Automatic first-breaks picking using linear moveout correction and complex seismic traces

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Abstract

Statics correction corresponds to a time-shift which is applied to the seismic trace to eliminate the misalignment of the reflections, caused by topography and weathered layer effects. This correction depends on the precise determination of the first breaks picking. The obtaining of the first breaks on the seismograms can be a arduous task if data were acquired in complex regions and with low signal to noise ratio. Besides, if the wavelet is generated from a vibroseis source the picking process is even more difficult once the wavelet is non-causal with energy lobes around the maximum value of the reflection. In the present paper we proposed an automatic method to obtain the first-breaks picking which use the envelope of the complex seismic trace. The picking is performed on shot-gathers corrected from the linear move-out, which makes the direct and the refracted waves horizontal. The first-breaks picking method is automatic, stable and reliable for the calculation of statics correction. We tested the method using shot-gathers from different sedimentary basin and acquired with explosive and vibroseis source. The results obtained with synthetic and real data show that the proposed method is robust, numerically stable, computationally efficient and easy to apply.

Introduction

The determination of statics correction constitutes a fundamental step in land-based seismic data processing. Static error are sufficient to completely modify the structural shape of reflectors in subsurface, creating false structures in seismic section (Cunha, 2010). In industrial scale, Seismic Refraction Tomography is the most used method for obtaining static correction, since it uses the first breaks in reflection seismograms which don't add any additional cost to data acquisition and represent great redundancy of information about the low velocity zone (LVZ). This redundancy is exploited, in the least-squares algorithms (Amorim, 1985), to obtain the thickness and velocities of the LVZ, used to compute the statics correction. Clearly, the efficiency of the static correction methods, relied on seismic refraction and refraction data, depending on the reliability of the first break picking (Yilmaz, 2001).

In general, quality of first break is related to the signal to noise ratio of the seismograms, the condition of the terrain and the type of source signature used in the acquisition. As consequence, the determination of the first breaks can be a very arduous task if data were acquired in complex regions and with low signal to noise ratio. Besides, if the wavelet is generated from a vibroseis source the picking process is even more difficult once the wavelet is non-causal with energy lobes around the maximum pick.

Traditionally, the determination of the time step, corresponding to first break was done by visual inspection of amplitudes and the picks were made manually. Depending on the volume and quality of the seismic data, the process of first break picking can take 20% to 30% of the total time spent in data processing (Sabbione, 2010). Besides being a time consuming way of determining first breaks, this strategy could lead to tendentious and inconsistent choices, because it would depend on the subjectivity of each professional. With the development of modern computers, software of automatic picking were created, but still in general this process is still too slow and subjective, because it still depends on visual inspection. Thus, the implementation of new method for automatic first-break picking, with the characteristic of being very objective and consistent is of great value for the processing of land seismic data.

Through decades, many techniques have been proposed for the obtaining of the first break picking. The first attempts were based on cross correlation of adjacent traces for searching the delay time of first breaks (Peraldi and Clement, 1972). However, this technique tends to fail when the pulse shape changes, or when bad or killed traces appear on data. Another approach, included in many commercial softwares, is based on the increase of energy of seismic signal (Coppens, 1985). This method is very robust when signal/noise ratio is relatively high.

Recent methods include algorithms based on neural network. This approach proved to be useful on determining the picks for the first breaks. Yet, without a good network training, the results can demand manual time consuming adjustment, specially with low quality data.

On this paper, a new first-breaks picking method is proposed. The method is based on linear normal moveout correction (LMO), combined with the spatial singular value decomposition (SVD) filtering which is applied on the envelope of the complex seismic trace.

Methodology

In the methodology proposed, the process is splitted into four steps: use of the discrete Hilbert transform to generate the complex seismic trace and its corresponding envelope; perform the linear moveout (LMO) correction, flattening the direct and refracted reflections; improve the signal/noise ratio by filtering the seismograms using the singular value decomposition (SVD) method on spatial sliding window as proposed by Porsani et al, (2009); pick the first break of individual seismic traces in a predefined time gate of the shot-gather defined around the first break region, using the accumulated energy up to satisfy a specified user parameter, and; apply the inverse LMO correction.

