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Extensive Noise attenuation of shallow water 3D seismic data in KG Offshore, India

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Summary

India is a peninsular country which is surrounded by sea in three sides, having huge offshore environs in its periphery. Among all the promising petroliferous basins of India, the Krishna Godavari Basin is one of most potential basin with viable & commercial accumulations of hydrocarbons and is located along the East Coast of India bordering the state of Andhra Pradesh and covers an area of 100,000 sq. km in both onland, shallow and deep waters. The estimated resources in the basin are around 2000 million tons of oil or oil-equivalent gas and the basin comprises a vast range of depositional settings such as coastal plains, deltas, shelf-slope aprons and deep-sea fans.

The basin comprises enormous marine shallow water coverage and the seismic data acquisition in this shallow marine area is really a challenging task. The dominant noises both random and coherent are very complicated in nature being generated by natural and man-made actions outside the control of the survey. The acquired seismic data in these large shallow marine areas are masked predominantly with unwanted multi-class prevailing noises and the seismic signals and showing an extremely poor signal to noise ratio. It is a major painstaking task to remove these different noises from seismic data.

The objective of this study is an attempt to provide a method for processing seismic data that more effectively removes unwanted prevailing noises from meaningful reflection signals for better & significant improvement of the quality of seismic processed data which would aid in meaningful & enhanced interpretability of the sub-surface intricacy focused to hydrocarbon discoveries.

Introduction

Recently, recurrent exploratory efforts for hydrocarbon findings in KG offshore area from syn-rift play and sands opening a demanding scope in large offshore areas for further exploration. Particularly in shallow water these exploration activities come up with a major challenge for us to handle the different predominant noises contaminating the seismic signals.

The seismic data comprises signal amplitude recorded over time by each of the receivers and contains primary reflection signals and typically mixed with a variety of noises. The principle behind seismology is, as seismic waves travel through the earth, portions of that energy are reflected back to the surface as the energy waves traverse different geological layers. Those seismic echoes or reflections give valuable information about the subsurface features. In addition, a signal may bounce off of a subsurface feature, bounce off the surface, and then bounce off the same or another subsurface feature, one or more times, creating so-called multiple reflection of signals. Some noise, both random and coherent, is generated by natural and man-made events. Other portions of the signal turn into noise as part of ground roll, refractions, and un-resolvable scattered events.

The present study provides progressive methods of processing seismic data in shallow offshore area to remove unwanted noises such as guided waves & multiples from meaningful reflection signals indicative of subsurface complexities.

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Backdrop of the study

The study area belongs to the large eastern continental margin of India in Krishna-Godavari offshore (Figure-1). The main aim of the survey is to have a total understanding of the hydrocarbon prospectivity of the area with respect to structural and stratigraphic features, to delineate faults and also to identify reservoir facies & thin sands.

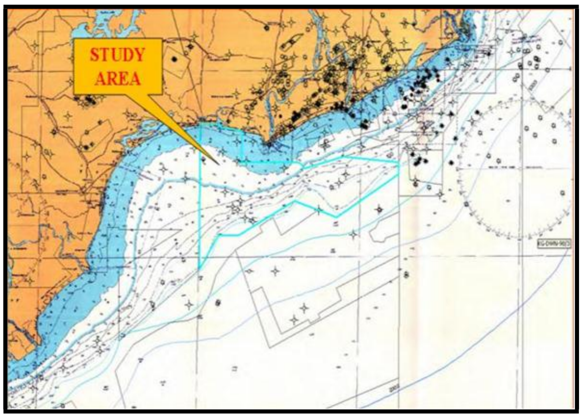


Figure – 1: Survey location map showing the Project Area.

The details of acquisition and recording parameters used to acquire 3D shallow marine data in KG offshore East Coast of India are as under in Table -1.

