An applied technique that separate P and S waves of a multicomponent seismic signal in logs vertical seismic profile (VSP)

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This paper was prepared for presentation at the 15th International Congress of the Brazilian Geophysical Society, held in Rio de Janeiro, Brazil, 31 July to 3 August, 2015.

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Abstract

This paper presents the results of the implementation of a technique for the separation of P and S waves in a multicomponent seismic records in Vertical Seismic Profile data (VSP). Principal Component Analysis (PCA) was conducted like a statistical analysis technique for the selection of this method, as also were implemented techniques in the analysis of signals, the ACP is very important because it can determine the angle of the first arrivals for P and S downward wavefield in VSP data. VSP data were processed and compared with the results in the Seismic Unix software. The method was tested using synthetic and real seismic data.

Introduction

The multicomponent seismic analysis is a good tool for the study of the subsurface earth in special for hidrocarbon exploration, one of its main advantages compared with the conventional seismic is the information of the shear waves (Barkved, 2004). Because there are limitations in the knowledge of their actual behavior during acquisition of the data, for the study and computational treatment must make some assumptions respect to their angles of incidence in the receptors, assumptions that are not entirely accurate.

The study on VSP records, has certain advantages in that due to the disposition of geophones and sources presents a better signal to noise ratio, reducing unwanted noise like ground roll and allows separate and identify the downward waves that move through the lithological layers near the well (J. Salmon, Ana V. Somoza).

Various techniques are present in the literature for the separation of the seismic waves P and S (S. Labonte), methods such as principal component analysis and independent, median filter, fk filter and other filtering techniques based on the prior knowledge of some wave characteristics such as speed or angle of incidence, used in some domains such as the fp, zt, fp and τ-p (K. Jovanovic, S. Labonte).

The Seismic Unix software allows the generation of synthetic seismic VSP with elastic characteristics, and also is an excellent instrument for processing in real and synthetic data, In this way we validated the techniques implemented in the software tool and it is compared with the results obtained with the code developed.

Theory

Principal Component Analysis (PCA) is a technique from the exploratory data analysis whose objective is the synthesis of information, or the reduction of the dimension (number of variables) (Rodríguez O. 2009). Its application allows to find orthogonal transformations of the original variables to get a new set of uncorrelated variables, called principal components, which are obtained in decreasing order of importance (equation (1)).

$$\begin{bmatrix} X_{11} & X_{12} & \dots & X_{1p} \\ X_{21} & X_{22} & \dots & X_{2p} \\ \vdots & \vdots & \ddots & \vdots \\ X_{n1} & X_{n2} & \dots & X_{np} \end{bmatrix} \Longrightarrow \begin{bmatrix} C_{11} & C_{12} & \dots & C_{1p} \\ C_{21} & C_{22} & \dots & C_{2p} \\ \vdots & \vdots & \ddots & \vdots \\ C_{n1} & C_{n2} & \dots & C_{np} \end{bmatrix} \quad (1)$$

All data with 100% Principal components

The n individuals in a data table can be seen as a cloud of points with its center located at the origin, this later is carried to a q-dimensional subspace, usually a plane (Figure 1), such that the projection on orthogonal of n points in this have the maximum variance, this will allow the study of relations, classes, etc between variables that want to analyze.

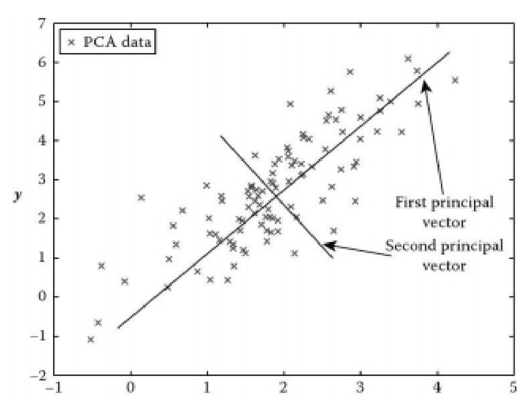

Figure 1: Flowchart for the implementation.

