Modeling and Suppression of Undesirable Rayleigh Surface Waves in Seismic Data from Onshore Niger Delta Using the Frequency–Wave Number (*F-K*) Technique.

Okechukwu F. Adizua, Ph.D. (in view)[1] and Michael C. Ohakwere-Eze, M.Sc.[2*]

[1]Department of Physics (Applied Geophysics Option), University of Port Harcourt, River State, Nigeria.
[2]Earth Sciences Department, Salem University, Lokoja, Kogi State, Nigeria.

E-mail: okechukwu.adizua@uniport.edu.ng*
michael.ohakwereze@gmail.com

ABSTRACT

In this study, a 2D frequency–wave number (*F-K*) domain filtering approach was applied to 3D onshore seismic data acquired from a Niger Delta field to suppress undesirable Rayleigh surface wave noise interferences on the seismic data so as to enhance signal to noise ratio. The approach adopted was to display the seismic data ensemble in a frequency – wave number spectrum using a VISTA software routine from which a low cut filter was designed to mute off the low frequency Rayleigh surface waves. The designed filter was then applied to the entire seismic data ensemble to model the Rayleigh surface waves and for the noise suppression. Results obtained showed a remarkable suppression of the undesired noise imprints which initially smeared the primary signals of interest.

(Keywords: *F-K* Domain, *F-K* Spectrum, Rayleigh surface waves, low cut filter, muting and primary reflections)

INTRODUCTION

Rayleigh waves (also known as ground roll) are a type of surface wave that traverses along the surface of solids. Their existence was predicted in 1885 by Lord Rayleigh, after whom they were named. In seismology, they are the most important type of surface wave and onshore seismic data is commonly contaminated with Rayleigh wave imprints which are termed noise. This noise interferes and masks the depth subsurface signal in seismic gathers (Linville, A., & Meck, R., 1995). These Rayleigh surface waves overwhelm or mask the desired useful primary reflections/signals which have information about the subsurface in shot gathers. They arise due to near surface lateral velocity variations. Rayleigh waves are dispersive, of low frequency and velocity and are characterized by their high amplitudes. Because of its dispersive nature, Rayleigh surface waves masks the shallow reflections, at short offsets, and deep reflections, at long offsets (Claerbout, 1983; Saatilar and Canitez, 1988; Henley, 2003).

Rayleigh surface waves which are the noise type of interest in this study could arise as a result of a generated seismic signal which travels both along the ground surface as well as through the geological layers of the subsurface. Since the velocity of these Rayleigh surface waves is low compared to the velocities of the signals that have been reflected at the boundaries of the geological layers, these reflected signals may be corrupted by the Rayleigh waves which are frequently present on a seismic record and can obscure signals of interest, degrading overall seismic data quality. Thus, Rayleigh surface waves most often constitute a serious problem for the interpretation of onshore seismic data and should be effectively suppressed before meaningful interpretation of seismic records can be achieved.

Several techniques are routinely applied in seismic data processing to attenuate coherent noise while attempting to preserve the primary signals and their amplitudes. These methods are based on the possibility of separating the signal and noise based on their distinguishing characteristics such as frequency content or apparent move out (Yilmaz, 1991). The aim of our study is to model and suppress undesirable Rayleigh surface waves (noise) from seismic data using the 2D Frequency-Wave number (*F-K*) domain filtering technique.

LOCATION AND GEOLOGY OF THE STUDY AREA

The present field is located in the onshore part of South - South Niger Delta, South-East of Nigeria. The field lies in Ohaji – Egbema LGA, a few kilometers from Owerri in Imo State (Figure 1). The Niger delta is underlain by three stratigraphic units, the deepest Akata Formation, the middle Agbada Formation and the top Benin Formation.

The Benin Formation is mainly made up of continental sand deposits with intercalation of shale and is covered with topmost low velocity layer which, in most cases, is weathered within which surface waves are excited and generated. Immediately below the Benin Formation is the reservoir sand of the Agbada Formation which is believed to house the oil and gas resource of the Niger delta. The Akata Formation is also believed to be the source rock for the petroleum resource and also hydrocarbons reservoirs in deep offshore.

