Detection of attenuation zones in a time section based on running window filtration

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Abstract. When developing oil reservoirs composed of carbonate rocks and those characterized by complex structure, the production well flow rate is largely determined by reservoir fracturing/ porosity rather than structure. These reservoir properties can often be reflected in a time section as significant attenuation of a seismic signal. The running time window spectral analysis has been proposed in the previous research to detect fractured zones. The calculations of seismic field diffraction due to a single pore and pore ensemble effects were made. The present research indicates that reservoir fracturing or porosity can cause qualitatively similar behavior of reflected signal amplitude spectra. Based on this finding, a rejection filter was constructed and applied to a real time section of the field in Tomsk Oblast, Prony and Fourier spectra being tested.

1. Problem setting

In [1, 2] we have proposed and further developed the method of running time window spectral analysis to determine fractured zones. The technique for amplitude spectrum analysis of seismic fields was based on the results of numerical finite-difference modeling of forward problems in mechanics of deformable solids in fractured bodies [3] and Gregory's laboratory test published in [4].

The unnormalized spectra obtained in the laboratory test and numerical computation are given in figure 1 a and b. Their comparison indicates that a section of high frequencies drops drastically within the spectrum of a wave reflected off the fractured zone; consequently, it distinctly differs from the wave spectrum in a continuous medium.

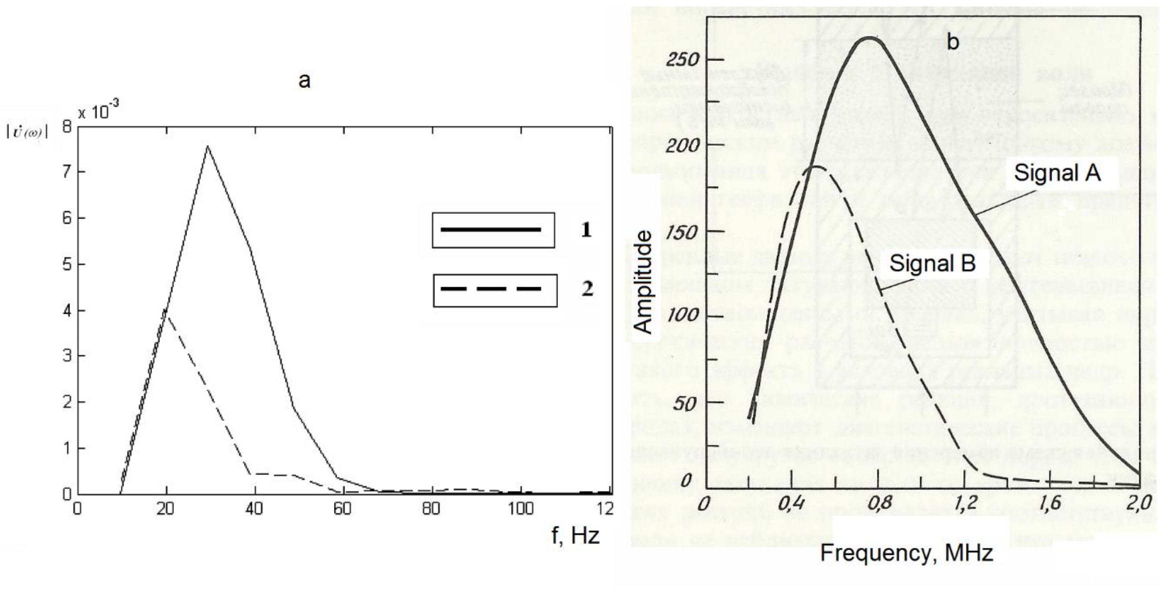

Figure 1. *a – unnormalized spectra of an incident (1) and a reflected (2) wave in a fractured layer [1,2], b – figure from [4]; spectra of an incident (A) and reflected (B) signals in the sandstone sample*

In [5] we solved the problem of plane-wave signal propagation through a medium which contains a single pore or a layer with a random ensemble of pores.

The numerical simulation processing resulted in calculation of the spectra of wave propagation before penetrating a porous layer, and while traveling through a porous medium. Amplitude spectrum moduli are aligned in figure 2.