Source Separation	**37.5m**	**Near Offset (m)**	**72**
Shooting Method	**Flip-Flop**	**Far Offset (m)**	**5172**
Channels In Spread	**816**	**Fold**	**51**
Group Interval (m)	**12.5**	**Source Depth (m)**	**5 +/- 0.5**
No. of Streamers	**2**	**Water Depth (m)**	**08 – 35**
Streamer Separation (m)	**75**	**Recording length (ms)**	**9216**
Streamer Depth (m)	**6 +/- 1**	**Bin Size (m)**	**6.25 X 18.75**
Streamer Length (m)	**5100**	**Air Gun Volume (Cu.in.)**	**3200**
Shot Point Interval (m)	**25**	**Air Gun Pressure (PSI)**	**2000**
Source	**Dual**	**Notch filter**	**Out**
Channels per Streamer	**408**	**Sampling interval (ms)**	**2**
Energy Source	**AIRGUN**	**Recording format**	**SEG-D 8058**

Table – 1: Acquisition & Recording Parameters of the seismic data in the survey area.

A wide variation of shallow water depth across and along the sail lines makes the acquisition as well as processing more challenging. The bathymetry map in Figure-2 shows that water depth of the acquisition area varies from 8 to 35 meters and the result was the contour of shallow area that allowed for the modification of the pre-plots so the lines could be extended for better coverage of the shallows to reach up to the 8 meters contour.

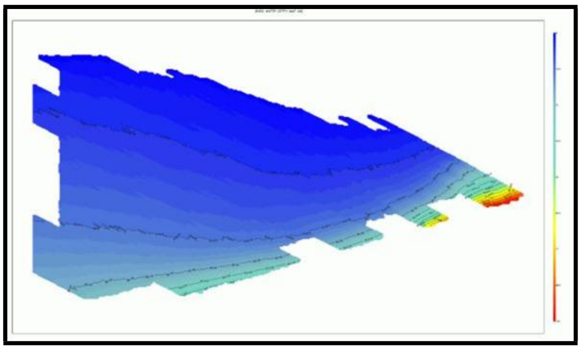


Figure – 2: Bathymetry map of the acquisition area with varying water depth from 8 to 35 meters.

Preparedness of Seismic Data for Processing

Seismic data are usually contaminated with both random and coherent noise. The seismic data comprises signal amplitudes recorded over time and contains both primary reflection signals and unwanted noise events. The utmost meaningful signals are the so-called primary reflection signals that travel down to the reflective surface and then come up to a receiver.

Basic processing, Noise attenuation & Data conditioning of this shallow water 3D seismic data was extensively done to enhance the seismic signals and also to produce amenable processed seismic output for the fulfillment of the interpretation objectives.

Extensive editing of field records were done according to the observer logs for bad files and traces. The seismic data were merged with the processed P1/90 navigation data for updating the trace header information of the source and receiver co-ordinates, cable and field channel numbers. The data were updated with the geometry, inline, crossline and all other 3D information into the seismic trace headers in 6.25m X 18.75m bin. Tide correction and Water Depths also were updated from P1/90 navigation data to the seismic trace headers. Geometry merging of seismic data with navigation was done with shot point.

After loading all the raw seismic data and updated with navigation data and geometry trace headers, the fold map of navigation data and seismic data are compared and found perfectly matched and the fold map of seismic data is shown in Figure-3. Furthermore, a QC NTG plot is generated to check the correctness of the full geometry merged data and it is shown in Figure-4.

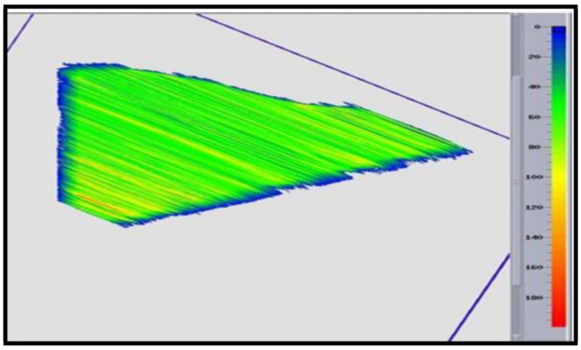


Figure – 3: Fold map of acquired seismic data.