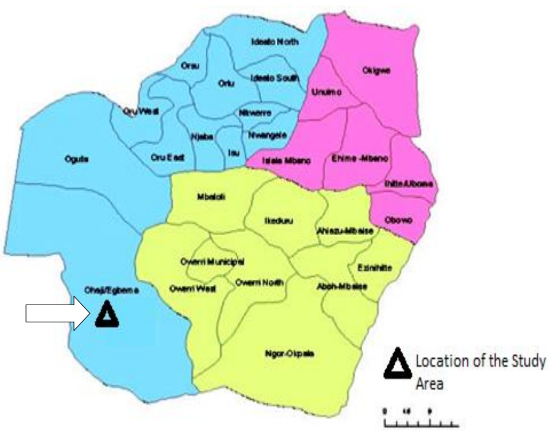


Figure 1: Map of Imo State showing the Location of Study Area

MATERIALS AND METHODS

The data used for this study (Figure 2) is an unprocessed 3D seismic data acquired from an onshore field in the southern part of the Niger delta basin. The data is an ensemble of signals recorded from shot 1025 by different receivers presented in common shot orders. The full shot record is long and continuous and could not have possibly been displayed in its full length, for this reason, only a panel from the full signal ensemble was selected for the illustration. The choice of shot 1025 was due to the fact that it contained a significant amount of Rayleigh surface wave imprints which we primarily seek to model and suppress. The shot record as displayed is presented in the conventional Distance/Channel – Time domain *(X-T).*

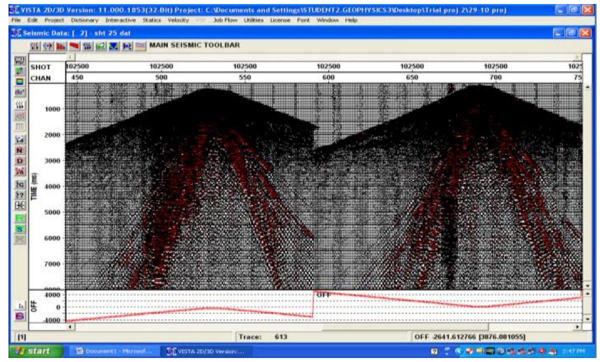


Figure 2: Input Unprocessed Data (Shot 1025).

The Rayleigh surface wave modeling and suppression was carried out by the 2D frequency- wave number domain filtering. The underlying principle of filtering in this domain is briefly explained below.

2D Frequency-Wave Number (*F-K*) Domain Filtering

The transformation of seismic data from the *t-x* domain to the *f-k* domain is achieved by the 2-D Fourier transform. The 2-D Fourier transform is able to separate events according to their dips in the *f-k* domain (Zhou and Greenhalgh, 1994). A linear event, $f\ (t,\ x)$, can be described by Equation (1).

$$f\,(t, x) = s\,(t) * \delta\,(t - \tan(\alpha)x + b) \qquad \textbf{(1)}$$

where the symbol "*" denotes convolution with respect to the variable time (*t*), *s(t)* is seismic wavelet, α is the angle between the simulated linear event and the space axis, and the constant *b* is the intercept of the event on the time axis.

The 2-D Fourier transformed expression of Equation (1) is given as:

$$F\,(\omega, k) = S\,(\omega)\, e^{i\omega b}\, \delta\,(k - \omega \tan(\alpha)) \qquad \textbf{(2)}$$

where $S\ (\omega)$ is the Fourier transform of the time function *s(t)* in Equation (1). Equation (2) shows vividly that any linear event in the *t-x* domain can be transformed into another linear event in the *f-k* domain (Zhou and Greenhalgh, 1994). Linear events such as Rayleigh surface waves in the *t-x* domain can be separated in the *f-k* domain by dip (Yilmaz, 1987).

Based on this property of the 2-D Fourier transform, a filter was designed in the *f-k* space or domain to remove the undesirable Rayleigh surface wave imprints from the seismic data. The designed filter was then applied to the data in the *f-k* space to model the noise and then to suppress it. The Data was thereafter transformed back to its original time offset domain now to a very large extent noise free. The processing work flow (Figure 3) was adopted for this study.

INPUT - UNPROCESSED 3D SEISMIC DATA

1) DISPLAY OF THE DATA WITH RAYLEIGH WAVE IMPRINTS
2) GENERATION OF AN F-K WINDOW TO DISPLAY SPECTRUM
3) IDENTIFY FREQUENCY BAND OF RAYLEIGH WAVES (NOISE) FROM SPECTRUM
4) DESIGN A FILTER (Low cut) FOR RAYLEIGH WAVE MODELING AND SUPPRESSION
5) GENERATION OF THE RALEIGH SURFACE WAVE IMPRINTS (NOISE) MODEL
6) IMPLEMENTATION OF THE FILTERING OPERATION ON THE SEISMIC DATA

OUTPUT – DEVOID OF RAYLEIGH SURFACE WAVE NOISE

Figure 3: Processing Workflow Adopted for the Modeling and Suppression of the Noise.

