Broad-bandwidth data processing of shallow marine conventional streamer data: A case study from Tapti Daman Area, Western Offshore Basin India

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Keywords
Broadband, De-ghosting, Notch diversity.

Summary

Marine seismic data is undergoing revolution of resolution , as new technologies overcome the traditional resolution limits imposed by notches in the frequency spectra introduced by surface ghosts. A number of technologies have been developed to remove/minimise the receiver notch at acquisition level such as over/under cables, hydrophone and geophone summation, variable depth streamer, wavefield reconstruction etc. Broadband acquisition itself takes care of de-ghosting techniques. However de-ghosting techniques are applied in processing on conventional data/legacy data with conventional acquisition also achieving significant improvements where data has sufficient underlying signal-to-background noise ratio.

In this paper we are demonstrating a case study of the newly developed de-ghosting techniques based on a "non-linear inversion process with a specific minimization criteria" applied on conventional data acquired in shallow water depth of Tapti Daman Area, Western Offshore Basin, India and the significant improvement it has brought out using M/S Paradigm software. This makes the interpretation becomes easier, as the character of events is more clearly seen as finer textures and subtler features are resolved. Also this will help the inversion process easier as lower frequencies are available directly from the seismic and at the same time higher frequencies make well matching easier.

Introduction

Now a days, exploration focus is moving towards complex reservoirs containing thin stratigraphic layers. Detailed reservoir characterization studies require broader frequency bandwidth. Marine seismic data bandwidth has traditionally been limited by the presence of notches in the amplitude spectrum brought about by the sea-surface ghost. The air-water interface forms an almost perfect mirror for sound waves, reflecting back the up-going wave. The mirror reflection is opposite in polarity and thus attenuates the frequencies associated with the round-trip travel from the receiver (and/or source) to the surface and back which causes the ghosting phenomena. Ghost notches in the seismic wavelet lead to loss of resolution in the seismic image.

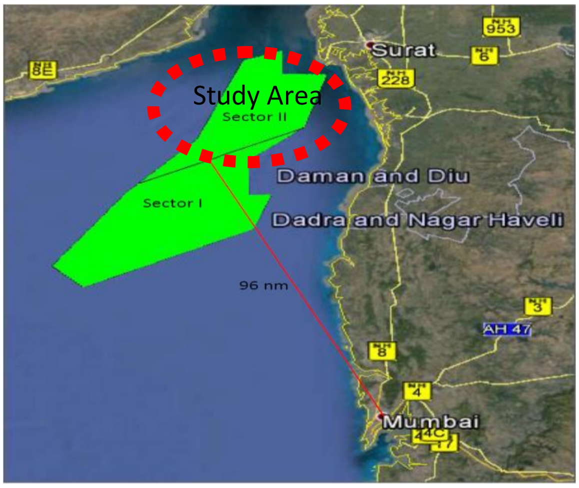

Figure 1: Location Map of the Study area

Conventional marine seismic data is highly affected by such interference from free surface (ghosts) on both the source and receiver sides. Though various technique has developed to minimise notches in the spectrum due to interference such as over/under cables, hydrophone and geophone summation, variable depth streamer, wave-field reconstruction etc. at the acquisition level, however the natural notch always exist and minimised notches. Angular ray dependency (of ghost) with offset, depth variations of sea water, sea surface reflectivity variance etc. are the main causes of natural notch diversity in conventional marine data. This means that the notches are not as deep as might be expected and that makes it possible to de-ghost the conventionally acquired data. Another improvement at the acquisition stage is the use of solid streamer. The use of solid streamers in modern acquisition technique further facilitate the de- ghosting process the low frequency content of the primary signal to background noise significantly improves.

De-ghosting at processing stage needs some special consideration especially for shallow water prospect. In shallow water prospect the major noise contamination in the record is direct waves, guided wave, mud roll, stoneley waves or other non-

reflective waves which needs to be eliminated from the data for effective de-ghosting.
A de-ghosting technique based on a recursive de-ghosting filter design applied on conventionally acquired data in shallow water prospect of Tapti Daman Area, Western Offshore Basin, India (the bathymetry of the area varies from 14m to 40m) (Figure. 1). To remove the interference of free surface ghosts, an accurate information of source depth, receiver depth and reflection coefficient at the sea surface is required or this method. The multiple removal process such as SRME, Tau-P deconvolution is more effective after the de-noise and de-ghosting because the wavelet becomes more stationary after these processes.
The result of migrated images after successful de-ghosting showing a remarkable improvement over legacy data processed conventionally.The finer textures and subtler features are now resolved in the de-ghosted output. The character of events are more clearly visible with improved signal to noise ratio.