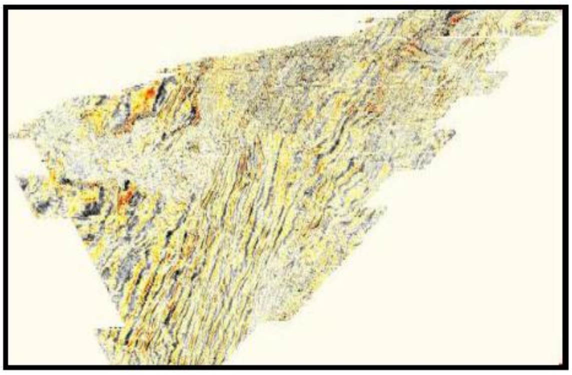
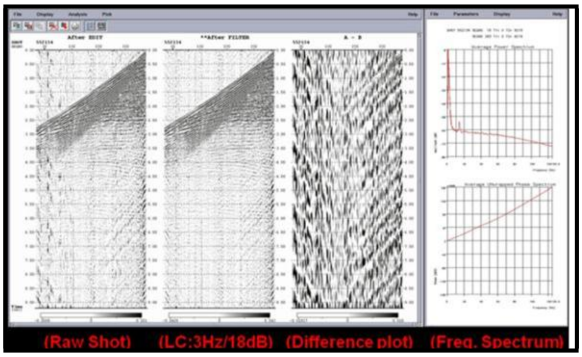


Figure – 4: NTG Time Slice at 500 ms – QC Plot.

Methodology adopted for sequential Noise Suppression

Attenuating the high-amplitude noises, such as swell noise, seismic interference, ground roll and multiples, is really a big challenge in the seismic data processing. Swell noise is caused by wave action in marginal weather conditions and is typically characterised by high amplitude bursts of incoherent noise over a range of channels in marine seismic data. The frequency content of swell noise usually falls in the low frequency band. Some other sources of noise, such as fish bites, can have similar characteristics. Swell noise attenuation methods typically use the spatial and spectral characteristics of the noise to identify and attenuate it while preserving data amplitudes of the underlying geology.

Direct arrivals in shot domain of the dataset is a common feature for data acquired in shallow water and the significant amount of swell noises was noticed on this survey. The best compromise for attenuating swell noise and preserving the signal was found with the low cut filter 3Hz/18dB/oct. The output along with the difference plot & corresponding frequency spectrum is shown in Figure-5.



Figure–5: Application of low cut filter for removal of swell noises.

For the suppression of impulsive noise by the detection and suppression of high amplitude impulsive noise, De-spiking is used. Within a time and space window, a rolling median amplitude is computed. If any component is greater than the median by a user specified threshold, it is deleted and either zeroed or scaled back to the median value. The module can be applied within any multi-trace ensemble. Similar approaches can be used to compare amplitudes above and below a low frequency threshold so as to better target and attenuate predominately low frequency noise such as swell noise and ground roll.

It is widespread to attempt to convert the data to minimum phase before applying predictive deconvolution. For De-ghosting & De-signature to minimum phase, an estimated far field signature (Figure-6) is derived from the notional sources and an operator can be designed for each shot to shape each computed far field signature to a single target output wavelet. In this case, the target output was an average far field signature with „de-bubble‟ applied. The Far Field Signature plus ghost & Spectrum is shown in Figure-7. The Minimum Phase Filter & the corresponding spectrum are also shown in Figure-8. The desired output (Figure-9) was derived from an average far field signature and then De-bubble was applied by shaping the far field to a trimmed wavelet and converted to minimum phase.

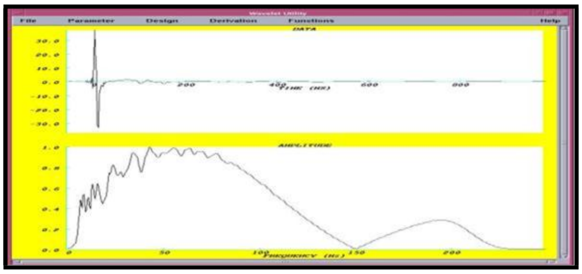


Figure – 6: Far Field Signature and spectrum.

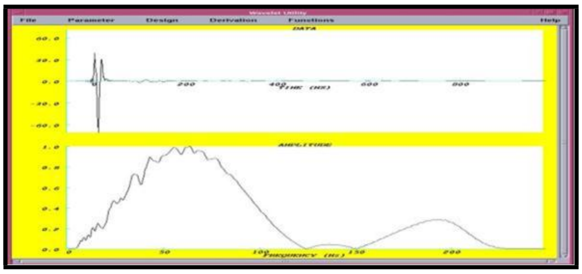


Figure – 7: Far Field Signature plus ghost & Spectrum.