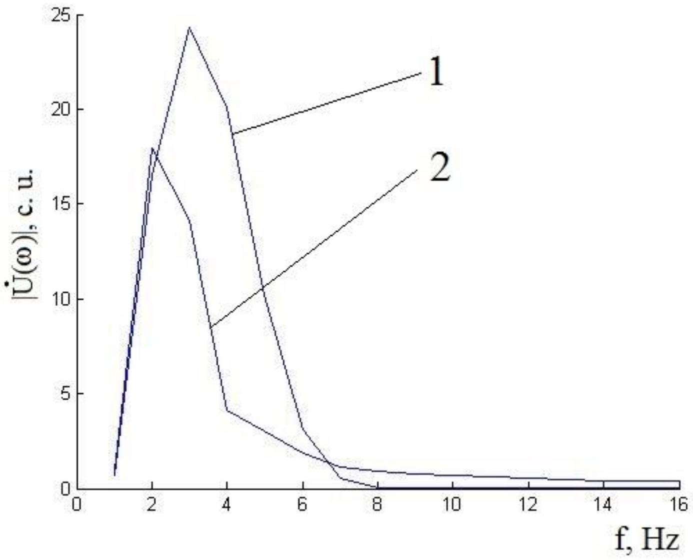

Figure 2. *Incident (1) and refracted (2) wave spectra in a porous layer*

It should be noted that in the course of our research we have observed that spectrum behavior models of seismic wave propagating fractured (figure 1, a) and porous (figure 2) media are similar.

The differences in spectral characteristic of an incident wave and a wave which penetrated fractured or porous zones are obvious. Consequently, the next stage of the research is to detect attenuation and spectrum change zones using real seismic data sets. Therefore, running window Prony and Fourier transforms [6] have been used in further real time section processing.

2. Processing technique

A real section analysis requires numerical filtration technique. Moreover, restrictions connected with sampling theorem and imposed due to final sizes of processing units do not allow extracting harmonic components of any pre-determined frequency. To bypass this restriction, we should apply Prony transform [7] which is not a spectral transformation in its pure form, but is a method to estimate discrete data based on linear combination of exponential functions (like least squares technique). Furthermore, it is possible to calculate spectral energy density (PSD) for any Prony frequency.

Prony method estimates *n*-element of *y(1), …,y(N)* sampling based on exponential *p*-order model:

$$y(n) = \sum_{k=1}^{p} h_k z_k^{n-1} \,, \qquad (1)$$

where factors h_k и z_k are generally complex and determined by the following formulas:

$$h_k = A_k exp(j\theta_k), \;\; z_k = \exp[(\alpha_k + j2\pi f_k)\, T].$$

where A_k – amplitude, α_k- attenuation coefficient (dimension - c^{-1}) of *k*-complex exponent, f_k(Hz), $\theta_k(rad)$ – frequency and *k*-sinusoid initial phase.

Figure 3 shows the first four terms of a series for values N=64 and p=15 (1). The first term (p1, the thickened line) is the attenuation exponent; the three remaining terms are damped sinusoids. For the majority of ordinary signals (including acoustic ones), the series (1) converges much quicker than Fourier series.

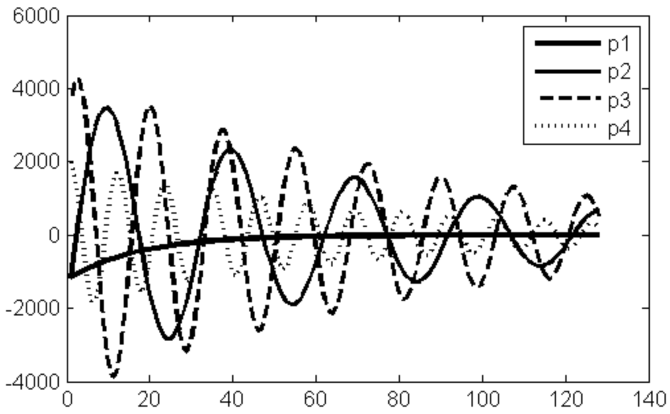

Figure 3. *The first terms of Prony series*

Having calculated h_k and z_k value arrays, it is possible to determine spectral energy density for any f_k frequency from $-(2\Delta t)^{-1} \leq f_k \leq (2\Delta t)^{-1}$ frequency range, where $(2\Delta t)^{-1}$ is an analogue of Nyquist frequency[8, 9].

For the chosen window [10] size N in case of Fourier transform Nyquist frequency is equal to f_N=N/2 (a nondimensional value which defines the amount of harmonics, i.e. events); whereas for the given reference value Δt, the cutoff frequency is fc=1/(2Δt) (a dimensional value, Hz). For example, if the window size is N=64 and Δt=0.002 s, then f_N=32, f_{th}=250Hz, while one harmonic of the window corresponds to 250/32=7.8125 Hz. For the chosen window and fixed reference value this number 7.8125 Hz remains the same.

