Application of Noise Attenuation on 2D Shallow Offshore Seismic Reflection Data: A Case Study from the Baltic Sea

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Abstract-Noise is always present in offshore seismic data, as there isn't a single method that could eliminate all the forms of noise. In this study, noise removal techniques were applied to attenuate different noises in 2D shallow-marine seismic data from the Baltic Sea area. Amplitude recovery should be applied before the noise attenuation stage as a preconditioning process for showing all noises in the deeper part of the seismic data. Frequency filters (notch filter and low-cut filter), frequency-wavenumber (FK) filter, and swell noise attenuation (Deswell) were applied as robust noise attenuation techniques. The method of directly modifying the amplitude spectrum of the seismic data is known as frequency filtering. A notch filter can be used to remove the harmonic noise of the power line harmonic noise (mono-frequency noise). A low-cut filter can be used to remove the low-frequency noises due to the influence of hydrostatic pressure variations. The linearly correlated events, such as tail-buoy and operational noise, were removed using the FK filter. Incoherent noise, such as swell noise, can be attenuated by swell noise attenuation (Deswell). The seismic results are displayed before and after the applied noise attenuation techniques to prove the validity of the applied filters. This study aimed to show the importance of shallow offshore seismic data processing in removing different types of noise, as it increases the value of data for seismic data interpretation and marine geohazard assessment.

Keywords-noise attenuation; frequency filtering; FK filter; swell noise attenuation

I. INTRODUCTION

Oilfield exploration and production from oil reservoirs are usually accompanied by high risks. During the implementation of oilfield development plans, the oil volume to be produced is unknown and uncertain as the oil reservoir lies hundreds of meters beneath the ground, and its volume, quality, and distribution cannot be determined with certainty [1]. Seismic waves are an essential tool for subsurface investigation due to their depth of penetration and multidimensional features [2]. The most common geophysical method, seismic reflection, studies subsurface structures. Geophysicists are interested in interpreting the travel times of the seismic waves [3,4]. This leads geophysicists to pay special attention to seismic data processing, particularly for the removal of various unwanted signals, because the quality of the subsurface imaging is largely determined by the accuracy of the processed data.

During a seismic survey, traces are recorded as a linear sum of wanted and unwanted signals. Noises in seismic data are classified as: (a) coherent noises, which are consistent from one trace to another, and (b) random noises, which are not consistent from one trace to another. Wind motion and traffic (vehicles, people, and animals) can cause random noise. Coherent noise can be guided waves (resulting from hard water bottom), cable noises (distinguished by their low amplitudes and frequencies), multiples (can be water bottom and peg-leg), direct arrivals, airwaves, and ship noises [5]. Denoising is a nontrivial task when the noise and signal overlap in multiple domains, such as time, frequency, and velocity. Therefore, the performance of noise suppression is greatly influenced by the choice of the suppression technique and the domain in which the approach will be implemented [6].

Compared to the traditional methods, this shallow offshore seismic survey utilized a sparker source to obtain high-frequency seismic data, resulting in a higher noise level in the recorded data. As there is no single method to eliminate all forms of noise in seismic data, frequency filters, FK filter, and Deswell were used as robust noise attenuation techniques.

II. DATA

The study area is located in the Baltic Sea region, which represents a connection between West and East Europe, as shown in Figure 1. Through 2D shallow marine seismic data from the region, the workflow was built to provide an optimal noise attenuation solution. The seismic data were recorded with the Geometrics Geode system and were acquired with the following field acquisition parameters: group and shot interval 3.125m, 48 channels, offset range 14:158m, record length 400ms, and sample rate 0.25ms.

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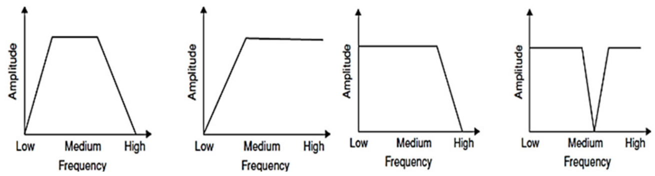
Fig. 1. A map showing the location of the study area in the Baltic Sea region. The black rectangle shows the location of the processed seismic line.