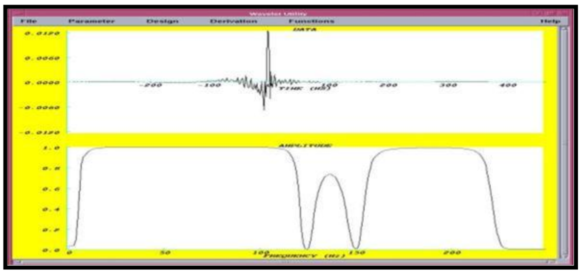


Figure – 8: Minimum Phase Filter Spectrum.

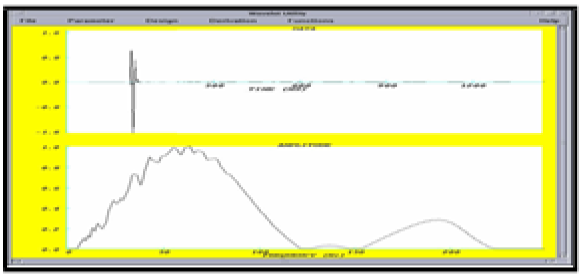


Figure – 9: Output Spectrum.

Subsequently, spherical divergence correction and absorption compensation, amplitude balancing and other conventional pre-processing were applied in shot gather and then Re-sampling was done from 2 msec to 4 msec. A conventional noisy shot gather along with their corresponding frequency spectrums is shown in Figure-10.

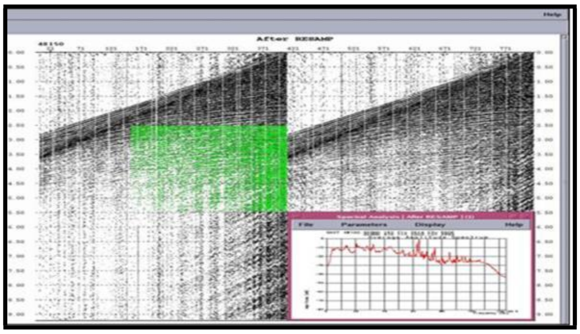


Figure – 10: Raw Data along with their spectrum.

The high amplitude component of the swell noise lies in a limited zone of the frequency spectrum. The affected traces are therefore corrected in a user specified frequency bandwidth. While acquiring the data, the seismic crew faced brutal "Laila Cyclone" from 19th May to 24th May"2010. Few representative shot records containing severe noises are revealed in Figure-11 to Figure-13.

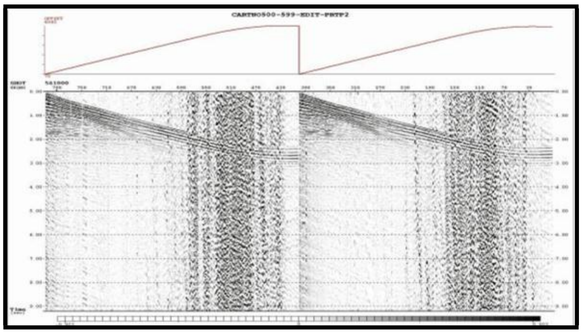


Figure – 11: Feathering Noises in Shot Gather (1818P2).

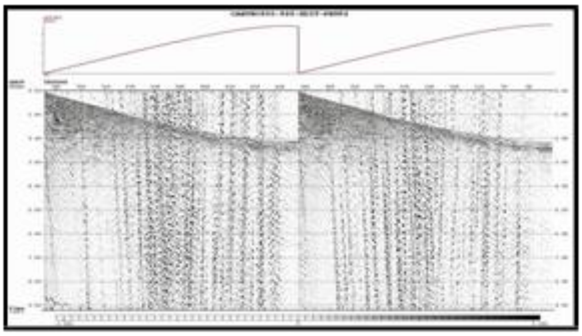


Figure – 12: Feathering Noises in Shot Gather (1854P1).