Methodology

Paradigm has implemented a solution to recover the notches in the seismic spectrum introduced by the source and receiver ghosts generated at the water surface by estimating and applying a recursive de-ghosting filter. The problem is formulated as a nonlinear inversion process with a specific minimization criterion to estimate the source and receiver ghost times. The method derives a recursive filter for the range of possible source/receiver depths and possible reflection coefficients at the air/water contact and estimates an operator based on least squares criteria, either minimum energy or minimum absolute amplitudes.

Acquisition and Processing Implications

The much higher bandwidth of data requires finer spatial sampling to avoid aliasing. The broader bandwidth signal needs special attention to record low frequency component, which is achieved by using state of the art technology in cable i.e. solid streamer. Special consideration for low frequency preservation is also needed during the processing sequence. In this case study area, the data acquired with channel spacing of 12.5m using 480 channels each in 4 solid streamer cables having separation of 100m. The spectrum of Figure 2 indicating improvement of streamer noise level of solid steamer over the gel-filled streamer especially at lower frequency side (source: sentinel).The advantage of solid streamer over others are : Low towing noise, thin diameter, lower drag, less space, less pull on cables and & can be towed at greater depth.

An analysis of signal to background noise is shown Figure 3.

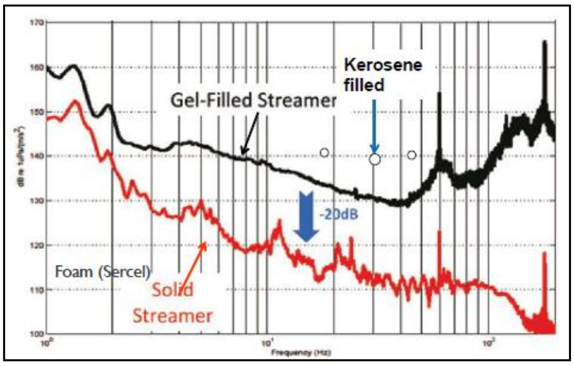

Figure 2. Streamer Noise Levels

Data Preparation

To obtain satisfactory result of de-ghosting for shallow water depth data, suitable processing methodology should be adopted to handle direct waves/guided waves/mud rolls etc. which are predominant in the recorded wave field. Beside these waves, various low frequency background noises are also found in the data. The background noise seen in the acquired data can be attributed due to:

- Hydrostatic pressure variation noise (0-2)Hz)
- Swell noise (1-10)Hz,
- Cross flow (1-10Hz)
- Tugging/strumming noise from the vessel (3-10Hz)
- Propeller cavitation noise from the vessel (0-10Hz) etc

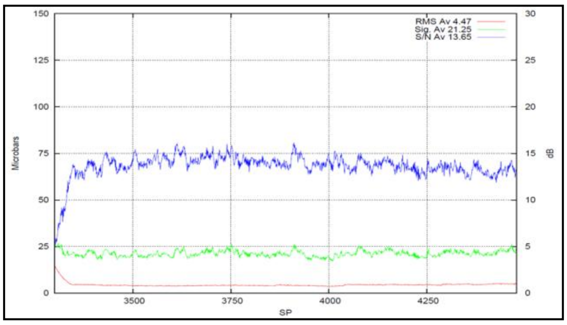

Figure 3: A graph of the shot averaged RMS noise, signal and signal-to-noise ratio.

A low cut filter of 1-2 Hz was used to remove low frequency noise (Figure 4). Swell noise attenuation was carried out in multiple iterations in both common shot and common channel domain using time-frequency filtering. Linear noises such as direct arrival, guided waves and tug/tail-buoy noise was attenuated using f-x dip filtering and move-out discrimination after linear move-out application. Since the de-ghosting process is based on the knowledge of Source side and Receiver side reflection coefficient, de-ghosting is more effective

after the removal of swell noise and linear noise attenuation. An example of shot gather before and after de-ghosting on noise attenuated data is shown in Figure 5 and their stack is taken for quality check (Figure 6). The de-ghosting process applied here has successfully attenuated both the source and receiver side notches (Figure 7).
An outline of the processing sequence is provided in Table 1.