Hilbert Transform and Envelope

The concept of complex seismic trace is illustrated in Figure 1, where $x(t)$ is the real seismic trace and $y(t)$ the Hilbert transform of $x(t)$. When the traces are summed, the result is the complex seismic trace $z(t)$ (helical curve), being defined by equation 1:

$$z(t) = x(t) + iy(t) \tag{1}$$

The imaginary part $y(t)$ is also denominated quadrature or conjugate and $z(t)$ can be determined solely in terms of Hilbert transform or by convolution in time domain, using the quadrature operator associated to the Hilbert transform. "The analytic signal doesn't contain negative frequency components", and it can be obtained from real signal by suppressing negative frequencies (Claerbout, 1976). Those techniques are based on the observation of the amplitude spectrum of the complex trace, which vanishes when $\omega < 0$ and it is twice the magnitude when $\omega > 0$. As phase keeps constant (except when it is not defined for $\omega < 0$) the complex trace can be estimated by the following form (Mojica et al, 2011): (i) Fourier transform of real trace, (ii) Zeroing the amplitudes of negative frequency and doubling the amplitude of positive frequencies, and (iii) Inverse Fourier transform.

The complex trace $z(t)$ can be visualized as a trace represented in a complex space of a vector which is continually changing its size and rotation, assuming the shape of a helix which shrinks and expands along the time axis, as shown in Figure 1. The concept of complex trace allows us to define amplitude or envelope, phase, instantaneous frequency and polarity. Those quantities also denominated "attributes" characterize the complex trace and the can be plotted the same way as the most used for plotting conventional seismic traces.

At any point along the time axis of complex seismic trace, the vector of instantaneous amplitude $a(t)$ can be calculated, representing the amplitude at that point. Mathematically, this amplitude is measured by Equation 2:

$$a(t) = \sqrt{x^2(t) + y^2(t)} \tag{2}$$

The illustration of the calculus of instantaneous amplitude associated to complex seismic trace is shown in Figure 2. Figure 2a represents seismic trace $x(t)$ and 2b is related to complex seismic trace. This last one consists in a real part $x(t)$ (black) and an imaginary part $y(t)$ (green) calculated by Hilbert transform. The amplitude can be checked in each step of the process of envelope construction (stars in red and yellow).

The conversion of complex seismic trace in a function of instantaneous amplitude in described in Figure 2c where a function of amplitude is represented graphically as an oscillatory envelope which involve both real and imaginary part of complex trace. The instantaneous amplitude is a positive function, meaning that its value will always be positive. However, it's being represented the positive and negative portions to enphasize that the envelope covers real and imaginary parts of seismic trace.

SVD Filtering

Following the procedure proposed by Porsani et al. (2009) we consider a seismic data set $d(t,x_n)$ where the time axis is given in sample number, $t = 1,2,\dots,N_t$ and the space axis is given in relative space position $x_n, n = 1,2,\dots,N_x$. The primary reflections have been corrected for LNMO so that they are horizontally aligned in the x-direction. A windowed data set of $2M+1$ traces centered at x_n is given by a matrix with components $d(t,x_{n+j}), t = 1,\dots,N_t$, $j = -M,\dots,0,\dots,M$. It can be represented by the reduced SVD (Golub and van Loan, 1996):

d(t,x$_{n+j}) = \sum_{k=1}^{2M+1} \sigma_k u_k(t) v_k(j)$

Here the singular values are sorted such that $\sigma_1 \geq \sigma_2 \geq \dots \geq \sigma_{2M+1} \geq 0$. In the filtered output data set only the first K eigenimages of the center trace are being used. That is, the output is

(t,x$_n) = \sum_{k=1}^{K} \sigma_k u_k(t) v_k(0)$

The procedure is started at $n = M+1$ where the filtered output is the sum of the K eigenimages corresponding to the K largest singular values of the first $M+1$ traces:

(t,x$_{M+1+j}) = \sum_{k=1}^{K} \sigma_k u_k(t) v_k(j)$, $j = -M,\dots,0.$

Then n is increased by one and equation is used until $n = N_x - M$ where the output data are given by the sum of the K first eigenimages of the last $M+1$ traces. That is

(t,x$_{N_x-M+j}) = \sum_{k=1}^{K} \sigma_k u_k(t) v_k(j), j = 0,\dots,M$

The result is a filtered data set $\tilde{d}(t,x_n)$ of the same dimension as the input data set where energy, which is not coherent in the x-direction, has been attenuated. Both the character and amplitude of the horizontal events are well preserved as they are represented by the center trace of the first eigenimages which have the largest energy.