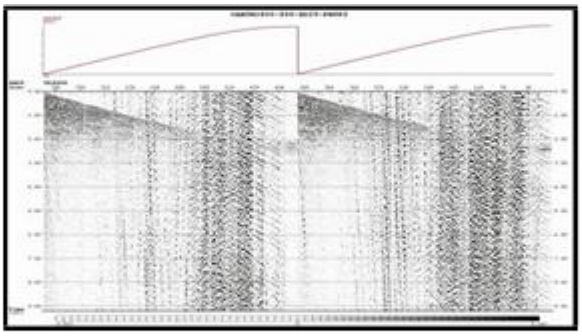
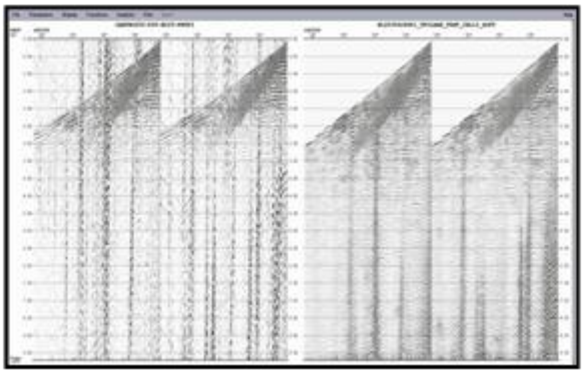


Figure – 13: Shot Noises after "Laila Cyclone".

Noise suppression in the time-frequency domain is used to attenuate random noise. This module is effective in eliminating the noise bursts in gathers without affecting nearby samples and/or traces. The noise suppression is applied sample by sample on various frequency components of the data resulting in a clean dataset with nicely balanced spectra. Each input gather is transformed to time-frequency (TF) domain by using Fast Fourier Transforms within short time windows centered on each input sample. The mapping process from signal space to the time-frequency plane requires the seismic trace to be decomposed into several different discrete frequency components within small running time gates. This process is repeated for each output sample by moving the small window to the next input sample.

The Inverse Transform is performed by taking the inverse FFT of the complex data corresponding for each time sample, then extracting the central sample from the transform to form the output. After completing this process for all the samples in all the frequency subbands, the unaltered phase information is combined with the balanced amplitude information and inverse TF transform yields the filtered TX data.

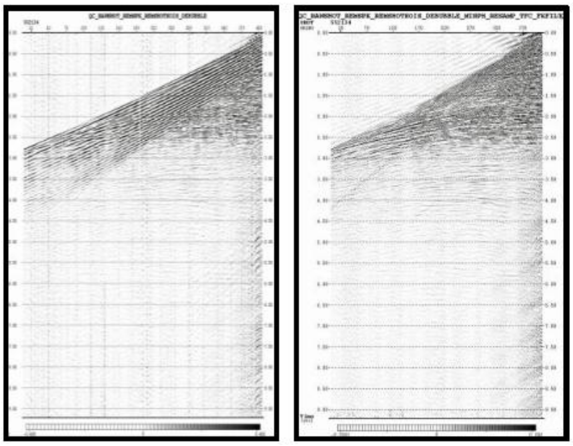


(Input shot Gather) (Output shot Gather)
Figure – 14: Noise attenuation through TF domain in shot Gather.

After the first pass of noise suppression in time-frequency domain, remnant residual noise was attenuated with a cascaded second pass of time-frequency cleaning incorporating higher frequencies. Most importantly, all these sequential processes were applied on in cable-wise shot gathers and the outputs are shown in Figure-14.

