Advanced high-resolution 3D streamer seismic acquisition solutions for new energy applications

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Summary

Advanced towing configurations which combine distributed multi-sources with dense multi-sensor streamer spreads have been frequently used for hydrocarbon exploration in recent years. These acquisition solutions enable accurate imaging from very shallow targets and geohazards to deep geological structures in a cost-effective manner. The improved near offset coverage and the dense spatial sampling provided by the wide-tow multi-source enables subsurface imaging with temporal and spatial resolution in the meter-range. The same survey design principles can be applied to near-surface high-resolution or ultra-high-resolution studies such as carbon capture and storage (CCS) site characterization or offshore wind farm 3D site surveying.

Typical site survey seismic technologies are based on hydrophone-only streamers that are towed a few meters below the sea surface. While shallow tow mitigates the receiver ghost problem at high frequencies, the operations are exposed to weather related downtime. With multi-sensor streamers, the receiver ghost problem is solved by combining pressure and particle motion recordings. This means the streamers can be towed deeper. In this paper, modern acquisition configurations are revisited, and it is shown how the same concepts have recently been used to design and acquire the first larger CCS site characterization surveys in Europe in 2022.

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Introduction

The demand for high quality marine streamer seismic with rich near offset coverage has grown steadily over the last few years. The focus on near field exploration and exploration in prolific basins very often requires improving or upgrading the existing seismic data in the area. Better spatial sampling, higher trace density, improved near offset coverage but also longer offsets and richer azimuth coverage are the typical design criteria. In addition, the emerging new energy markets require cost-efficient high-resolution or even ultra-high resolution 3D seismic data. Typical applications are imaging of the subsurface from a shallow seabed down to the reservoir level in Carbon Capture and Storage (CCS), mapping of the shallow geological structures for seabed mineral exploration, or site surveys for future offshore wind farms. In most cases, near offset and dense spatial sampling requirements are the key cost drivers.

New and innovative strategies for acquisition and imaging of shallow targets have been exploited by Widmaier et al. (2019, 2020, and 2021). The key technical solution was the introduction of wide-tow multi-sources, i.e., the distribution of multiple sources along the front of a streamer spread. The combination of wide-tow multi-sources with high-density streamer spreads overcomes the traditional 3D seismic challenge of imaging the near surface in shallow or moderate water depths.

In the meantime, we have acquired 15 commercial projects with this advanced method including wide-tow triple-, quad-, penta- and hexa-source configurations. In some cases, source-over-the spread solutions were deployed to enable close-to-zero offset coverage for ultra-shallow targets. While the method has initially been used for hydrocarbon exploration it has recently been adopted for a carbon capture and storage (CCS) seismic project.

Wide-tow multi-source method

The wide-tow multi-source concept was launched as an alternative to the marine survey design method commonly used to improve near-offset coverage, i.e., the reduction of the streamer spread width to minimize the distance between the sources in the centre and the outermost streamers. Figure 1 illustrates the concept for a quad-source configuration in front of a streamer spread with 50 m streamer separation. The source separation for the standard narrow source tow is 12.5 m, and for the wide-tow alternative it is increased to 62.5 m. Furthermore, if the sail line separation is made a function of the source geometry (4 x 62.5 m, i.e., 250 m), the lateral source line spacing (62.5 m) becomes regular for the entire survey area. The regular dense source line spacing in combination with the high-density streamer spread provides significantly improved near-offset coverage (Figure 1, right). In addition to the improved near-offset sampling, this configuration provides a symmetrical bin size of as little as 6.25 m x 6.25 m. This concept can be extended to higher source count configurations and even denser streamer spacing. With multi-sensor streamers, the receiver ghost problem is solved at all frequencies by combining pressure and particle motion recordings. This means the streamers are towed deep (e.g., at 25 m) and rough sea surface effects are avoided, which results in an increased operational weather window.

High-resolution exploration survey with wide-tow penta source

The wide-tow multi-source method was used in an exploration survey in the Barents Sea in 2020 (Widmaier et al., 2020). A high density multisensor 16-streamer spread was combined with a wide-tow penta source (Figure 2, left). The separation between adjacent source arrays was 78.75 m, resulting in a total source spread width of 315 m. The inline offset between the sources and the streamer front-end was as short as 65 m. The acquisition configuration enabled a bin size of 6.25 m x 6.25 m which is an ideal starting point for high resolution imagine. At the same time, the sail line separation of 450m kept cost and turnaround at reasonable levels. The tow depth of the multi-sensor streamers was at 25m and thus the survey could be acquired with minimal exposure to weather related downtime. Imaging of the

