Broadband marine seismic, how much difference does acquisition and or processing make? A case study from Southeast Asia

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SUMMARY

This paper describes a field experiment designed to test various forms of marine broadband acquisition and their appropriate processing techniques. These methods are compared against a traditional "shallow tow" (8m) cable depth and de-phasing processing flow. We take particular interest in a slanted cable acquisition technique and other ways of creating "notch diversity" with a marine streamer. We analyse the resultant data with displays, spectra and frequency split displays.

Overall the experiment shows that we can model the cable ghost response of the system well enough to understand the response of real data. This allows the application of deterministic inverse operators to not only "de-phase" and re-datum the data but also frequency shaping the output data closer to the spectrum of the input pulse. This is particularly important when the cable is slanted in an oblique manner relative to the sea surface. However, noise at frequency extremes will limit this process and other shaping methods. The final results show remarkably similar end results despite quite different acquisition methods.

Key words: marine broadband, deghosting, spectral shaping, resolution, detectability, slanted cable

INTRODUCTION

Expanding the bandwidth of surface seismic data, particularly towards low frequencies, is essential for many exploration and production objectives. Broader band signals, both in land and marine environments have marked benefits for imaging deeper targets, imaging through absorptive overburdens, and in particular, inversion for rock properties. Additional high frequency data will improve resolution; expanded low frequency data will improve detectability by reduction of the side lobes of the wavelet. Various methods have been proposed and implemented to expand seismic bandwidth; these include both acquisition and signal processing methods. Most of these marine acquisition methods generate diversity in the position of the free surface ghost notches. During processing, the ghost notches both at "DC" (low frequencies) and at high frequency (water velocity divided by twice the cable depth) are reduced. A question that is often asked is how much difference does changing the acquisition geometry make?

In this paper, we present a case study of a consistent, experimental offshore dataset in Southeast Asia. This data consists of a single boat pass of multiple cables at different depth configurations. The resultant sub lines were then processed with their appropriate deghosting methods and results compared.

The key determinants of the eventual bandwidth of surface seismic data are the convolution of the source pulse with near surface effects (free surface source and receiver ghosts in the marine situation), the overall earth attenuation, and the level of additive environmental noise. Some of these effects can be modified by changes in the field acquisition geometry or, at least, deterministically compensated in processing. The noise level may constrain or limit the capacity of signal processing tools to compensate for the "field" effects. When evaluating the raw and processed data it is wise to use various types of analysis and displays. Simple seismic amplitude stack sections and associated spectra can be misleading. Spectral "split" plots and inversion of the seismic data are often more indicative of success.

In marine seismic acquisition, the free-surface ghost effect is one factor that can strongly impact the data bandwidth dependant on the streamer and source depths. These are also easily adjusted in the survey design. Shallow towing favours the higher frequency response at the expense of low frequencies, whilst deeper towing favours the lower frequencies, at the expense of higher frequencies. Moreover, a deeper tow typically has lower levels of swell noise. At very low frequencies, the critical two octaves between two to eight Hz, we are presented with a "triple threat"; the level of ambient environmental noise rises, the "DC notch" strengthens, and the power output of airgun sources declines. This combination provides both the biggest challenge and the biggest opportunity for bandwidth expansion.

METHOD AND RESULTS

Marine Broadband Acquisition Techniques

A solution to the bandwidth 'barrier' is to create "notch diversity" and preferably also reduce environmental noise. A simple 'desktop' model is shown in figure 1. The two models have the same source parameters and earth attenuation but two different cable depths. Note the frequency domain graph is not normalised and is presented in the log frequency domain, hence it shows bandwidth. By deepening the cable the frequency where noise overcomes signal can be shifted lower than that of a typical 6 m. tow depth. The model shows towing deeper narrows the "DC" notch below 8 Hz. in addition, noise

in this band is expected to be lower. By contrast, towing shallower at 6 m. avoids the high frequency notch at 50 Hz seen with the 15 m. tow but reduces response in the green band 2-8 Hz. In principle, if we collect data using other than a simple "flat" cable design, we can have both responses in one acquisition system. However, there is a marked difference in both amplitude and phase of the wavelets when observed in the time domain. If we "slide the notch" between near and far offset with incremental cable depths (slanted cable mode) then this offset variable response requires compensation in processing.

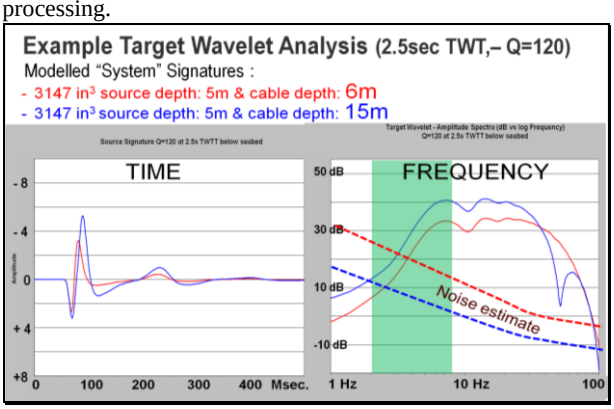

Figure 1. Model of two cable depth scenarios. The noise estimates are based on typical field measurements. (log frequency used on the non-normalised power spectra).

