Noise attenuation techniques for improving the quality of Ocean Bottom Seismic data

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ABSTRACT

Ocean bottom seismic recording has potentially many benefits over that from towed surface streamer. Besides the obvious ability to record in areas of production and development, there are a number of geophysical benefits. These include reducing spectral notches due to ghost interference, reducing water bottom multiples and general improvements in signal to noise due to reduced cable drag. In addition, sensors coupled to the sea floor have the ability to record shear energy if horizontal detectors are used.

In practice, ocean bottom recordings have often failed to live up to theoretical expectations. This is invariably due to excessive noise on the geophone component. In some instances the noise can be so severe that the geophone data has to be discarded entirely.

In this paper, we present noise attenuation techniques which can dramatically improve signal quality which when combined with an appropriate PZ summation yields a wider and flatter spectrum in the processed data.

Theoretically, well recorded and well processed ocean bottom seismic data has the potential to yield images which are superior to towed surface streamer seismic data. The reasons being:

1. A lower noise environment free from cable drag noise and surface swells.

2. Stationary recording units free from receiver motion.

3. After PZ summation, a flatter spectrum due to suppression of receiver ghost notches and multiples.

To achieve this in practice, both hydrophone and geophone must be well coupled to the sea floor and noise free.

As a general rule, hydrophones on the sea floor, although plagued with multiples, are free from other troublesome noises. Because hydrophones measure pressure, they are robust even when poorly coupled to the sea floor. They are also insensitive to tilt and orientation and do not ever record direct shear energy. The noises which are present are usually easily dealt with in processing.

However, geophones are much more problematic. Geophones measure particle motion not pressure and are thus much more sensitive to coupling. They are also sensitive to vertical tilt which makes them prone to shear wave contamination.

Following is a summary of the types of noise commonly encountered on OBC data.

A. **Scholte waves**. These are slow moving waves which propagate in the shallow unconsolidated mud layers on the sea floor (trapped between a liquid and a solid). It is analogous to ground roll on land data. The noise is usually low frequency and low velocity. Scholte waves are activated by the air gun source but only in shallow water before the airgun pulse has consolidated. It is usually absent in water depths of 30m or more. When present, both Hydrophones and Geophones will be contaminated with Scholte energy. Because the velocities are so slow, the noise can be prone to aliasing but in relative terms it is easily dealt with in data processing using adaptive velocity filters in either the shot or receiver domain (depending on which is best sampled).

B. **Spikes and noise bursts**. As a rule, it is rare for hydrophones to be badly contaminated with spikes and noise bursts. However, geophones can appear very noisy. In most instances, spikes are due to bad coupling, instrument movement or biological contact. Shear noise may also have the appearance of spikes when viewed in the shot domain.

C. **Trapped guided waves**. This is high amplitude broadband energy parallel to the first arrivals. It is often highly aliased and is present on both hydrophones and geophones. This noise dominates the higher angle reflections. It is important to remove this noise prior any AVO analysis. Usually a de-aliasing step is required prior to noise removal.

D. **Refracted bubble energy**. This noise only occurs with airgun sources (the most common source used on ocean bottom recordings). It appears as low amplitude low frequency bands parallel to and below the first arrivals and may penetrate deeper into the data. It is easily removed in processing with adaptive filtering in the same step as trapped and guided wave removal.

E. **Shear leakage**. Shear wave energy leaking onto the vertical geophone sensor is the most problematic and least understood noise on OBC data. It only occurs on the geophone component (hydrophones are only able to measure pressure and not the particle motion associated with shear waves). The noise is often so intense that there may be a temptation to discard the Geophone data completely. In fact, many noisy OBC surveys have been processed without incorporating geophone at all or weighing down their contribution in the summation to an insignificant level. The consequences of this approach could be disastrous, particularly in the presence of ghost and multiples associated with high impedance sea floors.

To appreciate more clearly the importance of the geophone in the summation we must go back to OBC basic theory.

When correctly combined, ocean floor hydrophone and geophone data has ability to eliminate receiver side ghosts and multiples. In isolation, the components will suffer spectral notches which are the result of frequencies being canceled by equal and opposite polarity down-going waves reflecting from the free surface. The specific frequencies cancelled are related to water depth. Due to the difference in vector response between hydrophone and geophone, the peaks and troughs are opposite, thus an appropriate combination results in a flat spectrum.

It is a common misconception that Hydrophone and Geophone should be weighed with equal amounts in the PZ sum. I.e., the scalar "s" in the sum P + sZ is a transduction constant only which balances the two systems.

This approach totally ignores the reflectivity of the sea floor. Ignoring the reflectivity will result in only partial attenuation of notches, ghosts and multiples.

