l and φ_m were the values of the phase spectrum defined for arbitrary frequencies $l\Delta\omega$ and $m\Delta\omega$, correspondently. We supposed that these values of the phase spectrum were obtained for a part of seismic trace having both the signal and a noise. The common view of the constructed function is shown in Figure 1(A); its projections for different values of the correlation coefficients ρ_{lm} between the real and the image components of its spectrum, obtained for different frequencies, are shown in Figure 1(B). It is necessary to point out that correlation of the values of the spectrum components is a direct consequence of time frame used for selection of the signal in spectral analysis processing.

Function $g(\varphi_l, \varphi_m)$ allowed us to consider some questions concerning the continuation of the phase spectrum for real signals and, due to this, to guarantee uniqueness of the phase component definition. The deal is that after simple analysis of the real and the image parts of the spectrum we can determine arbitrary value of φ_l in the interval $[-\pi, \pi]$, i.e. with precision $2\pi k$. It is sufficient for the construction of univocal correspondences between direct and inverse Fourier trans-forms. But in some cases it is necessary to know the exact value of the phase spectrum on fixed frequency. For example it is necessary in the joint processing of a large number of the phase

spectrums or in the homomorphic filtration of seismic signals.
For the creation of procedures for the stable continuation of the phase component of a real signal it was necessary to investigate the behavior of difference $\varphi_{l+1} - \varphi_l$. The given investigation was made using the function $g(\varphi_l, \varphi_m)$. Based on such a function, the frequency distribution function of the difference of the phase spectrum values $g(\varphi_{l+1} - \varphi_l)$ was made available. Some possible errors were considered, such as an omission of the true change of the phase spectrum value on 2π or -2π, and false changes of the phase spectrum on such quantities. These errors are connected to the fact that the following value φ_{l+1} must be determined in the interval $[\varphi_l - \pi, \varphi_l + \pi]$, but not in $[-\pi, \pi]$, see Figure 2(A). As a result of the fact that the value φ_l can be an arbitrary one, in the analysis of the corresponding errors we have to consider the domains indicated in Figure 2(B). It was shown that the continuation of the phase components of real signal could be effectively achieved using the simple rule $|\varphi_{l+1} - \varphi_l| < \delta$ only in the case of the correct choice of number δ. Behavior of the phase spectrum in the zero points of its amplitude spectrum can have an effect on the choice of δ, see Figure 3. Simultaneously there were constructed estimates for δ and it was shown how this number can depend on the used time frame and the signal/noise ratio, see Figure 4.

One significant aspect in the analysis of the phase spectrum is the possibility of the appearance of discontinuities, which contain useful information about the structure of the interference signal (such signals always have a place in reflection from thin layer objects). In this case there is a possible occurrence of the zero values of the amplitude spectrum and a corresponding uncertainty in the phase spectrum. We could see that a useful discontinuity can arise in the value of π. An illustration of such discontinuity is shown in Figure 3(A) where we can see the trajectory of the spectral point and direction of the phase when crossing the zero point. Figure 3(B) demonstrates a situation when we have no discontinuity of the phase component.

Analyzing Figure 4 it is possible to make a conclusion that the higher the signal/noise ratio the sharper the distribution with respect to φ_l. Real experimental data confirms this conclusion. Consider Figure 5(A), which represents the histograms of the real phase spectrums distribution, constructed for the given frequencies. One sees that the histogram in form is similar to the theoretical one for the basic signal frequency (12Hz). For other frequencies histograms have a more complex structure. This is connected not only to the change of the signal/noise ratio, but with significant dependence on the structure of distribution of the observed phase spectrum values from the value of the phase spectrum to the useful signal. Such dependence can lead to a significant distinction of empiric densities from theoretical function by reason of nonhomogeneity of reflecting properties of real medium. The structure of the histograms starts to change when we make a transition from the initial phase spectrums to their differences $\Delta\varphi_l = \varphi_{l+1} - \varphi_l$, determined by $\Delta\omega$, see Figure 5(B). In such case the histograms have more homogeneous form with marked maximum, specially taking into account the fact that the given difference must be close to one of three values 0, π, 2π. Blue color marks the empiric distribution functions for difference of the phase spectrums, obtained for the zero values of the amplitude spectrums.