The ACP can be understood as the search of the subspace of best fit, another application from Principal Component Analysis is to filter a signal removing one or more of its components which are not of interest.

Processing of the VSP data

We can summarize the steps for the processing of the VSP data:

1. Loads the VSP data to be processed.
2. Separation of the fields in upward and downward wave is conducted through the filter FK.
3. First arrival picking and flattened data.
4. Median filter to obtain separately the P and S waves.
5. First arrival of the downward P and S waves.
6. Calculate the angle of incidence of the the downward P and S waves, with the technique of Principal Component Analysis.

Synthetic data: A subsurface model of planar layers for validation

To verify the validity of the processes implemented in the code, were estimated a set of elastic synthetic signals (P and S waves) generated using synthetic multicomponent siesmic for VSP profiles (LatihanVSPsu), where was implemented ELA2D (Seismi Unix Software) for the generation of the traces (Figure 4) with a layered velocity model flatt and density (Figure 2 and 3). The model used for working have a range between 1524 [m/s] to 4000 [m/s], range of P waves (Figure 2, left), and a range between 890 [m/s] to 2350 [m/s], range of S waves (Figure 2, right).

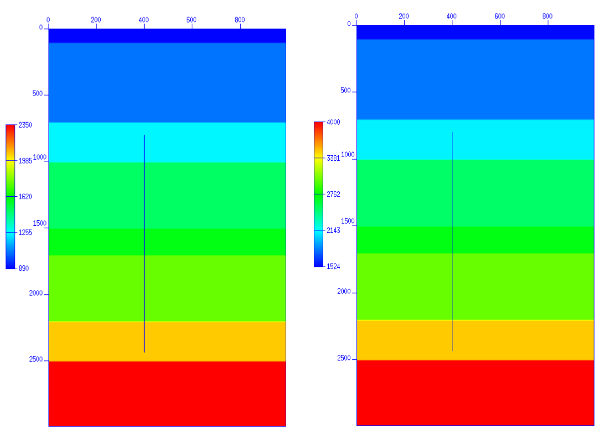

Figure 2: *(left)* velocity models with P wave; *(right)* velocity models with S wave.

This earth model has variable density values according to the depth, the surface layer has a density of 1930 $[kgr/cm^3]$, determining a density for the final layer to 2460 $[kgr/cm^3]$ (Figure 3).

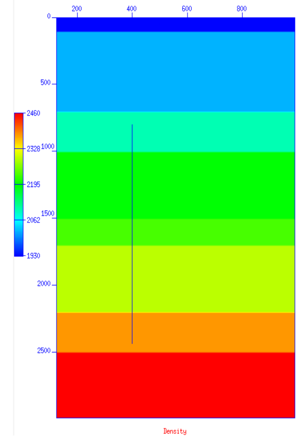

Figure 3: Density model with planar layer.

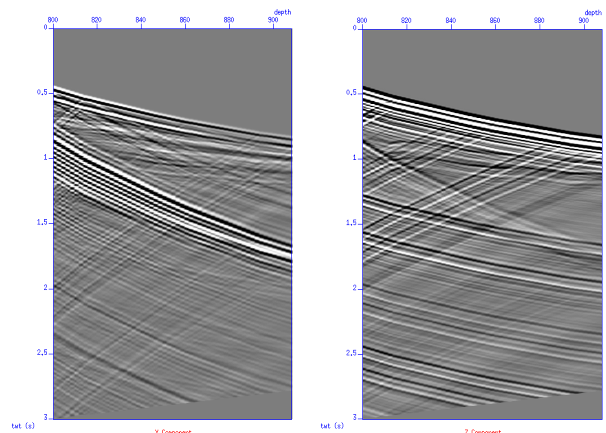

Figure 4: *(left)* radial component;*(right)* vertical component.