In case of Prony transform the method of frequency selection from $-(2\Delta t)^{-1} \leq f_k \leq (2\Delta t)^{-1}$ frequency range predetermines variability of frequencies with change in signal parameters. Furthermore, each number («harmonic») in a Prony series will correspond to a certain bandwidth, but not to a particular Hz-frequency. The behavior of these bands is of particular methodological interest for geophysical data processing and interpretation.

3. Results and discussion

Figure 4 below shows the results of Prony notch filter application to «C» area «№95» time section windowing.

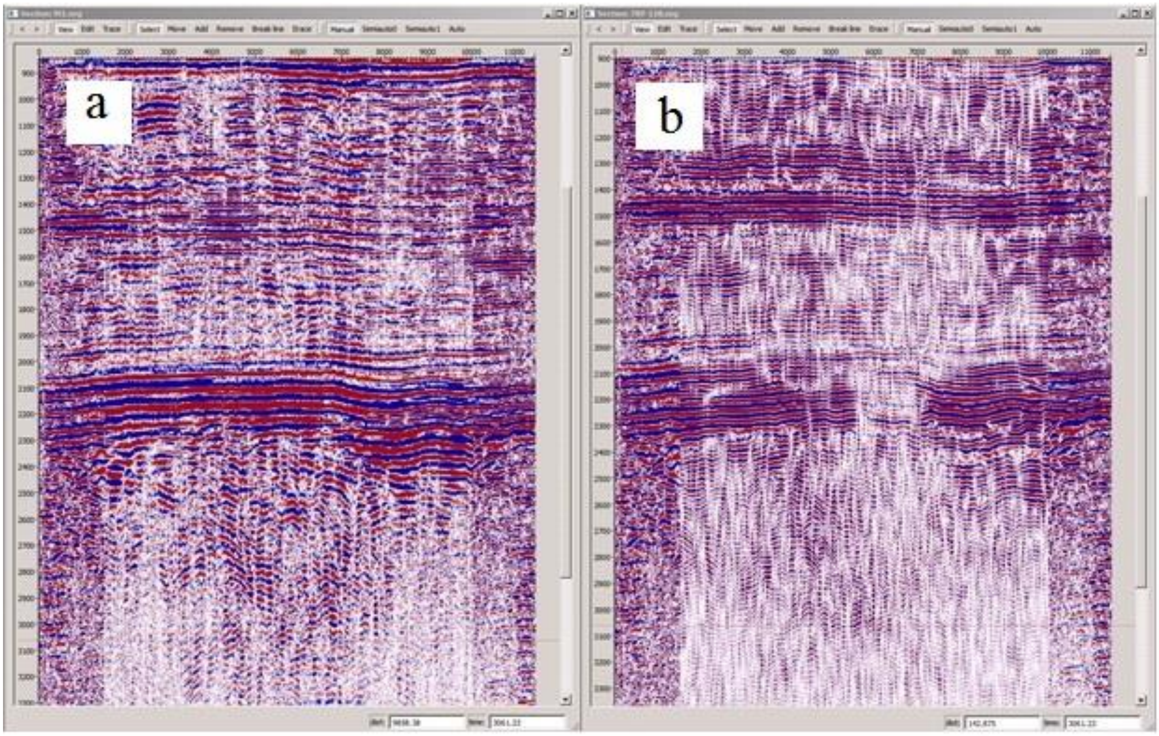

Figure 4. *Initial «C» area seismic section «№95» before (a) and after (b) Fourier transform being applied*

The proposed section processing sequence being applied, higher signal attenuation zones (probable increased fracturing/porosity and/or fluid saturation) are distinguished within the section due to lesser wave amplitude in comparison with the surrounding traces. This effect can be observed in the central section of the profile 95 in time sample of 2100-2300 ms, where the zone with violated phase sequence and low wave amplitudes can be detected among distinct phases of horizontally bedded Jurassic deposits of the sedimentary rocks.

It should be noted that the revealed zone corresponds to the actual pay interval.

The effect of porous/ fractured layer on a seismic signal has been studied in the investigation. In case of a reflected wave Prony and Fourier spectra are analysed. It has been indicated that amplitudes of certain frequencies decrease substantially in case of both porous and fractured layers. The similar spectrum change was observed previously in laboratory modeling of seismic wave propagation through the sandstone sample. In general it can be stated that zones of increase in attenuation can be displayed in a certain frequency band of the spectra. This can identify a procedure for filtration of real time sections to detect potential zones of increased signal attenuation. The presented technique can be used at the stage of processing seismic time sections in the laboratory, interpreting acoustic logging and mapping productive areas.

References

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