Figure 6 represents the results of the influence of different smoothing time frames and the value $\Delta\omega$ on the structure of the distribution of $\Delta\varphi_l$. There are shown the results of mathematical modeling (Figure 6(A)), the results of one real experiment (Figure 6(B)), the results using smoothing time frame (Figure 6(C)), and the results using $\Delta\omega/2$ (Figure 6(D)). These results allow us to understand some singularities in the phase spectrums of real seismic traces and to determine optimal values for the continuation of the phase spectrum, see Mitrofanov, 1986.

Examples

Let us consider now a model experiment, which was performed in a PETROBRAS project, see Priimenko, Mundim, et al., 2005. The basic aim of the project was an analysis of the pinching-out zones of thin layers, and the choosing of some approaches to analysis and processing of seismic data, allowed us to distinguish more accurately the position of the pinch point. The problem of a more precise definition of a pinching-out zone is an actual and complex problem in seismic investigations because in such problems there is a very serious problem relating to the resolution of seismic exploration.
Using real data a model was prepared having several basic boundaries and a target object. The structure of this model has a simple form with several basic intermediate boundaries having a smooth curvature. The form of the model was selected especially to maintain the general form and allow us to concentrate on the target object. Thin pinching-out layer, situated just below one of the bearing horizons – "Marco Azul", represents the target object in the given model. The position of both horizons can complicate separation and estimation of the waves singularities connected with the target object. The reflected waves were calculated using different techniques and the results obtained were analyzed.

Figure 7 represents some results from the two experiments. The wave field for the target object was calculated by the ray tracing method using the Ricker wavelet. In the first experiment wavelet frequency was equal to 50Hz (see Figure 7(A)); in the second experiment it was equal to 75Hz (see Figure 7(B)). On the both figures there were shown the initial signals reflected from the target object. The amplitude and the phase components of spectrum, calculated for these signals, are represented in these figures too; the amplitude component is shown in the middle part of the figure, and the phase component is represented in the lower part. The reflected signals were selected from zero-offset stack taking into account change of their travel-time.

It is possible to see that for frequency 50Hz on the initial profile (see Figure 7(A)) we can determine variations of the signal form connected with the pinch out horizon starting from traces 12-13 where extension of the impulse takes place. Similar determination of the pinch out horizon might be achieved using energetic characteristics, where there is an increase of energy, and by change of the amplitude spectrum of the signal, too. Using the phase spectrum we can definitely determine the change of the form of the impulse for the fifth signal. But the most interesting case appears when we analyze changing of the signal form connected with the pinch out horizon for frequency 75Hz, see Figure 7(B). The change of the signal form on the initial profile is determined already for trace 8. Analyzing the amplitude spectrum we can observe such changes starting from trace 6, and by the phase spectrum – from trace 5. In addition it is important to say that the structures of the phase spectrum for the impulses with frequencies 50Hz and 75Hz are very similar, see Figures 7(A) and 7(B). Thus analysis of the phase spectrum for the signal with low frequency allows us to obtain the same results, which were obtained for the signal with high frequency. The result obtained is based on the fact that the phase spectrum depends less on the basic frequency of observed reflected signal than the amplitude spectrum. Therefore the features connected with the pinch out horizon can become clear at relatively low frequencies of the signal.

The results, obtained in analysis of the phase spectrums for signals reflected from real target horizon can confirm the results, obtained in model experiments. The corresponding results are shown in Figure 8. We can observe a part of the stack, where there is reflected signal from the target horizon, see Figure 7(A). This reflection is situated in the picked time interval. The amplitude and the phase spectrums, calculated for this interval, see Figure 8(B), show that both initial signals and values of the amplitude spectrum allow us to determine the domain of the pinching-out of the target horizon up to trace 52. The precision of the estimates obtained can be low because the level of the corresponding values will be low too. At the same time using the values of the phase spectrum the given domain can be defined more accurately up to trace 61 with a higher level of reliability.