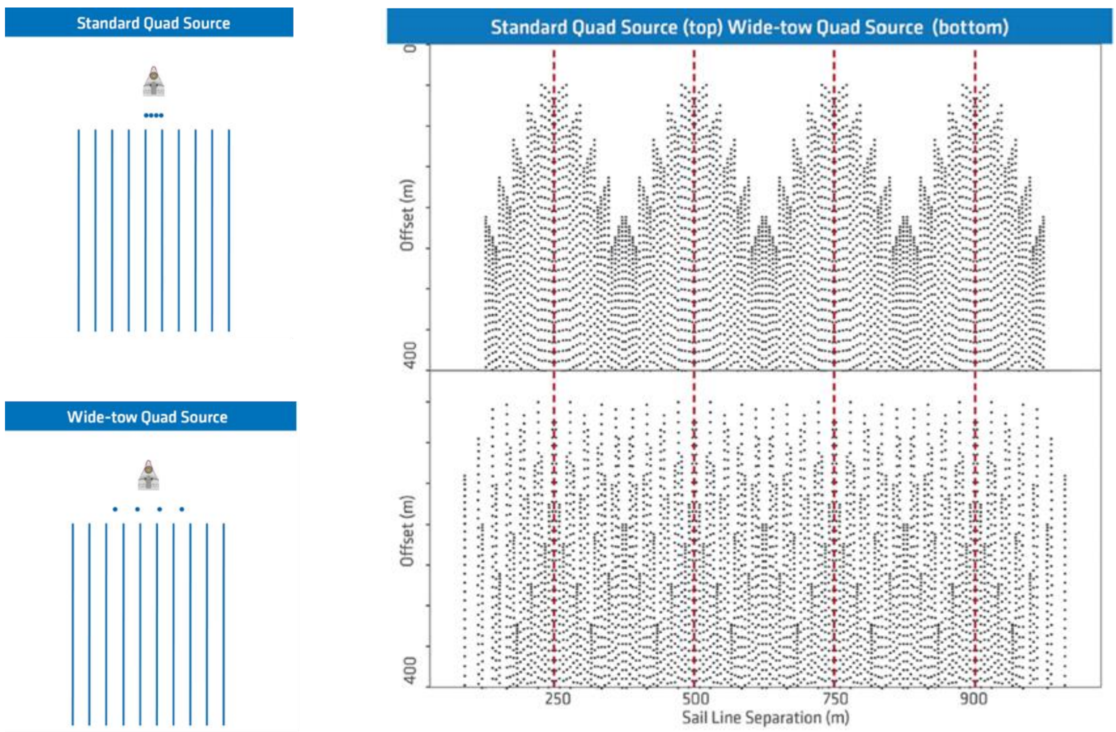

Figure 1 *High-density streamer configurations of 10 streamers with 50 m separation combined with a standard quad-source set-up (top left) and a wide-tow quad-source set-up (bottom left). The wide-tow source separation is 62.5 m, resulting in a total source spread width of 187.5 m. The corresponding near offset distributions are shown on the right. CMP-X positions are along the x-axis, and source-receiver offsets are along the y-axis. The red dashed lines indicate the centre of each sail line. Wide tow of sources provides a significantly improved and more uniform near offset coverage.*

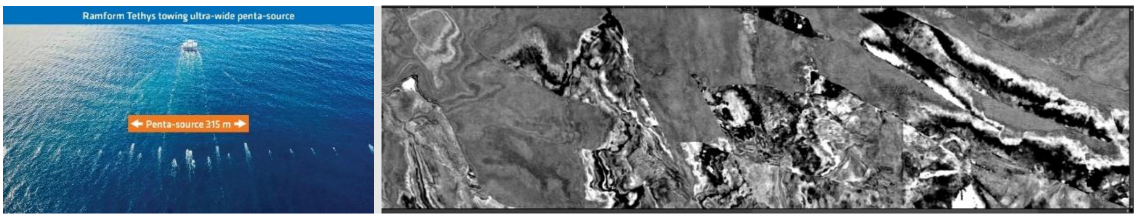

Figure 2: *Ramform Tethys (left) towing an ultra-wide penta source with 78.75 m source separation and 315 m total source spread width. The source separation is larger than the streamer separation (56.25 m). The corresponding imaging result (right) of the near-surface does not show any footprint typically caused by near-offset gaps at sail-line boundaries. The depth slice shown is extracted from 468 m below main sea level. Water depth ranges from 300 m to 400 m in the area. The ultra-wide penta source set up provided a natural processing bin size of 6.25m x 6.25m and uniform sampling of the ultra-near offsets.*

ultra-wide penta source data resulted in very high-resolution images of the near surface. A depth slice extracted just below the seabed is shown in Figure 2 (right). The image is free from any acquisition footprint due the uniform near-offset coverage made possible by the wider tow of multi-sources.

CCS high-resolution baseline survey with wide-tow quad source

The wide-tow quad source configuration shown in Figure 1 was the starting point for a novel high-resolution survey over three CCS structures in the Southern North Sea (Cooper, 2022) that we designed and acquired for the Northern Endurance Partnership (operated by BP) in 2022. One of the objectives was accurate imaging and characterisation of the geological formations above the CO2 storage reservoirs. Seismic modelling indicated that imaging of the near subsurface in the shallow water environment requires uniform coverage of near offsets down to the 30m-60m range. While the wider tow of the quad source enabled near offset coverage in crossline direction (Figure 1), it was still a challenge to meet the nearest offset needs given the typical towing solution with sources 65m in front of the spread. The inline offset challenge could be solved by moving the sources over the front ends of the streamers. Again, deep tow of multisensor streamers were key for broadband acquisition and to ensure high efficiency also under rougher weather conditions. Figure 3 shows the Ramform Hyperion operating with the innovative towing solution during the Northern Endurance project.