Ghosts and multiples recorded with a hydrophone sensor are enhanced relative to primary energy (1+R) whereas multiples recorded on a geophone are naturally attenuated (1-R). The correct scalar required to neutralize the ghosts and multiples is the one which boosts the geophone contribution to where the ghost and multiples are similar amplitude between hydrophone and geophone and cancel on summation.

Clearly, boosting the contribution of noisy geophones is going to degrade the quality of the resulting sum, thus the importance of a quality de-noising process.

The most popular theory as to why shear wave noise exists on geophones is that the vertical sensor unit is not truly vertical. This was often the case, especially with older systems. More modern systems using accelerometers have the ability to auto-correct to vertical based on gravity measurements. However, shear leakage noise is still observed on these recordings. This can only lead to the assumption that the horizontal particle motion has been tilted as the up-going shear wave passes through the mud layer.

Irrespective of the origin of Shear noise, it still needs to be attenuated. If we are fortunate enough to have recorded shear waves directly using a four component system, it is possible to estimate a model of the shear noise from the horizontal Y component, then adaptively match it to the leakage noise on the geophone and subtract it. If only two component data was recorded, we are forced to model and subtract the shear noise entirely on geophone data.

Next, we look at a case study of vintage proprietary data. This data was acquired in 1997 using a two component (hydrophone and geophone) ocean bottom cable system. This data is characterized by strong multiples on the hydrophone component and extremely strong shear noise on the geophone component. The data had been processed and re-processed.

A typical example of geophone recordings on this survey is shown in figure 1. It is clearly dominated by low velocity high amplitude shear energy. The faster velocity P wave reflectors are barely visible.

The data is displayed in the common receiver domain. In the shot domain, the shear energy appears random in both phase and amplitude. Figure 2 shows the same data after noise attenuation. This data is now ready for summation.

Figure 3 show the legacy PZ summation. This data appears to still be contaminated with noise and multiples.

Figure 4 is the result of careful and applied noise attenuation applied to each component attacking each type of noise as appropriate prior to the summation.

In particular, the geophone noise attenuation has allowed the geophone contribution to the summation to be optimized to suppress ghosts and multiples.