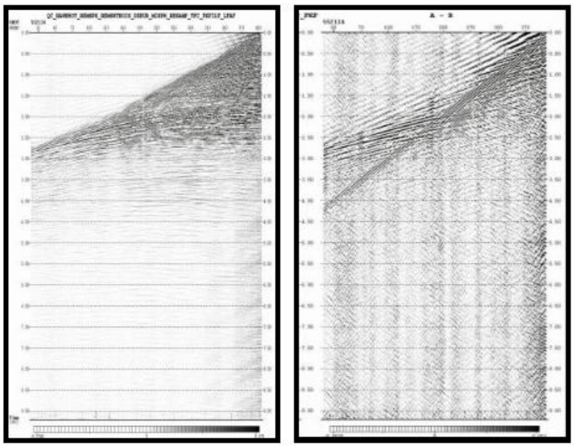
The FK filter designed for unstacked seismic data in F-K domain may be passed directly or may be stored in the seismic database by interactive process for later application. FK filter generates pass or reject filters. Multiple filters may be designed to be merged into a final filter for application in one pass. Filters may be specified by three alternate methods: They may be specified as the vertices of a polygon in f-k space. They may be specified by pairs of dip parameters, in units of milliseconds per trace. The third method allows explicit specification of the taper zone by using a four-point description analogous to a time-domain trapezoid filter. This F-K filter is used for suppression of noises with specific slopes (Interface waves) and also suppression of multiple reflections.

Surface-wave noises are attenuated via low-frequency array forming. This type of noise train has certain characteristics which may be exploited when designing attenuation methods. Typically, the amplitudes of the noise events are higher and reside in a lower frequency band than the desired seismic signal. Given the surface velocity and a low frequency band, the algorithm first transforms the data from the time-space domain to the frequency-space domain. Next each frequency component is convolved with a boxcar function, which is the appropriate calculated array to cancel the shot generated noise train with the specified velocity. Frequency components outside the specified frequency band remain unchanged. The data is returned to the time-space domain.



(A) Shot Gather after Time-Frequency cleaning

(B) Shot Gather after F-K Filter



(C) Shot Gather after Low Frequency Array filter

(D) Difference Plot of A and C.

Figure – 15: Shot Gather through sequential cleaning processes showing stage-wise attenuations of different noises.

Sequential comparisons of same shot gather at different stage of noise attenuation are depicted in Figure-15. Shot gather after successive cascaded cleaning in Time-Frequency domain is shown in Figure-15A. Then F-K filter was optimally designed and applied in shot gather. Several noise types such as ground roll or other seismic interference may be more readily separated in the FK amplitude domain than the time-space domain. In Figure-15B the same shot gather is shown after application of F-K Filter. And also consecutively the Low frequency array filter applied and the output shot gather is shown in Figure-15C. The corresponding difference plot as a whole depicting the removal of different noises between 15A and 15C is shown in Figure-15D.

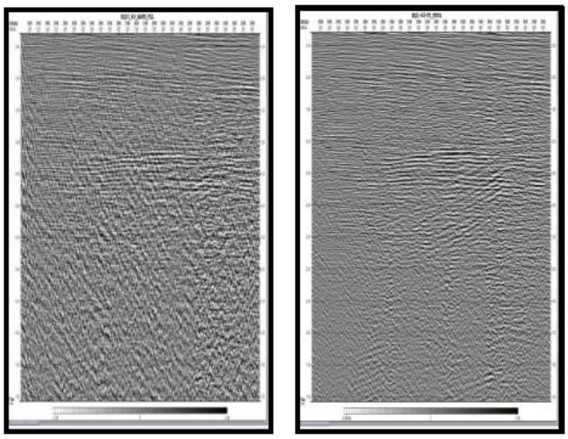


Figure – 16: (A) Raw Stack before any noise attenuation. (B) Raw Stack after swell noise attenuation and followed by noise attenuation in time-frequency domain (Inline1900).

The comparison of raw stack generated on raw gathers (before any noise attenuation) and the corresponding stack after swell noise attenuation and followed by cascaded noise attenuation in time-frequency domain are shown in Figure-16A & Figure-16B for an inline 1900.

Conclusions

The seismic prospecting, being one of the most significant inputs for oil exploration and exploitation, demands best of efforts and high quality outputs, so that the prospects generated yield the desired results.

Wide-ranging chronological noise attenuation processes adopted here to eliminate unwanted dominant noise events stepwise and to enhance the primary reflection signal content of the data. The sequential outcomes in each process progressively suppressed the different noise contents in the seismic data and the end results are befitting input prior to deconvolution process.

This study is a successful attempt towards optimization of processing parameters for optimal noise attenuation of seismic shallow marine data for improved & substantial enhancement of the quality of the seismic processed data for significant & enhanced interpretability of the sub-surface complexities.

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