Introduction

FreeCable™, a new marine seismic acquisition method and technology using autonomous surface vehicles was tested in the Mediterranean Sea (Haumonté et al., 2016). The main innovation of the system consists of the following points: i) the seismic cables are quasi-stationary with respect to the seabed (Midwater Stationary Cables, MSC) ii) the position of each MSC is controlled by a pair of autonomous surface vehicles (Recording Autonomous Vessels, RAV) iii) the typical MSC immersion depth is up to 100m iv) the separation between receiver lines is significantly larger than in towed streamers (typically 400m) v) the source vessels are not physically linked to the receiver array. Its positions are independent of the receiver array position.

For this sea trial, the system used two MSCs, four RAVs and a control room installed onboard a master vessel. Each MSC is fitted with four-component stations (hydrophone and tri-axial geophone) regularly spaced at 25m interval. The source was made up of two small GI guns of 45in³ and 105in³, respectively. The airgun depth was 7m. The objective of the test was to assess the data quality (high signal-to-noise ratio, broadband data), to estimate the system performance in terms of controllability and productivity, and to validate its operability (launch and recovery, sea keeping, fuel autonomy). It was performed in the deep offshore of the Mediterranean Sea, approximately 200km from Marseille and Barcelona. At this location, the water depth is 2.4km and it is at the toe of the continental slope which is the only place in the Gulf of Lion where the sedimentary column is fully complete i.e. without major erosion and hiatuses. This survey was optimal to record high quality true amplitudes due to the water depth and the MSC immersion depth. This data set was used to performed adaptive deghosting (Vrolijk and Blacquière, 2020) and multi-component deblending using a pattern-based approach (Jennings et al., 2018).

Method and Examples

The purpose of the work presented here is two-fold: i) analyse the frequency contents recorded with one MSC of 1.5km length (#6003 line, ‘Pourquoi Pas’ survey) ii) examine the water bottom reflection recorded on both the hydrophone and the vertical geophone in terms of amplitude and acoustic impedance.

- LF/ HF data

Figure 1 shows raw stacks of hydrophone and vertical geophone data (60 fold) after application of an NMO correction to line up the energy for both the direct reflections and its ghosts and a correction of spherical divergence.

To get a better understanding of how the frequency spectrum is built for both the hydrophone and the vertical geophone record, a series of filter panels were generated from 2 to 32Hz i.e. 5 octaves - see Figure 1, 2, 3 and 4.

![Figure 1 2-4Hz frequency panel for hydrophone (left) and vertical geophone (right).](image)

The above left image shows that the hydrophone responds at the water bottom reflection level (3.25s twt) and double level at 6.5s twt. This is a remarkable result as the used airgun emitted very few LFs.
Figure 2 4-8Hz frequency panel for hydrophone (left) and vertical geophone (right).

For Figure 2, reflected events start to appear on the hydrophone stack but for the geophone stack as in the 2-4Hz frequency band, only linear noise is present.

Figure 3 8-16Hz frequency panel for hydrophone (left) and vertical geophone (right).

The vertical geophone stack displayed on Figure 3 shows less noise with respect to the previous frequency panels and reflected signal on the water bottom only.

Figure 4 16-32Hz frequency panel for hydrophone (left) and vertical geophone (right).

The hydrophone stack presented Figure 4 shows a bright flatspot event at 4.7s twt which also shows up on the geophone stack from 16Hz.

Further analysis showed that the HF contents of the hydrophone is also remarkable because the flatspot reflection is still observable in the 96-192Hz frequency band whereas the vertical geophone stops in the 64-128Hz band.

One of the reasons which explains the difference between the hydrophone stack and the vertical geophone stack is the sensor response. Hydrophone being a first-order high-pass filter whereas geophone is a second-order one with a 15Hz natural frequency, seismic signals are strongly attenuated in the LFs i.e. from -35 to -22dB in the 2-4Hz band for the geophone vs -13 to -7dB for the hydrophone - see Figure 5.
Amplitude/impedance high-quality
Hydrophone and vertical geophone data were rotated and a theoretical sensitivity correction was applied. Because the analysis focuses on the water bottom reflection, a hyperbolic NMO stretch was applied. For the vertical geophone, an incidence correction was applied and a 24Hz high-pass filter was applied to attenuate the low-frequency noise - see Figure 1.

Figure 6 displays the selected window for the hydrophone and the vertical geophone encompassing the water bottom reflection at 3s twt and its ghost.

It can be observed that the travel times oscillate in an opposite way for the direct reflection and the ghost reflection (which comes from depth variations due to a suboptimal balancing of the MSC) and that the geophone traces are noisy in some areas. The advantage of a great MSC immersion depth with an airgun HF short signal is that allows to separate in time the primary reflection from its ghost.

Figure 7 shows pre-stack amplitude maps of the water bottom primary reflection for the hydrophone and vertical geophone in the cmp-trace domain. Horizontal cmp-consistent bands are visible and are due to the variation of the reflection coefficient of the water bottom. Notice those bands are common to the hydrophone and the vertical geophone records.
The ratio of the above two maps yields the acoustic impedance map, eliminating the variation effects of the reflection coefficient of the water bottom.

As it can be observed on Figure 8, the acoustic impedance value is very stable for every receiver and every CMP. The histogram confirms the impedance stability around the theoretical value of the seawater acoustic impedance, which is here 14.5 in our unit system.

Conclusions

The data analysis of this sea trial in deep offshore Mediterranean Sea using seismic cables immersed at 100m depth and a small airgun (150in³) demonstrated that the hydrophones record useful signals in the 2-4Hz frequency band. This is a remarkable result all the more that the airgun emits very few LFs. Despite the small source and the geophone low-cut filter, water bottom reflection is observed in the 6-12Hz band. The true amplitude and acoustic impedance maps are very stable for each sensor and each cmp. Hence, the sensor coupling is accurate, high-fidelity (in a 4C sense) and repeatable and the FreeCable method avoids the repeatability issue which is critical in 4D seismic surveys.

References