III. Methods

A. Frequency Filters

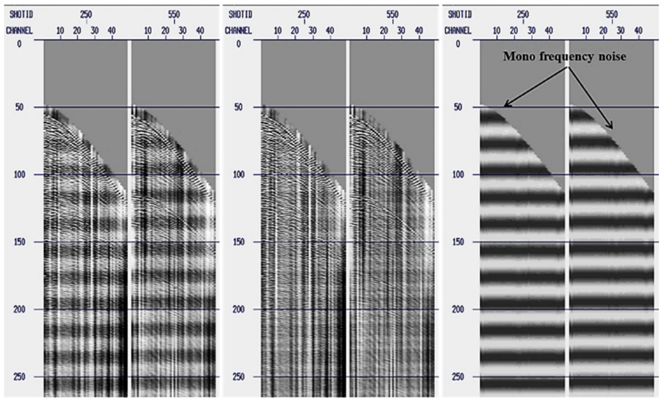
Filtering refers to a wide variety of data-processing techniques that aim to change the frequency composition of a waveform in a controlled way. Figure 2 shows different shaped filters. A bandpass filter enables frequencies within a certain range to pass through the filter without being attenuated. Low-cut (high pass) or high-cut (low pass) filters remove the low or high frequencies respectively. The following parameters must be determined before frequency filtering: frequency cut-off values, operator length, application domain: frequency or time, filter type (Butterworth or Ormsby), and filter phase (zero or minimum) [7, 8].



(a) (b) (c) (d)

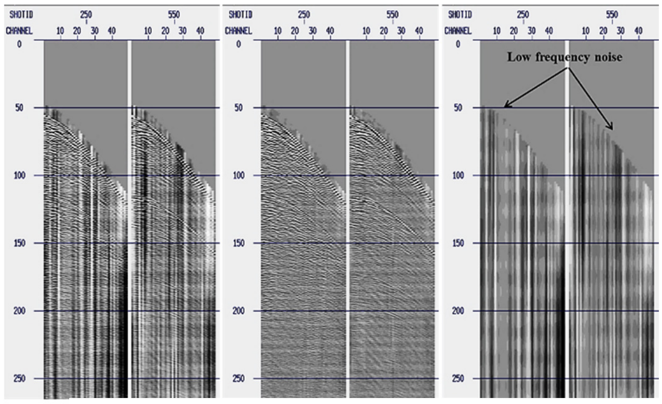
Fig. 2. Different filter designs: (a) band pass, (b) low cut, (c) high cut, and (d) notch.

The main characteristics of power line harmonic noise are that it appears in the amplitude spectrum as single frequency amplitude bursts at 50 or 60Hz and its amplitude remains relatively constant over time, whereas the amplitudes of seismic reflections decay over time [9]. A Notch filter was applied with optimum parameters as peak frequency: 55Hz and delta frequency=5, to remove power line harmonic noise (mono-frequency noise) as shown in the shots gathers in Figure 3. Ocean waves and streamer buckling produce changes in water depth over the seismic streamer cable, resulting in hydrostatic pressure variations that may be eliminated using a low-cut filter [10]. A low-cut filter was applied with the following optimum parameters: frequency filter: low cut, filter type: Butterworth, filter phase: zero, and frequency cut-off values: 4-8-0-0, to remove low-frequency noises as shown in shot gathers in Figure 4.



(a) (b) (c)

Fig. 3. QC shot gathers (a) before notch, (b) after notch, and (c) difference.



(a) (b) (c)

Fig. 4. QC shot gathers (a) before LCF, (b) after LCF, and (c) difference.

The amplitude spectrums before and after the notch filter and after the low cut filter are shown in Figure 5 to confirm the removal of the mono frequency noise (shown as a spike) and low-frequency noise.

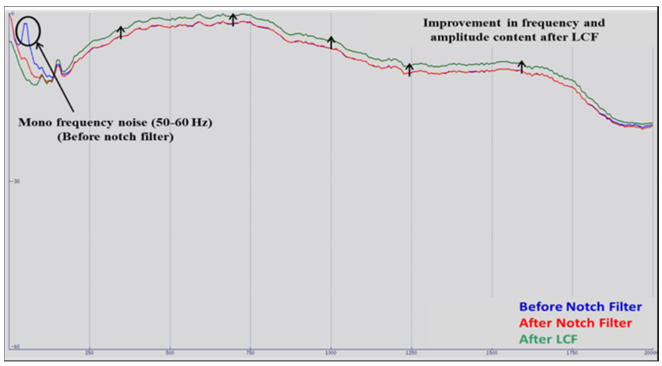


Fig. 5. Amplitude spectrum before notch (blue), after notch (red), and after LCF (green).