1. Re-datum to mean sea-level	9. Residual de-noising
2. De-bubble and designature	10. Q-Phase only
3 Low cut filter	11. Kirchhoff PSTM
4. Swell and linear noise attenuation	12. High-resolution demultiple
5. De-ghosting	13. Stack
6. 2D SRME	14. Poststack Q compensation
7 Tau-P deconvolution	15. Post-stack data conditioning and scaling
8. Offset regularization	

Table 1

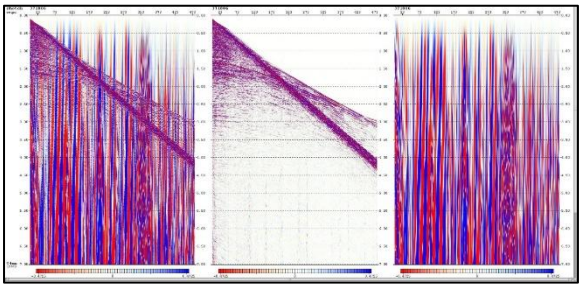

Figure 4: Raw Shot gather (left) and after low cut filter (1-2 Hz) (mid) and their difference plot (right)

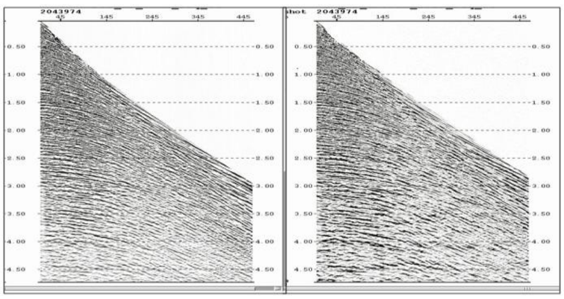

Figure 5: Shot gather without deghosting (left) and after de-ghosting (right) process

After successful de-ghosting, attenuation of multiples was carried out using a standard implementation of 2D SRME. The residual multiples was attenuated through tau-p deconvolution. To compensate the frequency dependent amplitude attenuation, Q and spectral shaping was applied on post migrated stack.

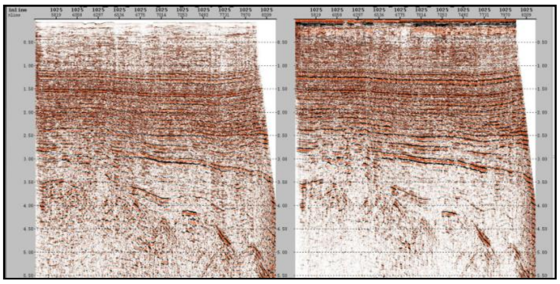

Figure 6: Stack response -without deghosting (left) and with deghosting (right)

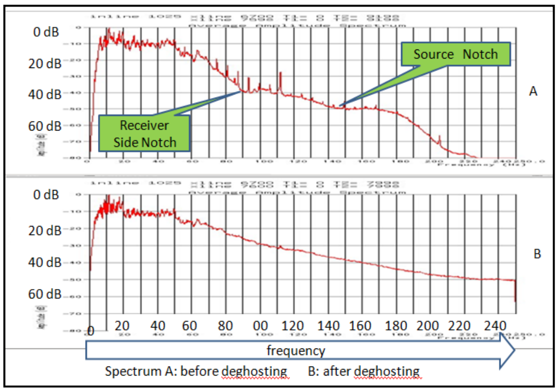

Figure 7: Spectrum before de-ghosting (top) and after de-ghosting (bottom)

