FILTRATION TECHNIQUES FOR WATER BOTTOM MULTIPLES

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ABSTRACT. In seismic processing multiples are events commonly seen in marine surveys, but they are also present in land seismic works. Multiples can be assumed as energy that has been reflected more than once. It is common knowledge in seismic processing that the whole energy that has to be recorded has a single upward reflection beneath the surface. In fact, the acoustic energy could experience two or more upward reflections before being recorded. The presence of multiple reflections in the section can lead to incorrect forward processing of the data and hence interpretation of the subsurface geology structure. For this reason, when detected this kind of seismic energy has to be removed from the processed data. Attenuation is often made by set of procedures specifically aimed at multiples suppression. In the following work the mechanism of multiples detection and some popular techniques for multiples suppression are described.

Keywords: seismic method, seismic multiples, multiple suppression.

ПОПУЛЯРНИ ТЕХНИКИ ЗА ФИЛТРАЦИЯ НА КРАТНИ ВЪЛНИ

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РЕЗЮМЕ. В сеизмичните проучвания, главно в моретата и океаните, едни от най-често срещаните негативни ефекти върху записите се дължат на наличието на кратни вълни в тях. В сеизмичните изследвания се счита, че цялата енергия, която се получава като сигнал има само едно отражение от под-повърхностен слой. На практика обаче акустичните вълни могат да се отразят няколко пъти под повърхността, променяйки посоката си на движение, което води до появата на така наречените кратни вълни. Кратните вълни се считат за шум и по тази причина трябва да бъдат премахнати от сеизмичните данни, за да се избегнат по-нататъшни грешки в обработката и интерпретацията на данните. Това се извършва чрез специални процедури, които са насочени специално към потискането и премахването на кратни отражения.

Ключови думи: сеизмични методи, кратни вълни, филтрация на кратни вълни.

Introduction

Multiple reflections in reflection seismograms are assumed as unwanted noise that often seriously harms correct imaging of the subsurface geology. To achieve accurate interpretation of subsurface seismic images, it is necessary this images to be of good quality and also to correspond to the energy from the primary reflections. Multiple reflections, energy that has been reflected at more than one interface, are particularly a problem for seismic interpretation since they can be easily mistaken as primary reflections. For this reason, multiple suppression techniques remain an integral part of almost every marine processing flow.

Described by Alvarez (2003) primary reflections in a common midpoint gather can be presented like a hyperbolic moveout as a function of offset. The equation of the hyperbolic move-out is:

$$t_x = \sqrt{t_0^2 + \frac{x^2}{V_s^2}} \qquad (1)$$

where t_x corresponds to the arrival time of the reflection at offset x, t_0 corresponds to the arrival time at zero offset and V_s is the NMO-stacking velocity. Stacking velocity is the one that best fits the move-out of the hyperbola and if correctly chosen, this velocity allows the moveout corrected primary reflections to become horizontal. In this way stacking velocities correct for the moveout of the primary reflections and not for the multiples. So, the difference in moveout makes it possible to flatten the primary reflections while leaving the multiples under-corrected with a moveout approximately parabolic (Hampson, 1986).

According to Basak et al. (2012) conventional processing methods have limited approaches to achieve a separation of signal and noise in t-x domain. By transforming the data from the t-x domain to other domains such as the frequency-wavenumber (f-k) domain or the time-slowness (τ-p) domain, those noises can be separated more effectively from the meaningful signal to produce the best subsurface precise images minimising artefacts.

Commonly used multiple suppression techniques

Removing multiples and reverberations from reflection seismograms has been a longstanding problem of exploration geophysics. Multiple reflections often destructively interfere with the primary ones making interpretation almost impossible.

The methods generally used to suppress multiples can be placed in three basic categories (Xiao et al., 2003):

- Methods based on a difference in spatial behaviour of multiple and primary reflections;
- Methods based on periodicity and predictability of the multiples.
- Wave field predication and subtraction methods that use recorded data or models to predict multiples and then subtract them from the original data.