Pick definition

It's the last step of the algorithm. After obtaining the trace's envelope, and applying the SVD filter after LNMO correction, it's time for defining the first break. This definition is made based on the energy of the envelope following the next steps:

- Calculate total energy of envelope, given Equation 3, where N is the total number of samples and X_i is the amplitude;
$$E = \sum_{i=1}^{N} X_i \tag{3}$$
- Definition of tolerance factor ε (Equation 4), which indicates the percentage of envelope's total energy (E). In this case, n is the percentage of energy which corresponds to sample where pick is defined, and it is chosen by user;
$$\varepsilon = n.E \tag{4}$$
- Definition of pick's sample happens when $\varepsilon = nE$, or, when $\varepsilon > nE$ the algorithm will consider the sample before as the first break pick.

After selecting the picks, it's applied inverse LNMO using same velocity as used on direct LNMO. This process is to repositioning the picks to their real position in the reflection seismogram.

Due to filtering and the model of definition of picks (a pre-stablished percentage of total energy), the picks won't follow a pattern of choosing always the max amplitude of first break. Instead of that, the picks will be around it. But as the most important for the first break pick is to follow a pattern, a last iteration is done.

Using the table of picks obtained by past steps, the user defines a new window with $N/2$ samples above and $N/2$ below previous pick. On original data, the algorithm will search for a sample which has the highest amplitude inside the window. After finding this sample, the pick is redefined and saved on a .txt table and then inserted on each trace header.

To show the step-by-step of proposed method, a synthetic data was generated and it was contaminated with different noises from different kinds, such as: 60 Hz noise; random noise; spikes of high and low frequency. Those kinds of noise where chosen to simulate the best a real case. Figure illustrate the main steps of proposed automatic first-breaks picking method. Figure 3a show the envelope of a synthetic seismogram. Figure 3b show data after LNMO correction and SVD filtering. It also has the definition of the window where method will operate (in this case, 60 samples from the beginning of each trace). Figure 3c represents the definition of picks based on envelopes energy. Figure 3d show inverse LNMO correction result, placing the picks on correct sample.

After adding picks trace header, the visualization of picks and static correction steps are all done on the software SeisSpace. Figura 4 show first break picks (red dots) obtained plotted on seismogram.

Results

Focusing on confirming the efficiency of proposed method, this chapter shows the application in data from different Brazilian sedimentary basins. Those basins are: Recôncavo; San Francisco; Solimões; and Tacutu. Those aforementioned data where all acquired with explosive sources. The method also was tested on a shot-gather obtained using a vibrating source.

Recôncavo basin is located in Bahia State, northeast of Brazil. Figure 5a shows picks plotted on seismogram (red dots). Clearly the first break was well defined, even with data contaminated with low frequency noise from acquisition done on rainy weather.

Solimões basin is located in Amazon State, north of Brazil and it's a intracratonic paleozoic basin. The seismogram is contaminated by noise above first freak, which has great amplitudes and all kinds of frequency. Because of it, the definition of first break is more difficult (Figure 5b).

Tacutu basin is defined as a mid-sized craton rift, with faults and from mesozoic age. It's located on center-northeast sector of Roraima State. Seismograms of this area have usually low frequency and high amplitude noise above first arrivals. Figure 5c show result of method on this data.

São Francisco basin is located above São Francisco craton, center of Brazil. For this example a mute was applied to zero all amplitudes above first break. The results of the method are shown in Figure 5d.

Vibroseis shot-gather is the most challenging example, which produces signal that arrive before the first break, making the picking process more difficult. Figure 6 illustrates the result of the automatic picking. Although the visual difficulty to define the first break, the algorithm proposed turned out to be efficient.

Conclusions

The automatic first-break picking method was applied in land-based Brazilian basins such as Recôncavo, São Francisco, Solimões, Tacutu basins. The data used approached different kinds of noise and still all results were satisfactory. In general, it was observed that the method is effective for determining the first breaks since they characterized as high energy event. It also had accurate results for vibrating source data. The proposed method is very robust for noisy data and it generates consistent pick tables even in the presence of noise that masks first arrivals and change the pulse form. It was also satisfactory for data with low signal/noise ratio. The method is very efficient and has low computing cost, with the user only defining a few parameters obtained after visual inspection.