Discussion

The success of broadband processing requires the removal of ghost events from seismic data. These cause frequency-dependent constructive and destructive interference, with a consequent attenuation of signal in specific frequency bands (notches). The notches are depends on source and receiver cable depth position. The present case study is from Tapti Daman area of Western Offshore Basin where water column varies from 15m to 40m. Due to shallow water depth, recorded seismic data is contaminated with various seismic noises among them direct arrivals, guided waves/ dispersive waves, mud rolls are predominant in nature. In addition to that, low frequency signals are masked with the low frequency background noises such as Hydrostatic pressure variation noise, Swell noise, Cross flow, Tugging/strumming noise, Propeller cavitations noise from the vessel. Some of the background noises are attenuated after the application of 2 Hz. low cut filter (Figure. 4). Low frequencies were preserved throughout the course of processing for this data. The success of de-ghosting process mentioned here is very much depends on the accurate estimation of sea-bottom reflectivity, source and receiver depths and data condition. To obtain a very accurate result, the data must be free from any linear noise and clean from background noise so that the sea bottom reflection coefficient estimation becomes accurate. The results also depends on how much natural notch diversity due to offset dependent incidence angle variation, depth variations of sea water, sea surface reflectivity variation present in the data. The left side image of Figure.5 is the conditioned gather after successful swell and linear noise attenuation. The right side image of Figure.5 is the gather after de-ghosting on noise attenuated shot gather. The stack response before and after the application of de-ghost process is shown in Figure. 6.There is a significant improvement in resolution and bandwidth after the deghosting step. Top image of Fig. 7 is the spectrum of the stack data before de-ghosting and the lower one is the spectrum of the stack data after application of de-ghost process. The lower spectrum is demonstrating the successful attenuation of notches due source and receiver ghosts for this dataset. Figure. 8 and Figure. 9 are the comparison of PSTM stack of newly acquired 3D data processed in broadband sense with the conventionally processed vintage data. The shallow part of the PSTM stack image (right side of Figure. 8) clearly showing the improvement in terms of event clarity, resolution and fault clarity over the vintage data. Figure. 9 is the comparison of the ghost free PSTM stack with the vintage data from the middle part of the section. Many subtle events are now clearly visible in the ghost free dataset. Figure. 10 is the PSTM stack images of deeper part of the data. Some of the missing events in vintage data is now clearly visible in the present dataset (circled).

Spectrum of legacy data processed without de-ghosting method and the newly acquired data processed in broadband sense are shown in Figure 11.The spectrum demonstrating the rich content of both low frequency and high frequency achieved through the broadband processing.

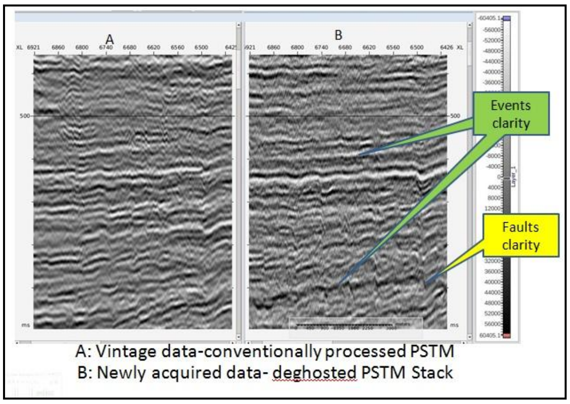

Figure 8: Comparison with the legacy data processed without de-ghosting (left) and newly acquired data processed in broadband sense (right)

Conclusions

Revolution is underway in marine data resolution and broadband processing techniques are rewriting how we see seismic data without the ghost. Traditional processing techniques work well at frequencies below the first receiver ghost notch. De-ghosting is the technique to reduce this limitation and broaden the usable frequency range. The de-ghosting process restores the bandwidth and reduces side lobes.

Inspection of NMO stacks, migrated images, and the spectrums, has demonstrated that successful broadband processing can be achieved for conventionally acquired seismic data if data is processed carefully keeping low frequeny content intact. The result confirmed that the algorithms designed for conventional seismic data are also suitable for broadband processing. Particular benefits of the broadband processing of this dataset are a high resolution wavelet and good low-frequency signal content for deeper part of the data. Though the de-ghosting here carried out in X-T domain, a still better result can be obtain from tau-p domain processing where ghost effect tends to exhibit sufficient stationarity. The result ensures a sharper wavelet with minimal side lobes and enhancement in textural information present in the seismic images thereby improving the interpretability of geologic features. It has also improves signal-to-noise ratio overall but particularly so in the deeper parts of the data.