Methods in the first category exploit the fact that multiples have travelled along a different path in the subsurface, so primaries and multiples show different moveout behaviour (Grigorova, 2013). These filtering techniques can be applied in the pre-stack domain, e.g. by differentiation on the moveout (NMO) in the mid-point offset domain, or in the post-stack domain, by the difference in dips between primaries and multiples.

One of the most useful and effective way to suppress multiples is stacking normal move-out (NMO) corrected seismic gathers (Foster, Mosher, 1992). A weak point of moveout algorithms is that they are less effective in the situation of complex wavefields e.g., non-hyperbolic wavefronts. Moreover, these algorithms start to fail when the moveouts of primaries and multiples approach each other e.g., with reflections from deep targets. According to Berkhout and Verschuur (2006) successful moveout-based methods use the Radon transform.

The second group of methods include deconvolution. Deconvolution methods use periodicity to suppress multiples.
The periodicity of the multiples is exploited to design a filter that removes the predictable part of the wavelet (multiples), leaving only its non-predictable part (signal). Deconvolution methods overall include predictive deconvolution, adaptive deconvolution and multichannel deconvolution. So, predictive deconvolution can be used to remove multiple energy from the seismic data by predicting and suppressing the multiple reflection series. A successful predictive deconvolution can remove the complete multiple energy from the seismic data. Generally speaking, periodic assumption is valid only at zero offset in the t-x domain and when the interfaces generating multiples are horizontal or have minor lateral variations. Even though, deconvolution methods still can be used when insignificant deformations of the interface or layer generating multiples are observed.

The third group of methods, wavefield prediction and subtraction, are based on the wave equation. These methods use recorded data to predict multiples by wave extrapolation and inversion procedures. The aim is to obtain multiple–free data by subtracting the predicted multiples, e.g. creating subsurface model. In this way all multiples generated by any system of reflectors can be suppressed theoretically, no matter how complicated it is. These methods assume that the medium between primaries and multiples is almost homogeneous. That group of methods are powerful because of their ability to suppress multiples that interfere with primaries without coincidentally attenuating the primaries. Wavefield prediction and subtraction methods have proved themselves as original and are among the most promising methods for multiple suppression, but they are limited by data acquisition and processing more than other methods (Verschuur et al., 1992).

In the following research real seismic data has been tested, using Radon filtration, deconvolution in τ-p domain and surface-relative wave equation multiple rejection methods (SRWEMR).

Radon transform for multiple attenuation

Radon filtering is able to separate the primary and multiple energy in τ-p domain because of their different moveout velocities. A velocity function is estimated and used to flatten the primaries on common midpoint gathers (Fig. 1). The moveout–corrected gathers are then transformed to the Radon domain. After the transformation the flattened hyperbolic primaries in time-offset domain (t-x) are presented as points in τ-p domain where the multiples are separated from the primaries. In practice this process differs from the theory. Because the transforms produce distortions, the multiples are estimated in Radon domain, transformed back to the t-x domain, and then subtracted from the original data, leaving only the primary data (Berndt, Moore, 1999).

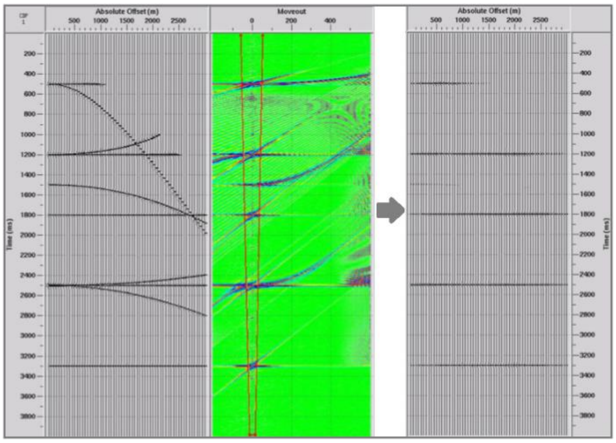

Fig. 1. Radon transform on synthetic data

The primaries are computed by subtracting the multiples from the original data in this domain. This method was first introduced with the name “inverse velocity stacking” (Hampson, 1986).

In Figure 2 Radon filter is effectively applied for attenuating the multiple reflections on real dataset.