B. Frequency-Wavenumber (FK) Filter

An FK filter is a coherent noise attenuation method in the frequency-wavenumber domain. The FK filter was applied in three steps: (a) A Fourier transform was used to convert from the time domain to the frequency domain. Signal and noise could be separated depending on the dipping angle after the transformation. So, the FK filter was referred to as a dip or velocity filter. (b) In the FK spectrum, filtering is conducted by muting the unwanted signal. (c) Inverse Fourier transformations were used to convert the frequency domain to the time domain [11]. As illustrated in Figure 6, the FK spectrum is a powerful tool for discriminating correlated events in time-domain seismic data with distinct dips. The amplitudes of an event in the frequency domain move closer to the horizontal wavenumber axis as the inclination of an event rises in the time domain. In the FK domain, a vertical event in the time domain, such as a bird noise on the shot gathers, looks horizontal. Primary reflection amplitudes are usually seen in the positive panel of the FK spectrum around the frequency axis [12]. After muting linear coherent noises in the FK spectrum, as shown in Figure 7, QC was applied before and after the FK filter for shot gathers (Figure 8) to ensure that linear noises were removed without hurting the primary signals.

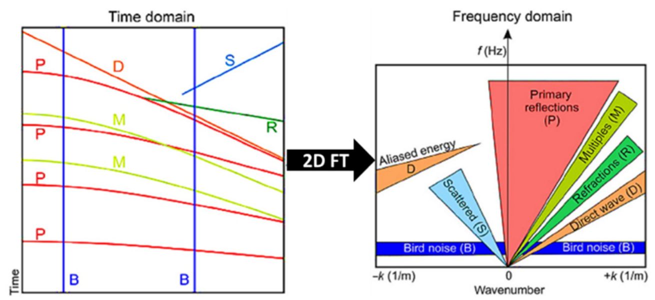
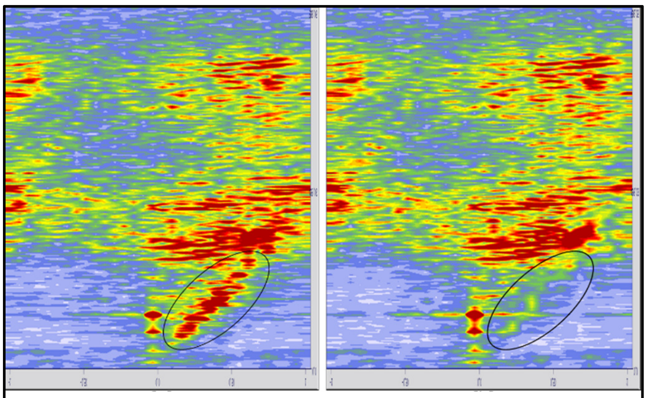


Fig. 6. Schematic illustrations of common events on a marine shot gather (right) and schematic FK spectra of this shot gather (left).

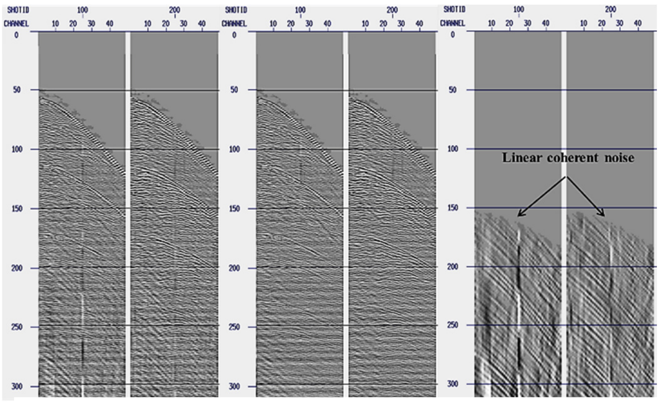


(a) (b)

Fig. 7. QC FK spectrum (a) before and (b) after the muting of linear coherent noises.