RESULTS AND DISCUSSION

The results obtained after the implementation of the processing workflow are hereby presented.

Input Data, *F-K* spectrum and Designed Filter

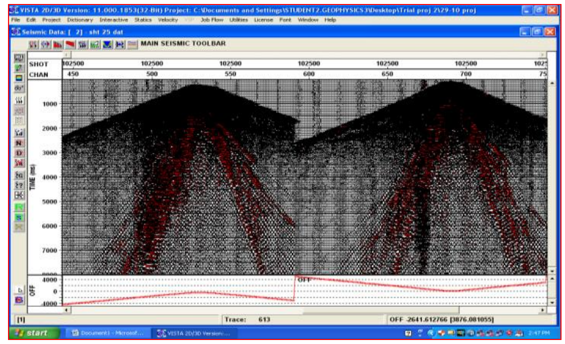


Figure 4: Input Unprocessed Data with Visible Rayleigh Surface Wave Noise Imprints.

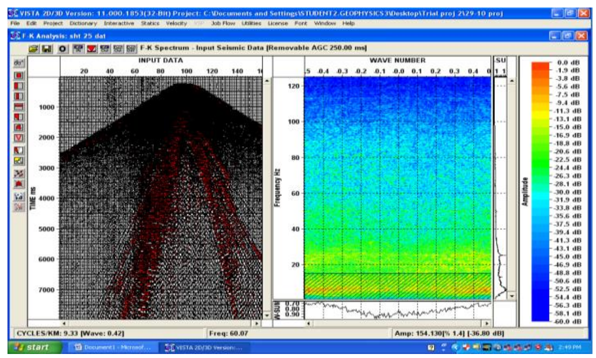


Figure 5: Input Data (1st Panel) with an F-K Spectrum Analysis Window. A rejection zone has been identified and marked in the filter for the noise modeling and suppression.

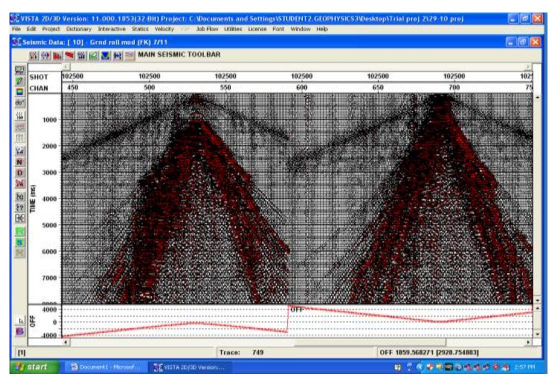


Figure 6: Rayleigh Surface Wave Noise Model.

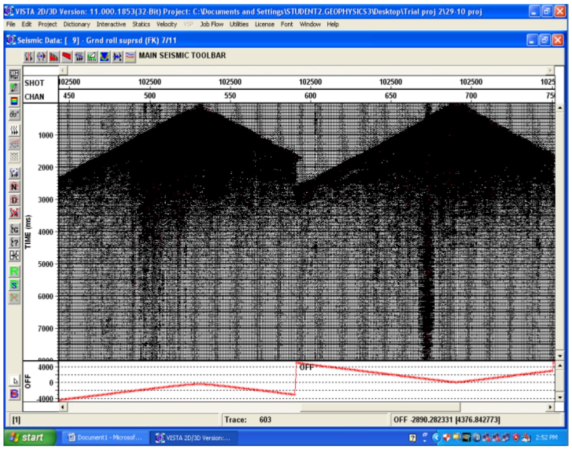
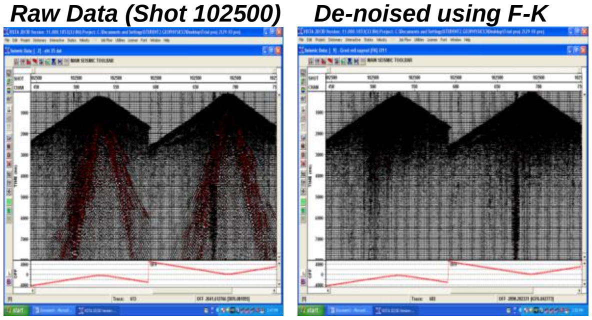


Figure 7: Input Data after Rayleigh Surface Wave (Noise) Suppression using *F-K* Domain Technique.