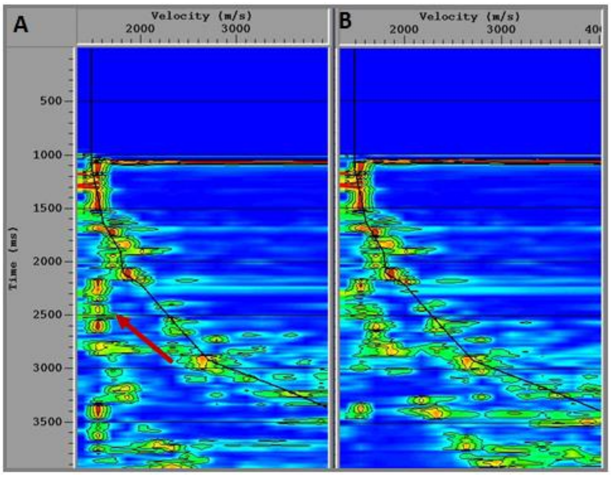

Fig. 2. Velocity analysis before (A) and after (B) applying Radon filter

On the figure is shown velocity gather before (A) and after (B) applying Radon filtration. It can be observed that velocity events in the range 2000–2500 ms are caused by first water bottom multiple. After applying filtration, the first water bottom multiple is being effected and more confident velocity picking can be applied.

A comparison of stack data obtained before (A) and after (B) Radon filter is shown in Figure 3. The image obtained after the application of Radon filter is helpful in carrying out correct imaging of the data and for achieving more accurate geological interpretation.

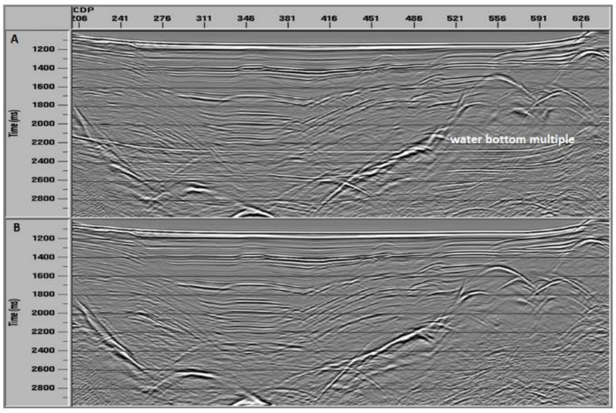

Fig. 3. Part of stack data before (A) and after (B) Radon filter

Radon filter provides a high degree of multiple attenuation, especially on long period multiples found in deep water. It works similarly well in all areas, but experiences difficulties when the moveout differential decreases under 30ms from near trace to far trace, such as with peg-leg multiples.

Deconvolution techniques in the tau-p domain

Deconvolution in the τ-p domain can be classified as multiple attenuation techniques that rely on the periodicity of the multiple wavefield. Multiples are periodic in the τ-p domain, and predictive deconvolution applied in the τ-p domain can be successfully used to suppress them. According to Brooymans et al. (2013) perfect periodicity in the time-space domain occurs only for plane wave propagation, so the best alternative is to compute the τ-p transform of common shot point or common midpoint gathers, which simulates plane waves. By transforming data into the τ-p domain, multiples can be forced to behave like periodic events for all values of p and effectively attenuated with predictive deconvolution. This technique is particularly effective in shallow water areas where muting in the τ-p domain can be accompanied with linear noise attenuation.

This τ-p processing can be applied to remove unwanted noise from meaningful reflection signals and for more truthfully determining the stacking velocity function. In Figure 4 velocity semblance after applying τ-p deconvolution allows more adequate and reliable conclusions about stacking velocity to be made. It is clearly obvious how first water bottom multiple is affected of applying the procedure.