The combination of designing field methods providing notch diversity, and careful data processing, can improve bandwidth, particularly at very low frequencies. We shall illustrate these methods with a comparative field test recently conducted in Southeast Asia. These examples are also processed with their matched methods of compensation. From this test, we can draw some conclusions as to the applicability of these notch diversity methods relative to recent practice and survey needs.

Field Test

In the experimental data, multiple cables were towed by the vessel at differing depths as shown, in Figure 2.

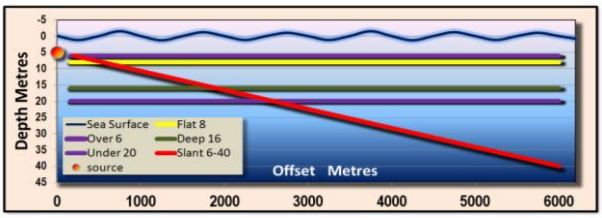

Figure 2. The various cable towing depths in the experiment (schematic).

Inducing notch diversity by slanting the cable (Ray and Moore, 1982) is one of the tests (labelled SC in figures) This is shown by the red line in Figure 1. This shape in particular, presents a challenge to data processing, as particularly the phase response of the recorded data will progressively change over offset. Unless compensated for, this will bias multichannel processes that work across the entire spread. Of particular concern would be velocity analysis, SRME based demultiple, and prestack AVO analysis. In this experiment, the slanted cable data is processed using a proprietary single streamer deghosting (SSD) technique implemented at an early stage of processing immediately after initial noise attenuation. The over-under cable configuration (Haggerty, 1956) is another test (labelled OU in the figures), this data is de-ghosted using a proprietary, optimal deghosting technique ODG (Ozdemir et. al., 2003). The 16 m. deep cable (a deep & flat tow or DF) is also processed with SSD and residual spectral shaping (RSS) for the remaining, but weak notch at around 48 and 96 Hz. Here the notch diversity is assumed to be generated by the wave action on the sea surface, The nominal cable depth of 16m is assumed to change during acquisition. In addition to processing each method with their matching deghosting technique, all data was processed at 6.25 m. group interval (digitally group formed on the vessel). Some of the deghosting techniques assume transforms that are aliased at the traditional 12.5 m. group spacing. For instance, water borne linear noise will alias beyond 62.5 Hz at 12.5 m. sampling. More importantly, a flat reflector event at long offset with a RMS velocity of 2000 m/sec will alias beyond 80 Hz, steep dips will also be in danger if processing at 12.5 m. Aliasing in the shot domain can become important if we attempt to extend bandwidth to frequencies beyond 60-80 Hz

Results and Analysis

Some of the final results are shown in Figure 3, this compares a traditional shallow (8 m.) and "flat" cable (SF) acquisition and processing strategy against the two designed notch diversity techniques (OU and SC) and the 16 m deep & flat tow (DF).

In this experiment, all broadband methods tested increased the band width compared to the 'traditional' SC approach. An additional octave or more of signal is added at the low frequency end of the spectra. Varying amounts of high frequency enhancement have been achieved. The over-under technique OU provides approximately 30 Hz. more than the traditional shallow& flat tow method while the slant cable method SC achieved a 15 Hz increase (see figure 3-right).

Overall, the dual cable method provides the broadest bandwidth, consistent with it having two measurements along the entire offset range. The slanted cable method provides the second best result. The deep cable result is surprisingly good and it was noticed that the high frequency notches are not as severe as may be expected. This is most likely due to the fact that even with a nominal constant cable depth there is some notch diversity in the data as the sea level rises and falls. This data was collected in quite rough conditions when the average swell range was ±1.5 m., hence the ghost can be considered "fuzzy" especially when averaged via prestack migration and stacking. There is conjecture that in very calm conditions the severity of the notches may become stronger. With this data set and the ~3 m. wave motion, some residual spectral shaping (RSS) was required to remove the weak but persistent notches that were in the data even after stacking.

As a further test, we tried to improve the traditional SF data by simple targeted post stack spectral shaping. In effect a 'processing only' solution to bandwidth broadening. By way of example, Figure 4 shows that the traditional data "SF" can be spectrally shaped to a broader nominal spectrum, when compared to the slanted cable "SC". As long as the signal to noise level in a dataset is good, the visual impact (the top ~20 dB of the spectra) of the imposed free surface ghost filter can be reduced. The image in Figure 4 shows that when additional spectral shaping is applied it can partially make the shallow flat tow 'look like' the slanted cable data. But on close inspection and by use of spectral split displays, we observe that the slanted cable data demonstrates lower noise

levels and stronger signal in the low frequency band of 0-15 Hz.