Validation with synthetic data

After having elastic synthetic traces generated is applied to each corresponding to the processing steps, both where tested in Seismic Unix (SU) and MATLAB, and thus able to compare and verify that the latter is properly perform each of processes.

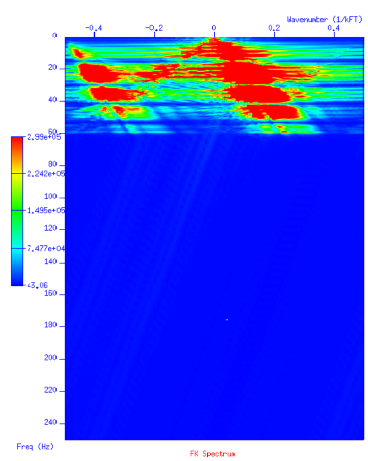

Figure 5: F-K spectrum of a VSP synthetic seismic data

As a first step was applied a FK filter (Figure 5) in order to perform the separation of the downward and upward field, where was applied a cut filter in the FK spectrum, the figure 6 shown the result for the separation with the the downward and upward field.

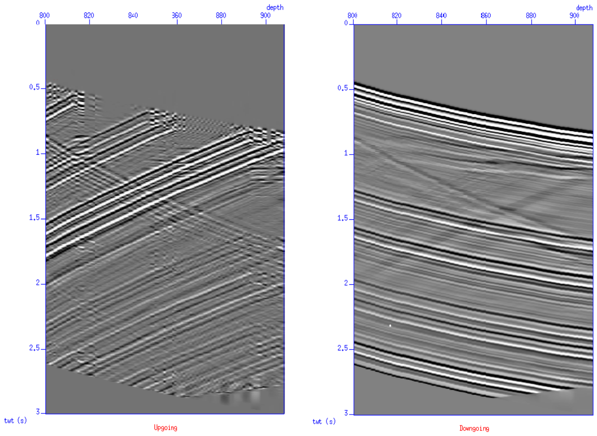

Figure 6: Separations of the wavefields *(left)*) Upward wavefield; *(right)*) Downward wavefield

the next step was to separate the P and S waves, first of all was applied the first breaks picking for the downward wavefield (Figure 7), the picking work is important for flattening the wave events taking as reference the first arrival time where also was applied a median filter, finaly was possible to make the subtraction of the orginal data, getting the residual events (Figure 8), separating the P and S waves (Figure 9).

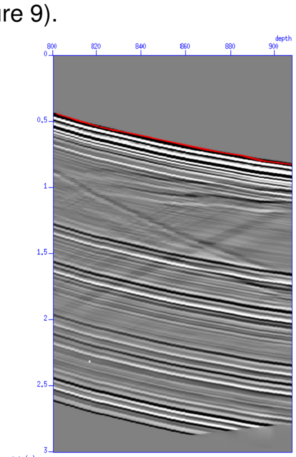

Figure 7: The first breaks picking for the downward wavefield (synthetic data).

Finally we can see the behavior of the incidence angle with which the first arrivals of the S and P wavefield were sensed, as well is verified its orthogonality relation by the product point (Figure 10). In the case of P waves shows a tendency to 90° as the depth increases, expected result because the wave is more vertical in the geophone when is deeper, another hand the angle of S waves shows a tendency to 180°, observing the angle changes between 200° and 170°, however these changes are due to residual waves in the separation process. We can see the dot product shows a trend of values near zero confirming expected for P and S waves because theoretically these two waves are orthogonal to each other.