Conclusions

We have presented the results of investigations of the phase spectrums for pinch out domains of the target horizon. We can see that the given characteristics of the signal could contain more useful information then the amplitude spectrum. By analysis of the phase spectrums it is possible to determine more accurately the pinch out point, reducing the domain of uncertainty. One important aspect is that the results obtained are connected with signals having frequencies similar to real ones. We investigated the discontinuities of the phase components of signal spectrum and its statistical characteristics, caused by presence of noise in real data, too. These investigations allowed us to explain the behavior of sets of the phase spectrums, calculated for real signals. It enabled us to formulate some recommendations for joint processing of the phase spectrums.

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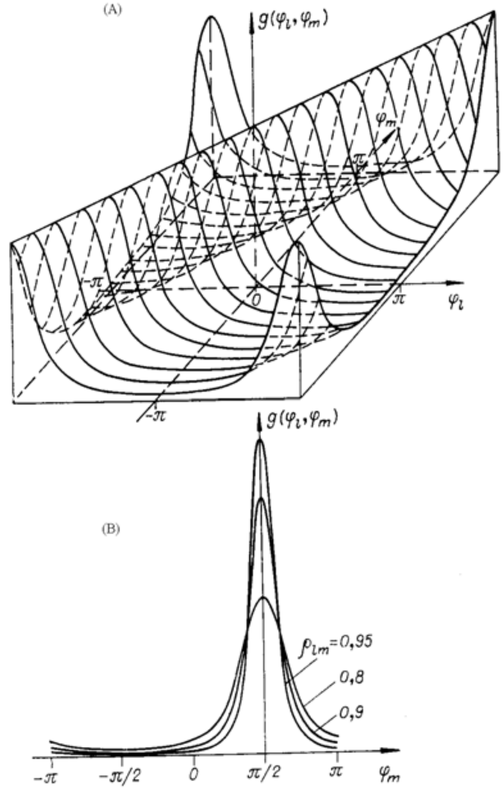

Figure 1. Frequency distribution for couple values of phase spectrum (A) and its projection (B) when $\varphi_l = \pi / 2$.

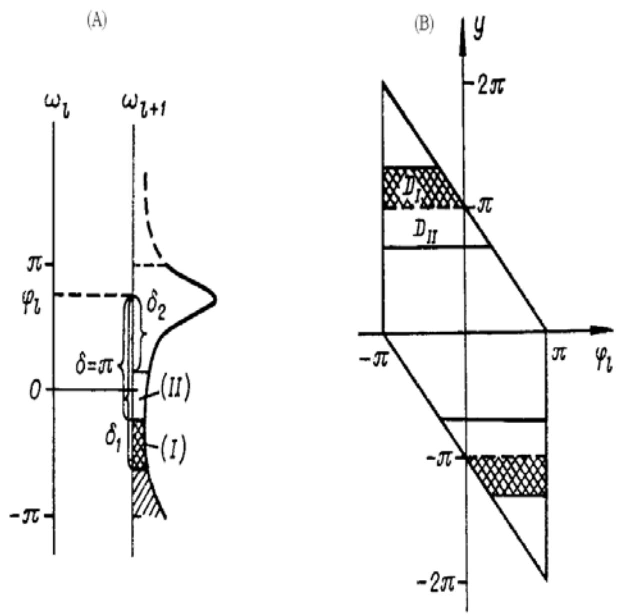

Figure 2. Determination of probability of different kind breaks when φ_l is a fixed value (A) or changed evenly (B).