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References

Amorim, W. N. 1985. Cálculo das correções estáticas através do princípio da tomografia sísmica, Tese de doutorado, Universidade Federal Da Bahia, Salvador, Brasil.

Coppens, F. 1985. First arrivals picking on common-offset trace collections for automatic estimation of static corrections, Geophysical Prospecting, 33:1212-1231.

Claerbout, J. 1976. Fundamentals of geophysical data processing with aplications to petroleum prospecting, Mc Graw-Hill, New York.

Cunha, R. S. 2010. Cálculo das correções estáticas, Trabalho de graduação, Universidade Federal Da Bahia, Salvador, Brasil.

Freire, S. L. M. 1986. Aplicações do método de decomposição em valores singulares no processamento de dados sísmicos, Tese de Doutorado, Universidade Federal da Bahia, Salvador, Brasil.

Mojica, O. F. & Porsani, M. J. & Silva, M. G. 2011. Aplicações da filtragem svd na análise de velocidades e no empilhamento cmp, Resumo Expandido CisBGf.

Peraldi, R. & Clement, A. 1972. Digital processing of refraction data: Study of first arrivals, Geophysical Prospecting, 20:529-548.

Porsani, M. J. & Silva, M. G. & Melo, P. E. M. & Ursin, B. 2009. Ground-roll attenuation based on svd FIltering, SEG

Expanded Abstracts, 28:3381-3385

Sabbione, J. I. & Velis, D. 2010. Automatic first-breaks picking: New strategies and algorithms, Geophysics, 75:67-76.

YILMAZ O. 2001. Seismic data analysis: processing, inversion and interpretation of seismic data, SEG.

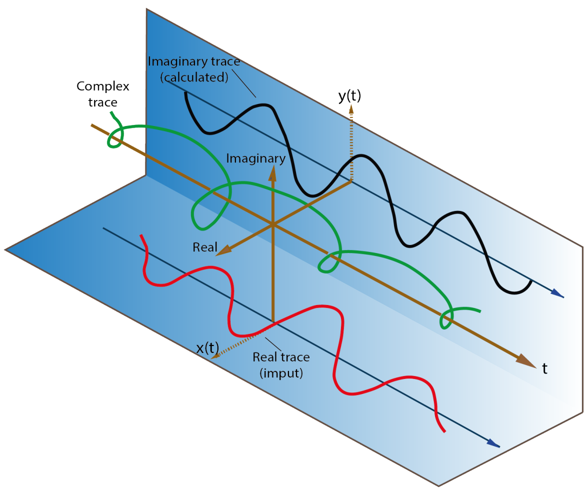

Figure 1: Complex seismic trace. In black, real part, and in red the imaginary part.

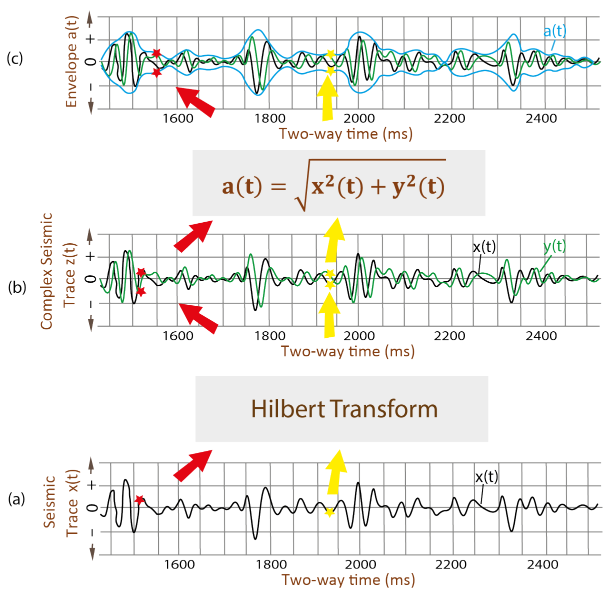

Figure 2: Complex seismic trace and envelope construction $z(t)$ and $a(t)$, respectively, from seismic trace $x(t)$.