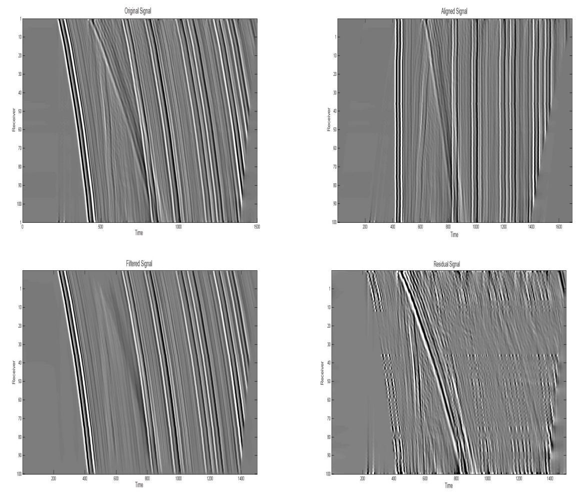

Figure 8: Process of flattening, aligned and filtered: *(top left)* downward wavefield Z component; *(top right)* downward wavefield Z component flattened, *(bottom left)* downward wavefield Z component filtered; *(bottom right)* downward wavefield Z component with process of subtraction with residual P wavefield).

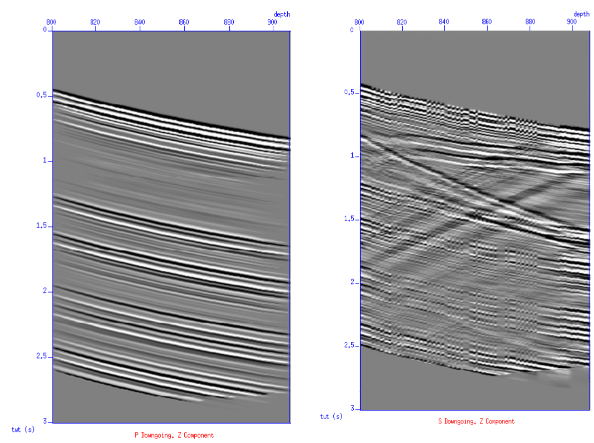

Figure 9: *(left)* Downward P wave; *(rigth)* Downward S wave

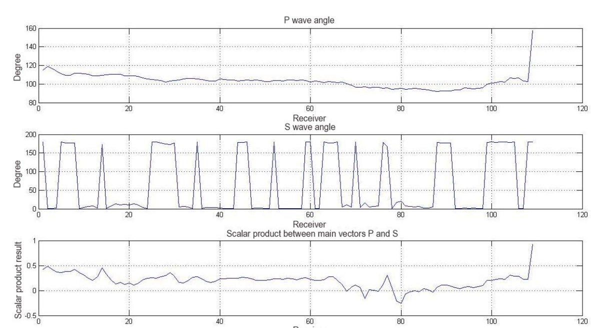

Figure 10: Angles of incidence between P and S wavefield for synthetic VSP data, (top to bottom) angle of P wavefield, angle of S wavefield, dot product operation between S and P wavefield.

Results

This method also was implemented for the analysis of real seismic data supplied by the Colombian Petroleum Institute (ICP). The data used were acquired in 2010 by Zero Offset VSP settings in the municipality of Tenerife (Middle Magdalena Basin), with the paremeters of the acquisition: a source trucks vibroseis, distance between source and receivers is 60m with an azimuth 70° and finally were used 48 geophones, the first receiver was at a depth of 455m and the last at 2118m (with synthetic data the information is present in two components, it is ideal), the figure 11 shown the real VSP seismic data of Tenerife, for the real case the energy is present in all directions due the variation in the orientation of the geophones in the well, therefore the VSP seismic data has 3 components. The component with more energy is the Z-component and this was used, for the X and Y-component sometimes is good reorganize the data with rotation, because it can present more concentrated energy in X or Y plane, however the horizontal rotation was not carried out because only was applied the conventional steps for this work.