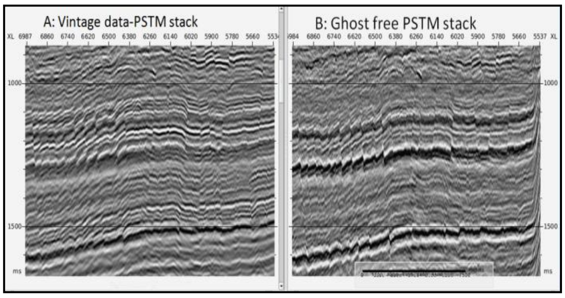

Figure 9: Comparison with the legacy data processed without de-ghosting (left) and newly acquired data processed in broadband sense (right)

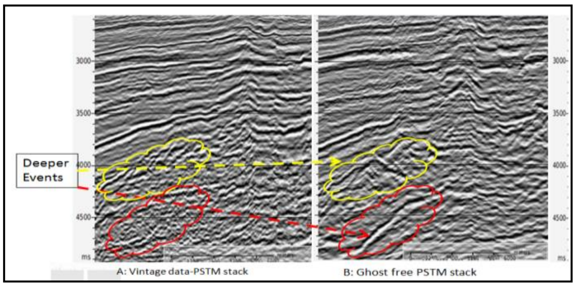

Figure 10: Comparison with the legacy data processed without de-ghosting (left) and newly acquired data processed in broadband sense (right)

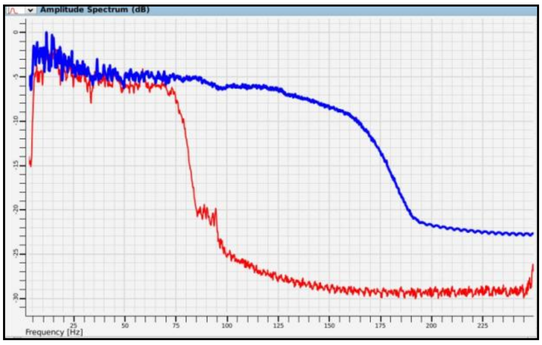

Figure 11: Comparison of spectrum on PSTM Stack section of legacy data processed without de-ghosting (red) and newly acquired data processed in broadbandwidth sense (blue)

Reference

Dowle, R. (2006). Solid streamer noise reduction principles. 75th SEG Annual Meeting, Expanded Abstracts 25, pp. 85-89.

Hardwick, Anthony, et al. "Broadband Processing in the Norwegian Barents Sea–Practical Aspects of Deghosting in a Challenging Marine Environment."2014 SEG Annual Meeting. Society of Exploration Geophysicists, 2014.

Lin, Dechun, et al. "Challenges in processing variable-depth streamer data."2011 SEG Annual Meeting. Society of Exploration Geophysicists, 2011.

Lin, Dechun, et al. "Optimizing the processing flow for variable-depth streamer data." First Break 29.9 (2011): 89-95.

Masoomzadeh, H., and N. Woodburn. "Broadband Processing of Conventional Streamer Data-Optimized De-Ghosting in the Tau-P Domain." 75th EAGE Conference & Exhibition incorporating SPE EUROPEC 2013. 2013.

Sablon, R., et al., 2011, De-multiple for depth-variant cable data from deep water to shallow water: 81st Annual International Meeting, SEG, 2011.

Soubaras, R. (2010). Deghosting by joint deconvolution of a migration and a mirror migration. 80th SEG Annual Meeting, Expanded Abstracts, pp. 3406-3410.

Soubaras, R. and R. Dowle (2010). Variable-depth streamer – a broadband marine solution. First Break vol. 28, December 2010, pp. 89-96.

Rebert, T., et al. "Improving presalt imaging with variable-depth streamer data: Presented at the 82nd Annual International Meeting." (2012).SEG 2012

Yilmaz, O., and E. Baysal. "An Effective Ghost Removal Method for Marine Broadband Seismic Data Processing." 77th EAGE Conference and Exhibition 2015. 2015.

Zhou, Jun, et al. "Pre-stack deghosting: Bringing out the seismic bandwidth in legacy marine data." ASEG Extended Abstracts 2015.1: 1-4.

Zhou, Zhengzheng, et al. "Analysis of a broadband processing technology applicable to conventional streamer data." first break 30.10 (2012).

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