Below are the input (unprocessed) data and output (de-noised) data juxtaposed for a quick assessment of the efficiency of the designed *F-K* filter and by extension the 2D *F-K* domain filtering technique in suppression dispersive Rayleigh surface wave imprints on acquired seismic datasets.

Raw Data (Shot 102500) ***De-noised using F-K***



(a) (b)

Figure 8: (a) Data before Rayleigh Surface Wave Suppression and (b) Data after Rayleigh Surface Wave Suppression using the 2D *F-K* Filtering Technique.

DISCUSSIONS OF RESULTS

The *F-K* technique using the designed filter (Figure 5) was able to model the Rayleigh surface wave imprints (noise) appreciably (Figure 6) and performed optimally when applied on the dataset (Figure 4) for the noise suppression. This is evident from the results presented. The low cut filter (or high pass filter) was designed in a way to carry out an outright mute of frequencies below 13Hz. Our choice of cut off frequency in the f-k filter used was guided by the known characteristic low frequency of Rayleigh surface wave (usually < 15Hz) on seismic data. This filter design may probably as well destroy some useful low frequency primary reflections. This is however very minimal as primary reflection signals were better enhanced as shown from the output panel (Figure 7). The F-K approach with the aid of the choice filter suppressed effectively all the Rayleigh surface wave imprints (Figure 8). We have thus demonstrated that the 2D *F-K* domain filtering is a viable tool on seismic dataset for the modeling and suppression of Rayleigh surface wave noise.

CONCLUSION

We have applied the 2D frequency–wave number (*F-K*) domain filtering technique which is based on simple local wave field decomposition (LWD) of reflected wave fields recorded during an acquisition, to unprocessed 3D seismic data acquired from a Niger delta field to model and suppress undesirable Rayleigh surface wave noise. The noise suppression result achieved by the *F-K* filter was very satisfactory.

FUTURE SCOPE

Muting the noise component of data without affecting useful signals most times is challenging and difficult. We recommend for future research for ways to minimize muting of useful primary reflections together with the noise when carrying out filtering operations.

ACKNOWLEDGEMENT

We thank SPDC for providing the seismic datasets used in this investigation. We equally acknowledge GEDCO Company of Canada for the license given to use the VISTA software tool for Academic Purpose at the University of Port Harcourt, Nigeria.

REFERENCES

1. Linville, A. and R. Meck. 1995. “A Procedure for Optimally Removing Localized Coherent Noise”. *Geophysics*. 60:191–203.

2. Saatilar, R. and N. Canitez. 1988. "A Method of Ground-Roll Elimination". *Geophysics*. 53(7):894-902.

3. Yilmaz, Ö. and S.M. Doherty. 1987. *Seismic Data Processing*. SEG.

4. Yilmaz, Ö. 1989. "Velocity Stack Processing". *Geophysical Prospecting*. 37:357–382.

5. Yilmaz, Ö. 2001. "Seismic Data Analysis: Processing Inversion, and Interpretation of Seismic Data". Volume 1. *Investigation in Geophysics*. No. 10.

6. Zhou, B., and S.A. Greenhalgh. 1994. "Wave-Equation Extrapolation-Based Multiple Attenuation: 2-D Filtering in the F-K Domain". *Geophysics*. 59:1377–1391.

ABOUT THE AUTHORS

Okechukwu F. Adizua, is a Geoscientist and member of Physics/Applied Geophysics faculty at the University of Port Harcourt, Rivers State, Nigeria. His B.Sc. and M.Sc. Degrees in Applied Geophysics were obtained from a Physics background. He is currently pursuing a Ph.D. degree in Applied Geophysics from a Geological Sciences background.

Michael C. Ohakwere-Eze, is a Geoscientist and Lecturer in the Earth Sciences Department of Salem University, Lokoja in Kogi State, Nigeria. He is a member of many professional (Geosciences) associations and holds a Master of Science (M.Sc.) Degree in Applied Geophysics.

SUGGESTED CITATION

Adizua, O.F. and M.C. Ohakwere-Eze. 2014. "Modeling and Suppression of Undesirable Rayleigh Surface Waves in Seismic Data from Onshore Niger Delta Using the Frequency – Wave number (*F-K*) Technique". *Pacific Journal of Science and Technology*. 15(2):265-269.

Pacific Journal of Science and Technology