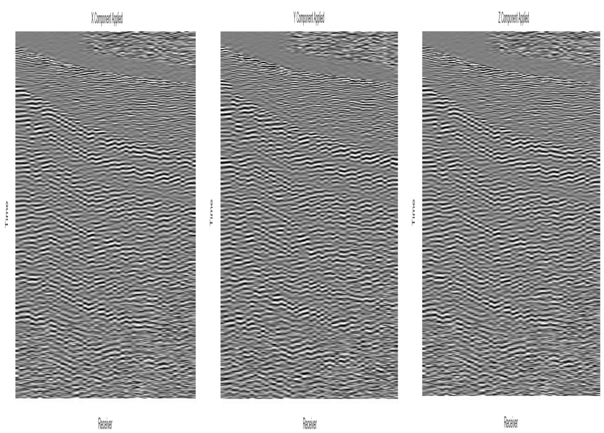

Figure 11: Real VSP data. *(left)* X component; *(center)* Y component, *(rigth)* Z component.

For the separation of the downward and upward field also was applied a cut filter with the FK spectrum, the figure 12 shown the result of the separation.

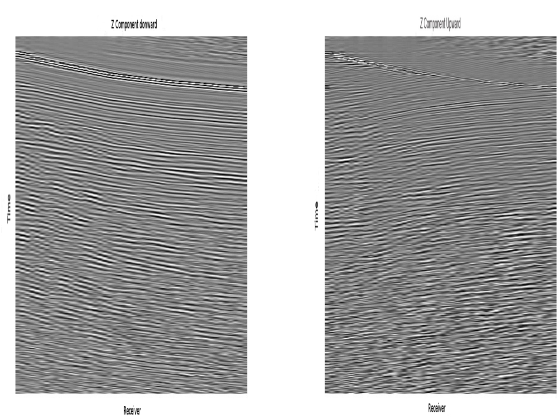

Figure 12: Z-component and separations of the wavefields *(left)*) downward wavefield; *(right)*) upward wavefield

After separation of the downward and upward field was applied the first arrivals (only downward wavefield) (Figure 13). With the interest to separate the P and S wavefield, similar to analysis with synthetic data the picking work is important for flattening the wave events taking as reference the first arrival time where also was applied a median filter, also was possible to make the subtraction of the orginal data (Figure 14), getting the residual events and separating the P and S waves (Figure 15).

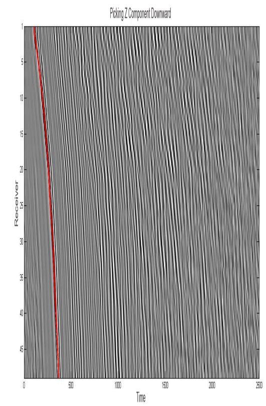

Figure 13: The first breaks picking for the downward wavefield (real data)

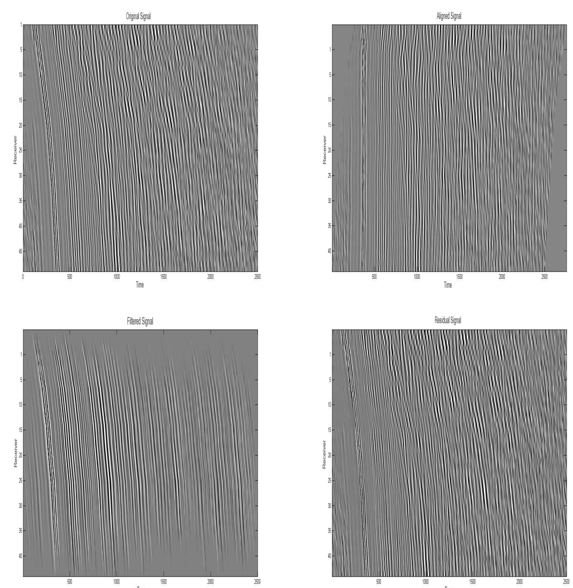

Figure 14: Process of flattening, aligned and filtered: *(top left)* downward wavefield Z component; *(top right)* downward wavefield Z component flattened, *(bottom left)* downward wavefield Z component filtered; *(bottom right)* downward wavefield Z component with process of subtraction with residual P wavefield).