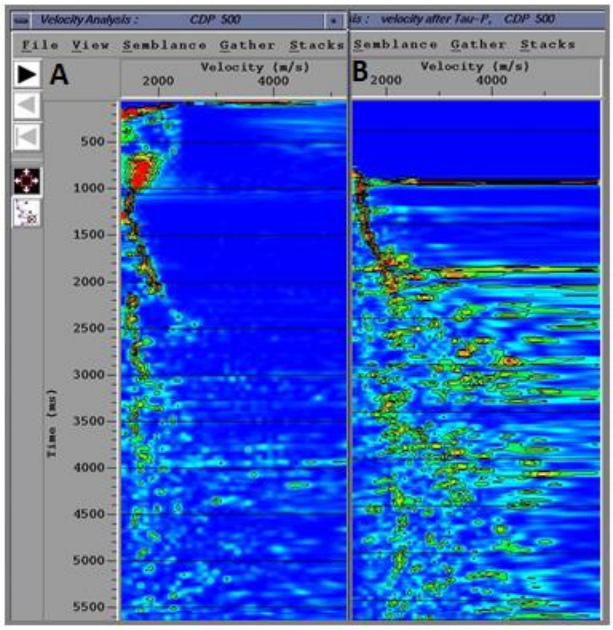

Fig. 4. Velocity analysis before (A) and after (B) applying τ-p deconvolution

According to Xiao et al. (2003) in shallow water, where the water bottom is very flat and peg–leg multiples are the main problem, τ-p deconvolution can be very effective. On the other hand, deconvolution methods are less effective in deep water where the period of the multiples is longer, relative to the length of the record. One possible reason can be the lack of enough multiples in the record length to satisfy the periodic requirements. Another problem is that long–period multiples require long operators. Since primaries can be periodic over long time windows, long operators have the potential to suppress primaries as well as multiples.

In principle, periodic assumption is valid only at zero offset in the time–space domain, so pre-stack deconvolution has limited use as a multiple suppression technique.

In Figure 5 is demonstrated stack data with clearly defined water bottom multiple. This seismic section confirms the rule for effectiveness of τ-p deconvolution in shallow waters.

Very often multiple attenuation techniques modify the whole dataset and produced artefacts on the section. As Stewart et al. (2007) mentioned as a drawback of τ-p deconvolution, is that the entire ensemble passes through the transform. As a consequence, transform artefacts may be embedded in the data. Many multiple attenuation techniques model the multiple reflections and subtract them from the original data. This helps minimise process-induced artefact. It becomes clear that there is no single multiple attenuation technique suitable for all datasets.

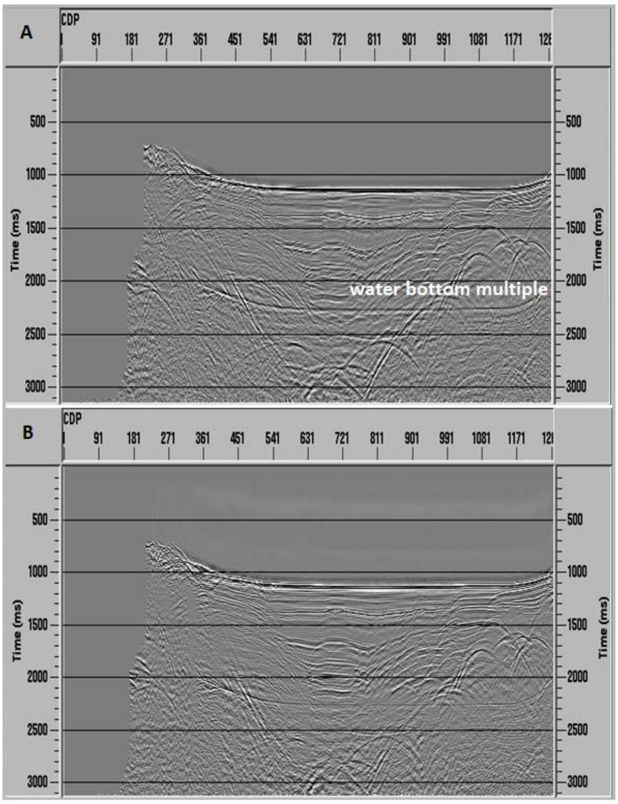

Fig. 5. Part of stack data before (A) and after (B) applying τ-p deconvolution

Wavefield prediction and subtraction technique - surface-relative wave equation multiple rejection (SRWEMR)

Wavefield prediction and subtraction methods are among the most promising methods of multiple suppression. These methods use wave equation and recorded data to predict multiples in the section. As Xiao et al. (2003) pointed out wave extrapolation and inversion procedures are designed to subtract the predicted multiples from the original data and to produce multiple – free data. The biggest advantage of these methods over other multiple attenuation methods is their ability to suppress all multiples, especially the multiples that have stacking velocities close to the primary reflections without attenuating the primaries.