Figure 3: *Ramform Hyperion acquiring a high-resolution CCS baseline survey for the Northern Endurance Partnership offshore UK in 2022. The configuration consisted of 11 multisensor streamers with 50m separation and a wide quad source that was towed over the front end of the streamer spread. The resulting nominal acquisition bin size was 6.25m x 6.25m.*

Ultra-high-resolution 3D site surveys for offshore wind farms

The wide-tow multi-source survey design principles as discussed above for high-resolution hydrocarbon and CCS surveys are also applicable to ultra-high resolution 3D surveys for offshore wind farm sites. However, configurations must be scaled down to meet temporal and spatial resolution requirements. I.e., the wavefield must be sampled at higher sampling rate temporally and much denser spatially. The P-cable system, originally developed by Sverre Planke and Christian Berndt (Planke & Berndt, 2003), has recently been adopted for applications in the energy transition (MacGregor et al, 2022). In the P-cable system, short streamers (typically 50-100m long) are towed from a cross cable (Figure 4, left). For ultra-high-resolution applications, sparker or boomer sources are used, and temporal sampling rates are at 0.125-0.25 msec. The configuration example in Figure 4 has a streamer separation of 6.25m. The very dense streamer spread in combination with a wide tow triple source leads to a bin size in the 1m range and very good coverage of nearest offsets (0m-20m range).

In contrast to multisensor streamers referred to in the previous sections, ultra-high-resolution systems such as the P-cable are towed at very shallow depths to emphasize the high frequency content in the recorded date. The shallow tow depth increases the weather exposure of ultra-high-resolution seismic surveys. Also, de-ghosting becomes a more critical step compared to multisensor streamers.

Conclusions

Wide-tow multi-sources enable cost effective acquisition of high-quality seismic data with good coverage of the nearest offsets and dense spatial sampling. A novel marine seismic survey was acquired by combining a dense multi-sensor streamer spread with an ultra-wide penta source in the Barents Sea in 2020. Processing of the high-resolution seismic data delivered high-quality images of shallow targets just below the seabed without the acquisition footprint typically caused by lack of near offsets.

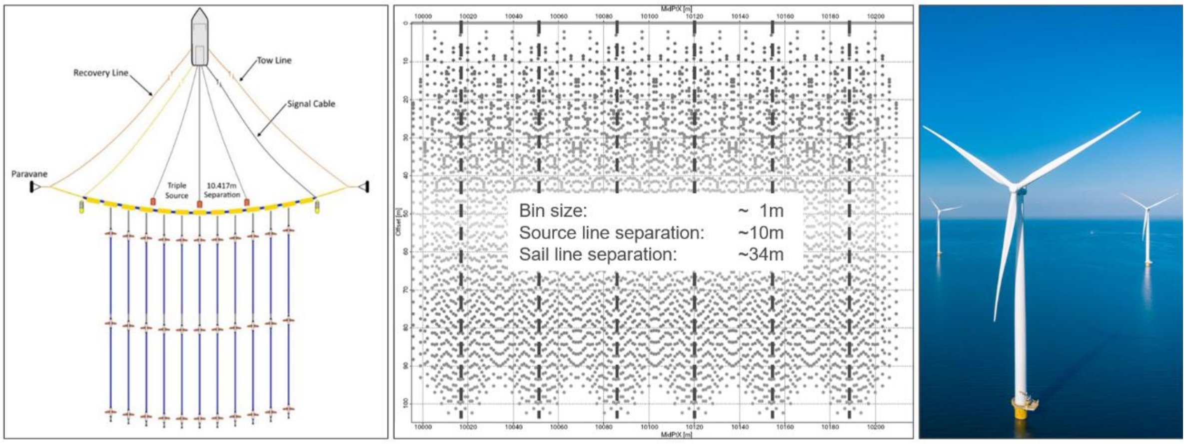

Figure 4: *P-cable configuration for ultra-high resolution 3D site surveys for offshore windfarms in shallow water. The streamer spread of 11 x 100m x 6.25m has been combined with a wide-tow triple source to achieve a bin size of 1m and good spatial sampling of the very near offsets.*

The same survey design principles can be applied to specialized near-surface high-resolution 3D studies such as CCS site characterization, or offshore wind farm site surveying. As near-surface seismic or seabed mapping in shallow water requires recording of seismic data with close-to-zero offset, the inline distance between sources and streamers can be minimized by moving the sources over the front end of the streamer spread as demonstrated in novel quad source acquisition over the Northern Endurance CCS structures. We have also demonstrated how a scaled configuration (P-cable) can deliver ultra-high resolution seismic of 1m spatial sampling.

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