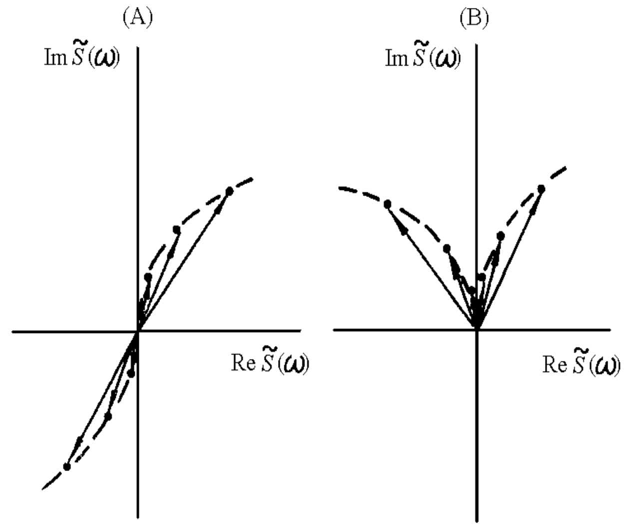

Figure 3. Examples of discontinuous (A) and continuous (B) function $\varphi\ (\omega)$.

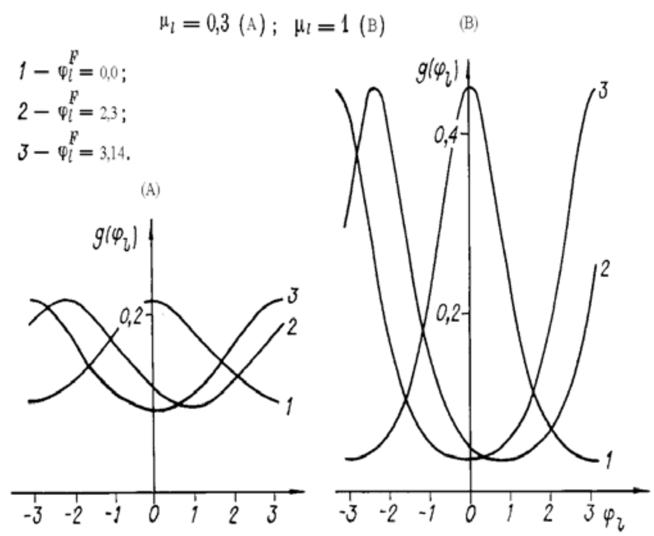

Figure 4. Frequency distribution for different ratio signal/noise μ_l and values of φ_l.

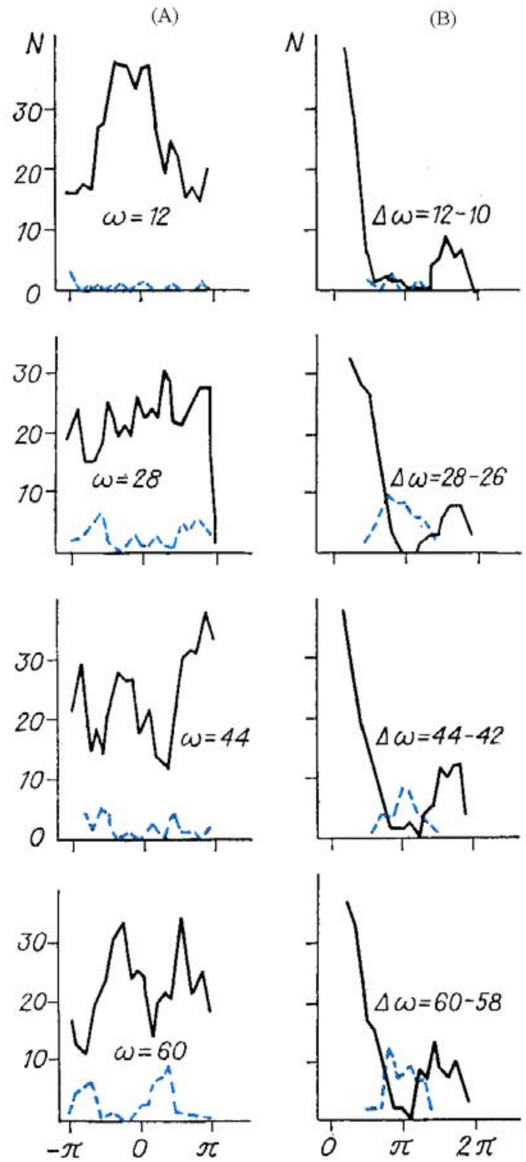

Figure 5.