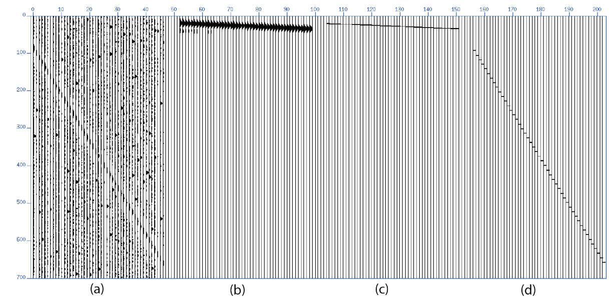

Figure 3: Steps of algorithm: (a) envelope; (b) SVD filtering after LMO correction; (c) picks determination; (d) inverse LMO and repositioning of picks on correct samples.

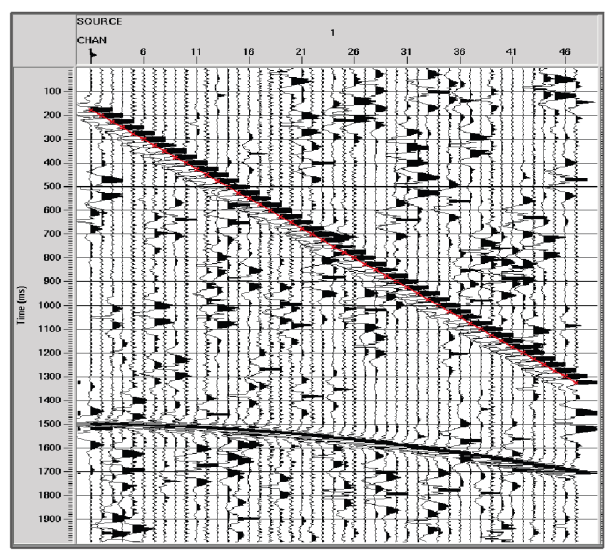

Figure 4: Synthetic seismogram with first break picks in red dots.