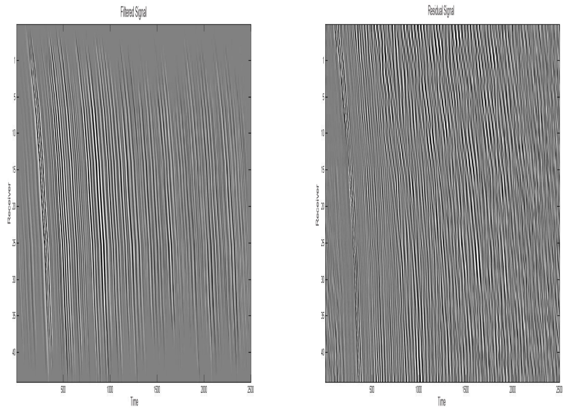

Figure 15: *(left)* Downward P wave (Z component filtered); *(rigth)* Downward S wave (subtraction with residual P wavefield)

Finally, in Figure 15 we can see the behavior of the angles of incidence of P and S waves, where there is a tendency of the P wave to $90°$, expected behavior and consistent compared to the theory, similarly the behavior of the angle of S waves has some variations in value due to residual P waves, but this present angles less than $30°$ what is to be expected (theoretically is $0°$). The orthogonality is confirmed by observing the point product operation, at which we can see the fluctuations due to changes in the angle of S but with a tendency to 0.

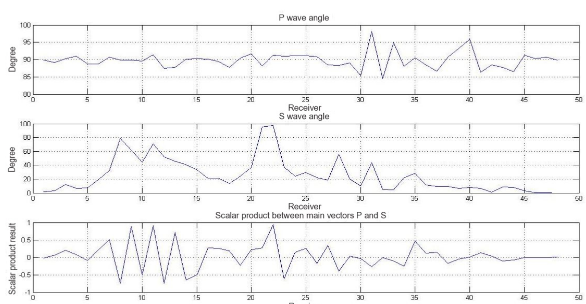

Figure 16: Angles of incidence between P and S wavefield in real VSP data, (top to bottom) angle of P wavefield, angle of S wavefield, dot product operation between S and P wavefield.

Conclusions

In this work was implemented a new method (Principal Component Analysis (PCA)) for calculate the arrival angle in the receivers between P and S wave with VSP data, the knowledge of the inclination of the arrival of the waves to the receivers allows to identify if adquisition of the data was carried out correctly, with the posibilty to make better the redirecction of the geophones in the well, therefore we can to obtain a better energy and a good quality of image, also was applied the conventional VSP data processing with good result, the evalution of method was tested in synthetic and real data.

References

Barkved, O., Jhons, T., Kristiansen P., Otoño de 2004, Oildfield review: Las diversas facetas de los datos sísmicos de componentes múltiples, Schlumberger.

Latihan VSP su, Febrero 2012.

Ana V. Somoza, abril de 2008, Efecto de los parámetros de anisotropía en la generación de imágenes a partir de datos Offset VSP y Walkaway VSP.

J. Salmon, Análisis de ondas S para detección de fallas utilizando sísmica VSP en sitio (Forsmark, Suecia)

K. Jovanovic, dieciembre 2004, P and SV polarization filtering of a multicomponent vector VSP.

S. Labonte, february 1990 Modal separation, mapping and inverting three - component VSP data.

E. Lorca, M. Recabarren, Chile 1994 , Terremotos y tsunamis o maremotos.

E. E. Hernández, Bucaramanga 2009, Implementación y evaluación de técnicas de tratamiento de señales en el modelamiento y cálculo de atenuación en la propagación de ondas sísmicas.

Hardage B. A., Vertical Seismic Profiling Principles.

Yilmaz, O., 1987. Seismic Data Processing: SEG, Tulsa

Acknowledgments

The authors wish to express their gratitude to Industrial University of Santander and ICP-Ecopetrol (Colombian national oil company).