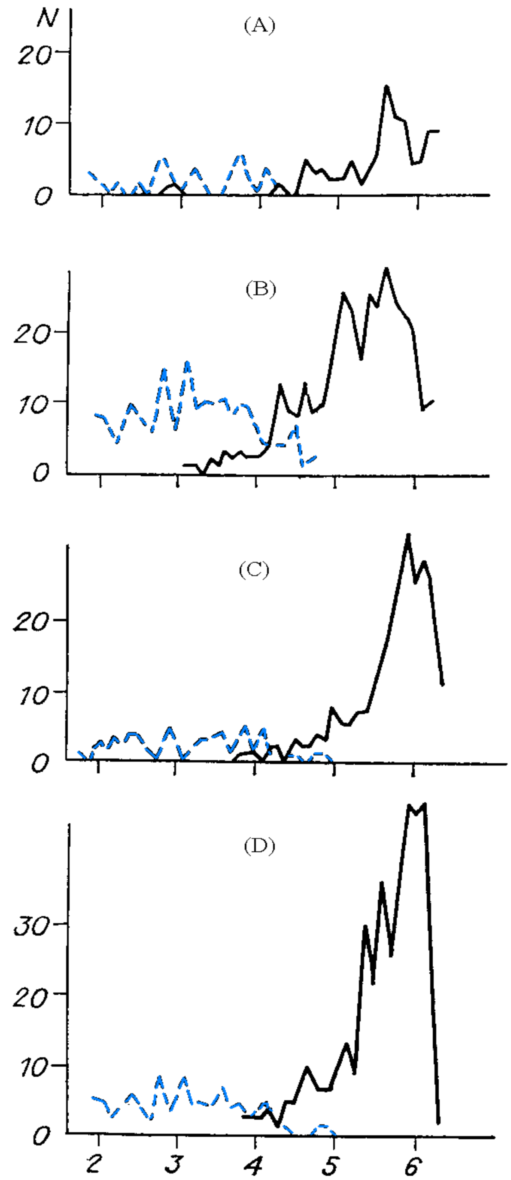

Figure 6.