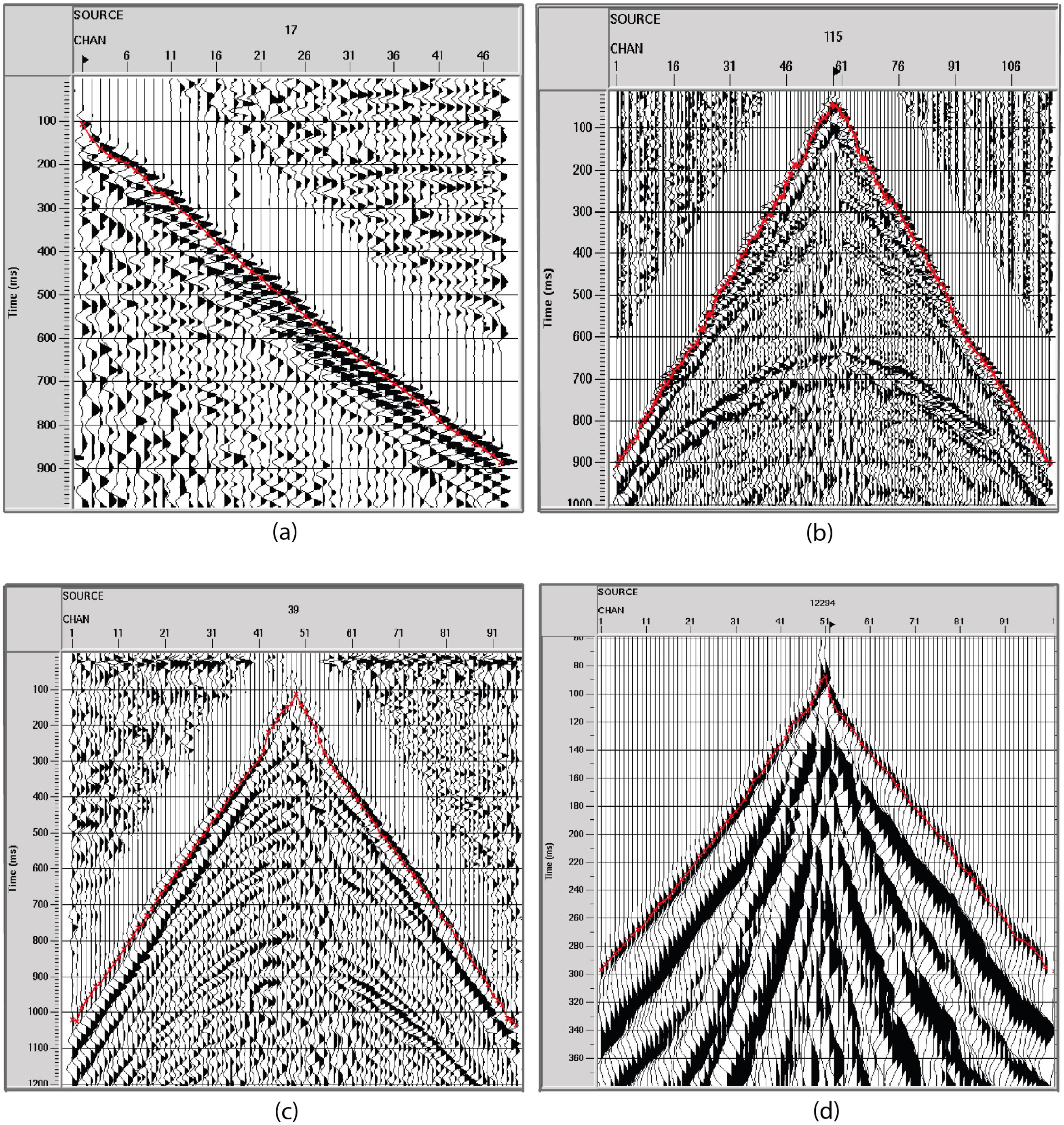

Figure 5: Automatic picking in explosive source data: (a) Recôncavo basin; (b) Solimões basin; (c) Tacutu basin; (d) São Francisco basin.

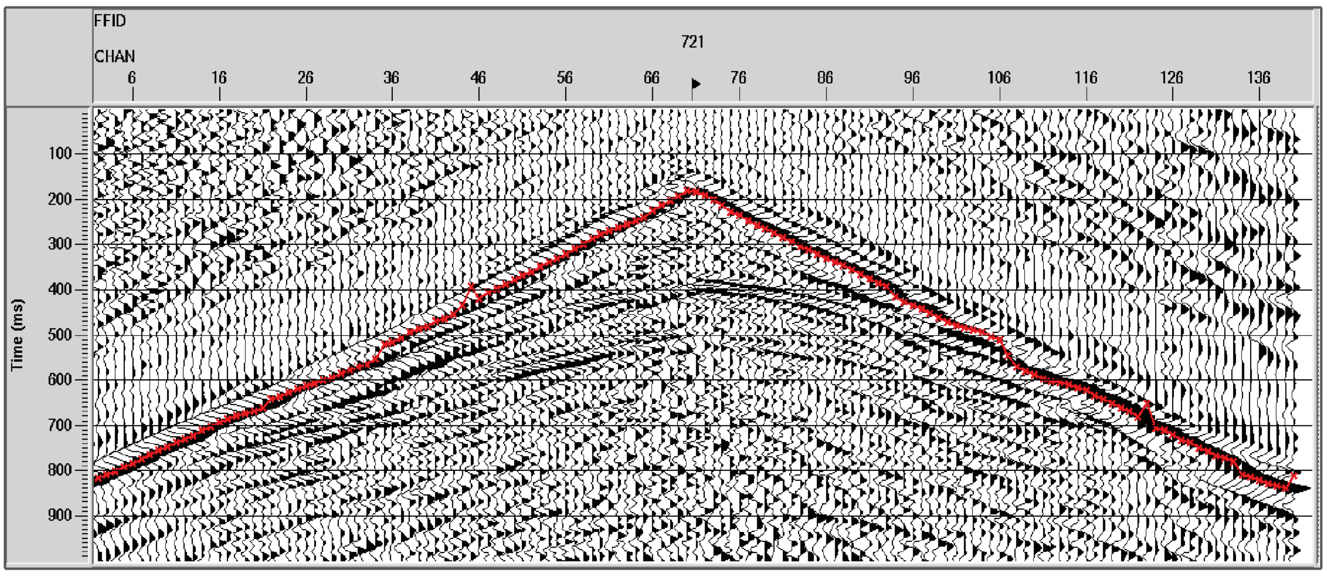

Figure 6: Seismogram with first break picks in red in vibrating source data from Parnaíba basin.