Prediction and subtraction techniques for multiple attenuation have also another advantage over the other multiple subtraction methods – these methods are suitable for prestack analysis and particularly for amplitude– versus–offset analysis, because they do not transform the input signal.

In Figure 6 is presented the result of application of surface-relative wave equation multiple rejection method (SRWEMR) before (A) and after (B) filtration. The technique proved itself as the most promising amongst the tested methods in this research. Multiple reflections generated by the water bottom are predicted by a combination of wave extrapolation through the water layer and estimation of the water bottom reflectivity, then the predicted wave field is subtracted from the original data.

This method can be used successfully to attenuate the long period multiple reflection, because the attenuation is based on wave equation inversion. As stated by Wiggins (1988) multiple reflections that are generated by the water bottom in marine seismic data can be predicted by a combination of numerical wave extrapolation through the water layer and estimation of the water bottom reflectivity. Therefore, inversion of wave equation and seismic wave amplitude observed are used to get the water bottom reflectivity which is then used to design the prediction filter to eliminate the multiple reflections.

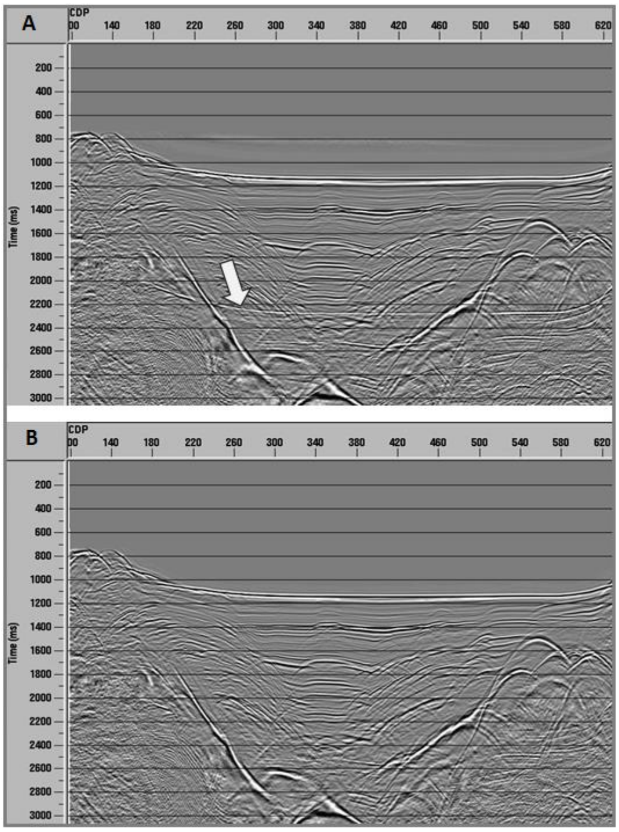

Fig. 6. Part of stack data before (A) and after (B) surface-relative wave equation multiple rejection

According to Erlangga (2015) the SRWEMR method does not depend on the moveout difference to attenuate the long period multiple reflection. So, the SRWEMR method can be applied to the seismic data which has even small moveout difference.

Conclusion

Over the years, many multiple attenuation techniques have been tested. Most of them proved to be effective in certain physical-geological conditions. It is essential a proper multiple suppression approach to be chosen depending on the type of multiples, data acquisition and processing flow.

Multiple attenuation not only makes interpretation easier by highlighting the primaries, but also improves the resolution of the primaries by allowing a better selection of the primary stacking velocities. A careful examination of stacking velocity leads to more confident and adequate seismic section, which is the main goal in the process of seismic investigations. These are just few key issues multiple suppression methods to be recognized as an integral part of almost every marine processing flow.

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