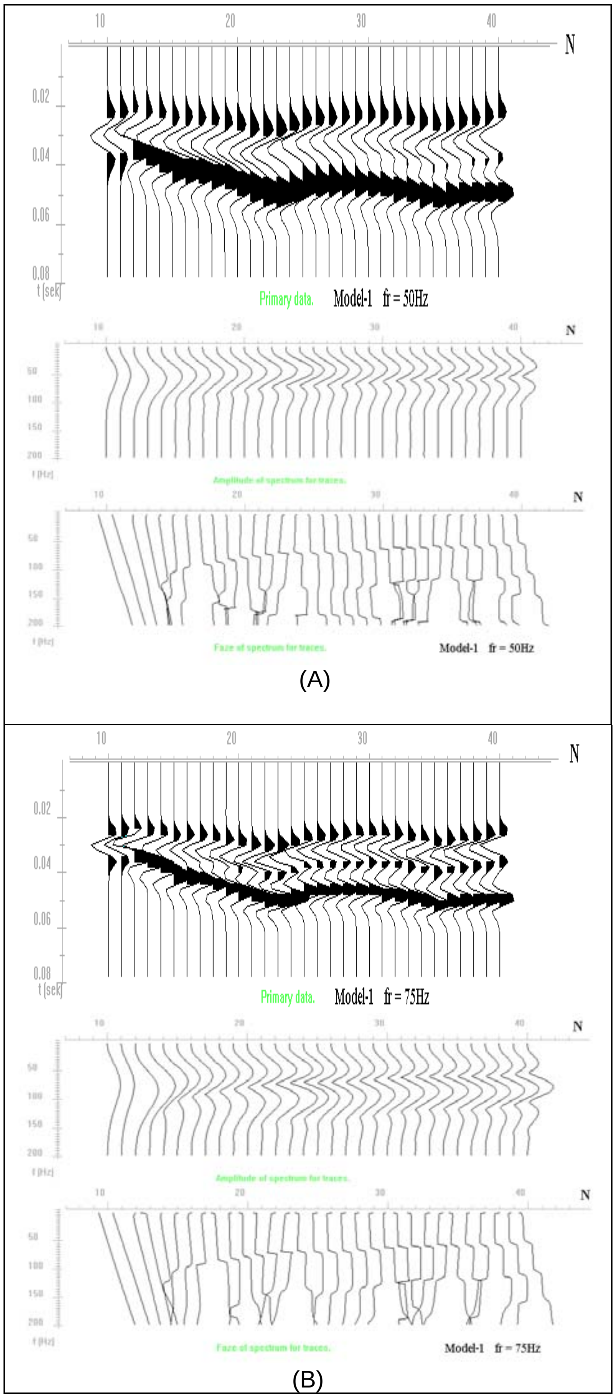

Figure 7. Model example.

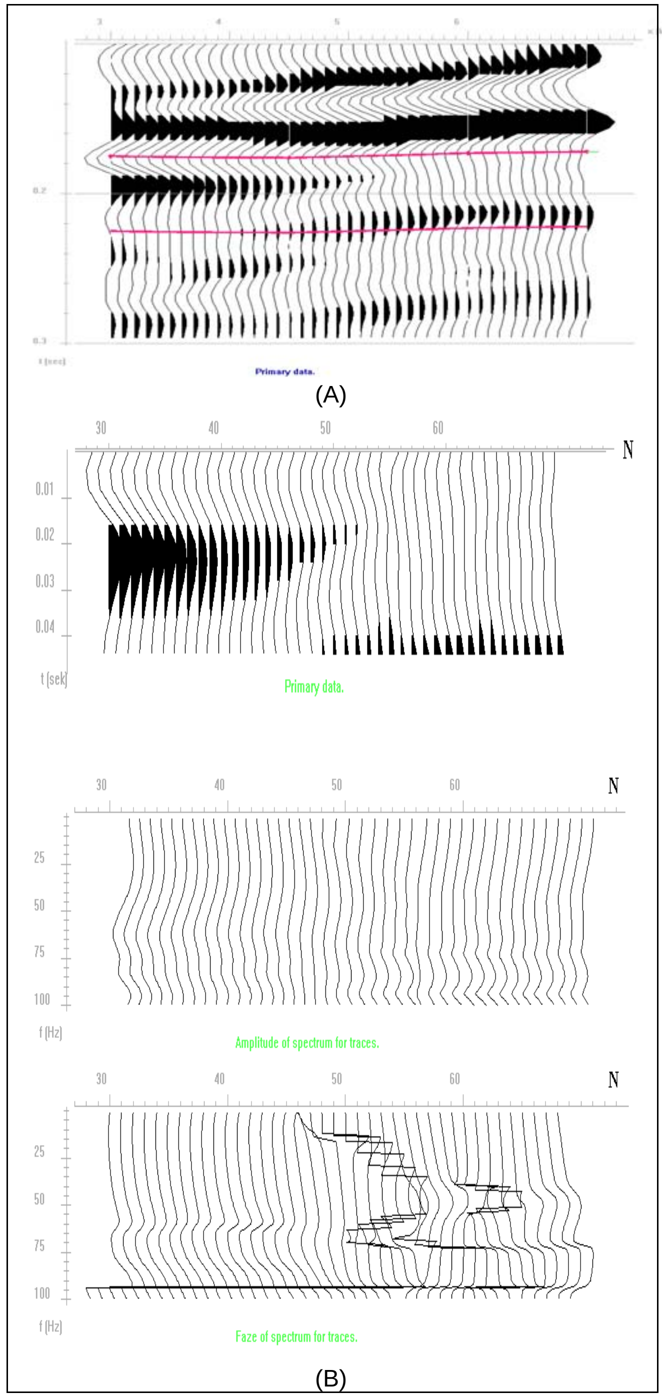

Figure 8. Real data analysis.