C. Swell Noise Attenuation (Deswell)

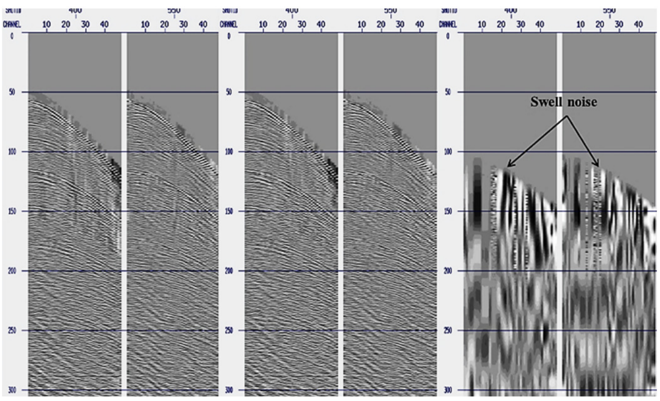
Swell noise is the most common noise type in raw marine seismic data. It is a form of incoherent noise that has low frequencies (2-20Hz), high-amplitude, and can be recognized as vertical streaks in seismic data. It is critical to have clean results, as swell noise's high-amplitude characteristics might obscure the seismic signal. It is caused by changes on the ocean surface over extended periods, such as wind-driven longitudinal sea surface waves and dynamic pressure variations along the streamer [13].



(a) (b) (c)

Fig. 8. QC shot gathers (a) before the FK filter, (b) after the FK filter, and (c) difference.

A bandpass filter is not recommended to remove swell noise as it could hurt the seismic signal. The Deswell technique uses time-frequency filtering to preserve the seismic signal and attenuate the swell noises. Once the seismic data are converted into the frequency domain, the seismic signals are disconnected from the swell noise because of their different frequencies. It should provide a threshold factor to estimate the amplitude and frequency thresholds for noise detection and find which seismic traces are contaminated with the swell noises. Then, the filter is applied using frequency bands interpolated from seismic traces to remove the swell noises [14]. The Deswell technique was applied with the following optimum parameters: threshold range: 15-5 and window in traces: 30-50, to remove the low-frequency swell noise as shown in shot gathers in Figure 9.



(a) (b) (c)

Fig. 9. QC shots (a) before Deswell, (b) after Deswell, and (c) difference.

IV. RESULTS AND DISCUSSION

By checking the field record, different types of noise were detected: mono-frequency noise, low-frequency noise, linear coherent noise, and swell noise. These noises degrade the quality of the seismic data, cause several difficulties during the interpretation of the subsurface, and obscure the geological structure and stratigraphy of the subsurface. The noise reduction techniques used in this study did not affect the seismic bandwidth. At first, notch and low-cut filters were used to remove the mono-frequency and low-frequency noise respectively. Afterward, the FK filter was applied to remove linear coherent noise, and then the swell noise was attenuated by the Deswell technique. Different types of noise were removed by the integrated noise attenuation techniques as shown in Figure 10.

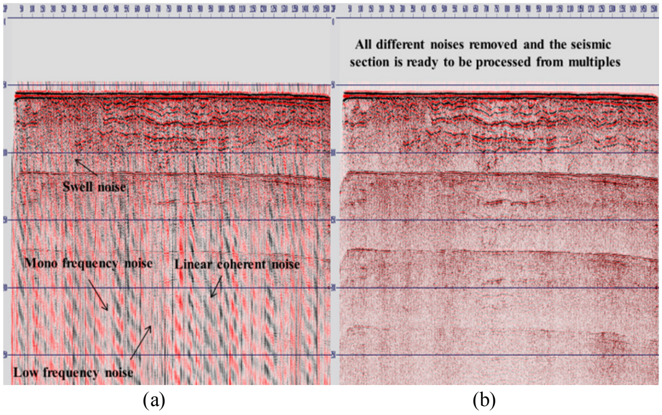


Fig. 10. QC stacks (a) before and (b) after integrated noise attenuation.

V. CONCLUSION

As it is impossible to prevent recording noises during seismic data acquisition, the attenuation of all noises from the seismic data is essential to (1) improve the seismic data resolution, (2) enhance the signal-to-noise ratio, and (3) avoid confusion in structural and stratigraphic seismic data interpretation and environmental hazard evaluation. Knowing how noise works is crucial, as it allows selecting the best method to remove the unwanted signal depending on its unique features. The notch filter was used to remove power line harmonic noises (mono-frequency noises). Low-frequency noises were removed by a low-cut filter. The FK filter was used to eliminate the coherent noise caused by the ship's propeller while maintaining the frequency content of the marine seismic data. The Deswell technique was applied to remove swell noise, which has high-amplitude and low-frequency characteristics. Shallow marine seismic data from the Baltic Sea showed the validity of these noise attenuation techniques.

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