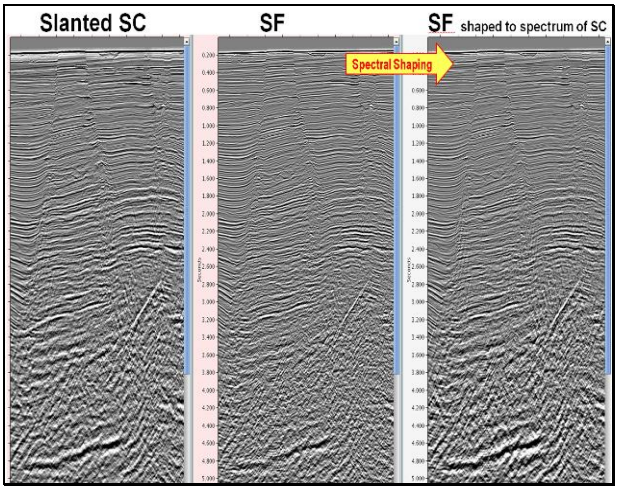

Figure 4. Post stack targeted spectral shaping applied to the shallow & flat data, thereby reducing the differences in spectral content. (But not completely – noise levels vary)

CONCLUSIONS

The expanded bandwidth and in particular, the ultra-low frequencies, are very useful not only for penetration through deep or highly absorptive media but also for various inversion types. Low frequency signal significantly reduces the dependency of low frequency modelling in the case of inversion for acoustic impedance and is essential for emerging technologies such as full waveform inversion (FWI).

Comprehension of the principles governing the bandwidth of both the signal and noise of seismic data enables the design of field systems and inverse operators to provide optimal data for modern processing techniques. The broadband acquisition methods tested here do make a difference to the acquired data, in conjunction with a complimentary processing technique to complete the challenge. In a perfect noise free world, this would not be the case as spectral shaping and processing alone could overcome any free surface ghost amplitude attenuation and the phase effects via modelling and inverse filters. However, environmental noise is always present to some degree, consequently, noise mitigation via deeper tows, finer sampling and notch diversity via acquisition design and methods can assist in improving the starting data.

In conclusion, to answer the question in the title, yes, acquisition does play an important role in generating broadband marine data, but equally important is a correct, matching de-phasing and de-ghosting methodology in processing. In practice, the exact acquisition method employed is most likely to be chosen based on operational, logistical and project objectives.

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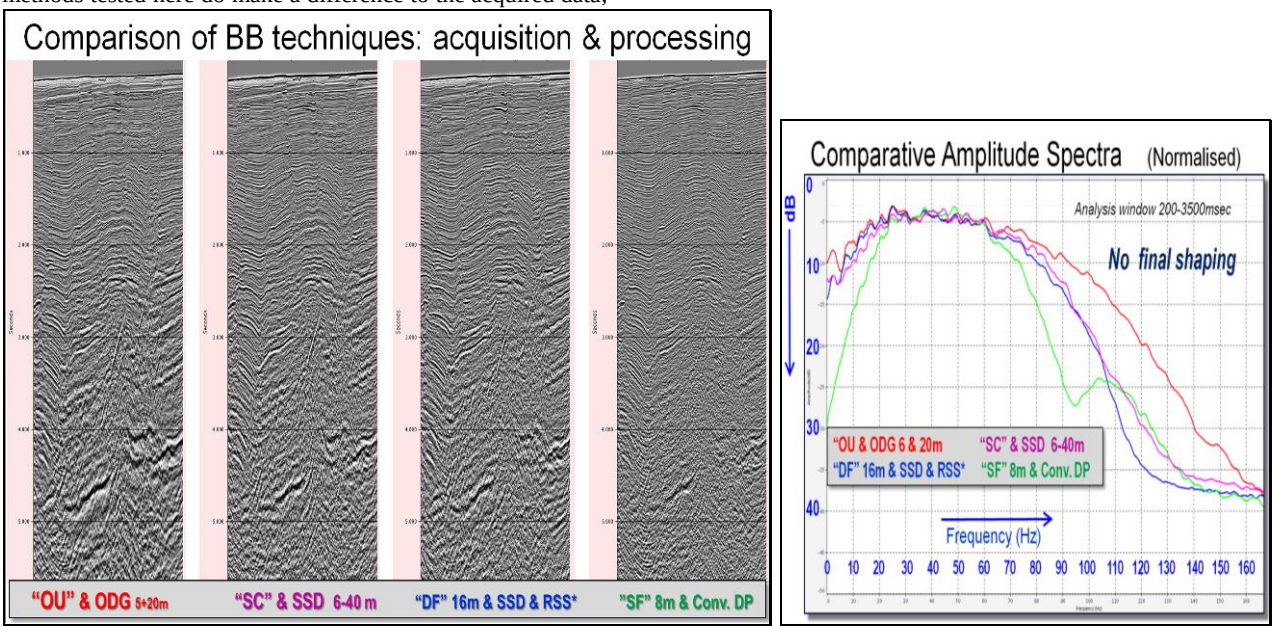

Figure 3. Comparisons of various acquisition techniques and their associated signal processing techniques -stacks of zero to five seconds TWT (left panel). Comparative amplitude spectra of the stack sections (right panel).