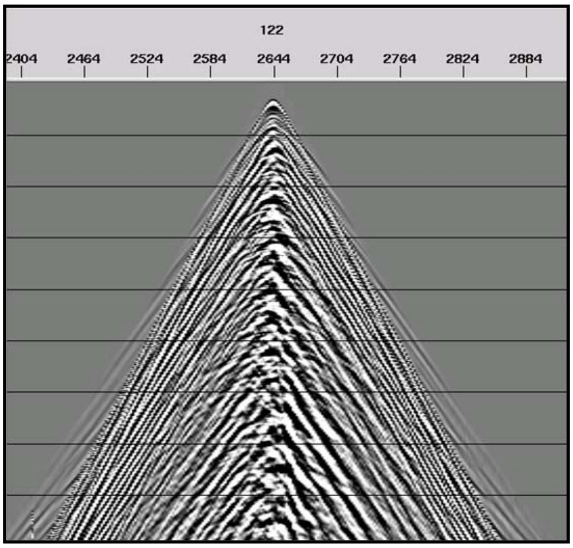

Figure 1 Raw Geophone data

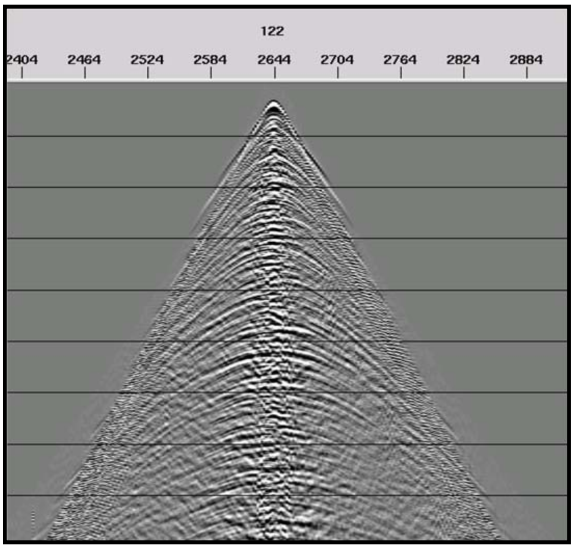

Figure 2 De-noised geophone data

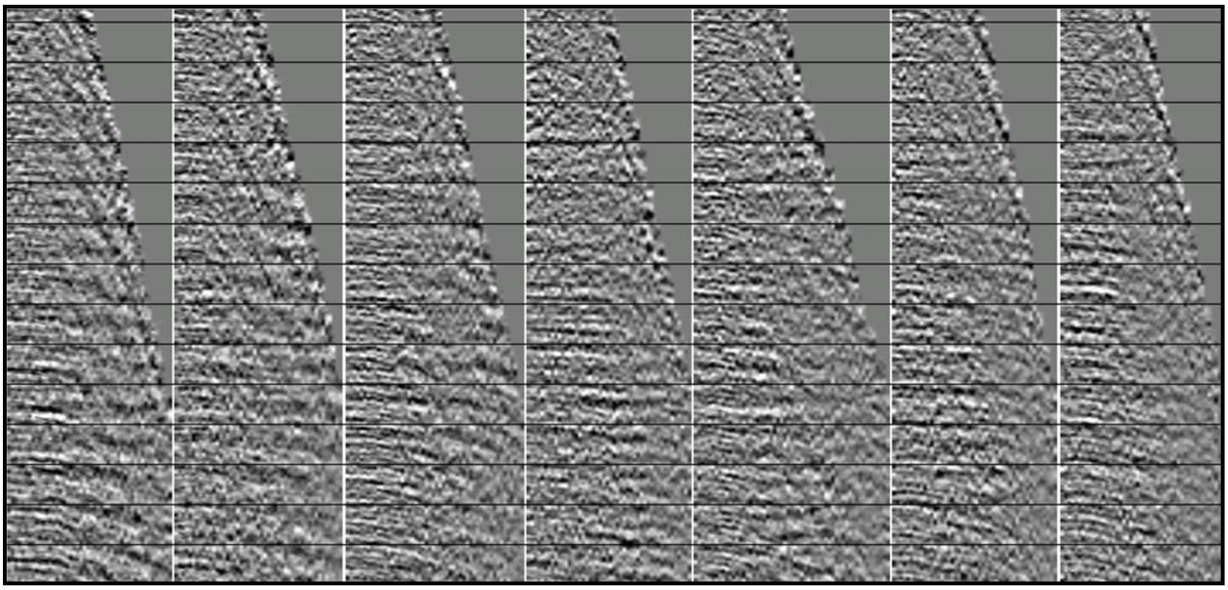

Figure 3. CMP gathers: Legacy PZ summation

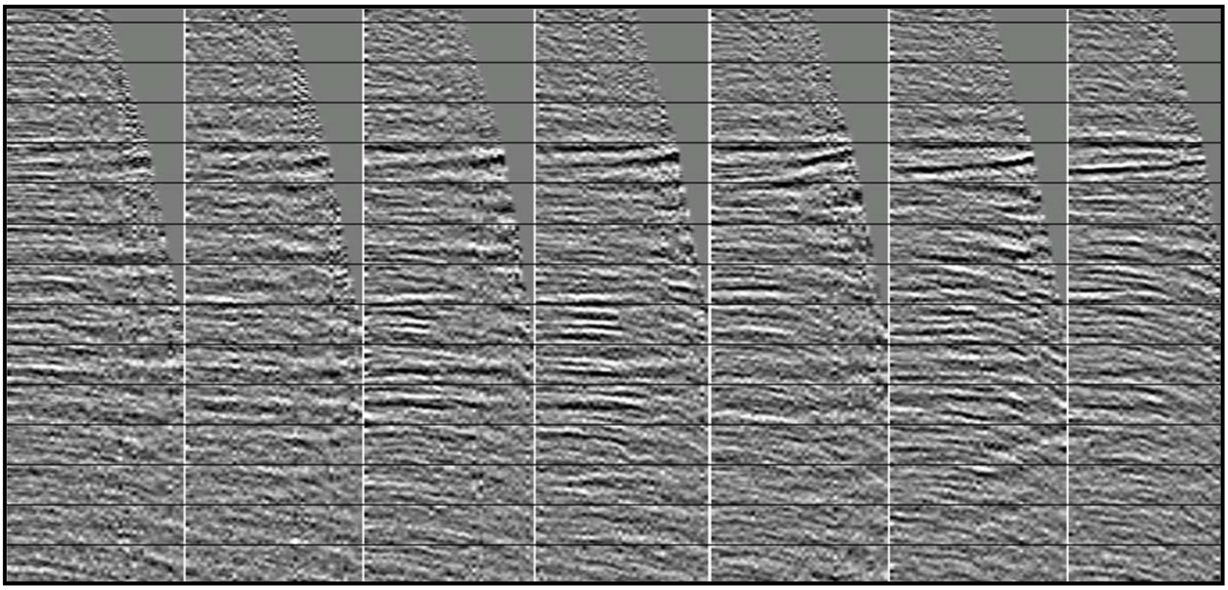

Figure 4. CMP gathers: New PZ summation