Ultra-high resolution 3D survey design for seismic site characterization

Introduction

Narrow tow-source configurations lack sufficient near-offset sampling to enable high-quality 3D imaging of the shallow subsurface. Advanced acquisition configurations with multiple wide-tow sources have been presented by Widmaier et al. (2019). This technology can be leveraged to improve acquisition efficiency or enhance image quality. By providing better near offset coverage, improved spatial sampling, and higher trace density, they are effective for imaging both shallow and deep targets. The emergence of ultra-high resolution 3D seismic acquisition for offshore wind site characterization and high-density 3D for CCS container delineation has led to an adapted wide-tow multi-source concept with uniform source lines, as described by Widmaier et al. (2023). These designs feature uniform source-line sampling, dense near-offset coverage, small bin sizes, high trace density, and compact, environmentally friendly sources. In this paper, we describe survey design considerations for these

Ultra-high-resolution 3D seismic for offshore wind farm site characterization

With the high demand for renewable energy, wind turbines are increasingly being deployed in shallow to deep waters. Water depth and sediment composition dictate the foundation type and, consequently, the imaging depth required in the seismic surveys. Depending on local geology, identifying geohazards and deriving geotechnical parameters from multi-physics data is essential, with 3D seismic data serving as a critical component. 3D seismic site surveys can begin with exploratory acquisition over a large area, followed by a targeted appraisal survey. Depending on the objectives—boulder detection, soil unitization, or both—tailor-made seismic solutions are designed. Shallow-water sites with abundant boulders typically benefit from very dense acquisition geometries, while deeper-water sites are suited for more cost-effective acquisition. The denser configurations with very narrow mini-streamer spreads provide dense spatial sampling. Corridor-type survey layouts may be used to reduce costs. Wider configurations with relaxed spatial sampling are more efficient and can cover full 3D survey areas.

Acquisition configuration	# Sources	Source line separation (m)	Normalized efficiency (%)	Firing / pop interval (m)	Firing / pop interval (ms)	Vessel speed (knots)	Nominal inline / crossline bin size (m)	Nominal amplitude density [full offset]/sqkm	Maximum minimum offset (m)	Nominal amplitude density [max. min. offset] /sqkm
8 x 6m x 100m WPS	5	4.8	100	0.4	180	4.32	0.78125 / 0.6	53333333	31	16533333
10 x 5m x 100m WHS	6	4.2	104	0.33	150	4.32	0.78125 / 0.42	76807680	33	25346534
14 x 10m x 200m WPS	5	14	289	0.55	250	4.27	1.5625 / 1.0	23272727	93	10821818
14 x 12m x 200m WPS	5	16.8	347	0.55	250	4.27	1.5625 / 1.2	19393939	112	10860606

Table 1 *Configuration parameters for ultra-high-resolution seismic surveys.*

Figure 1 shows two very dense ultra-high-resolution configurations designed for 25 m water depth: 8 × 6 m Wide Penta Source (WPS) and 10 × 5 m Wide Hexa Source (WHS). The channel spacing is 1.5625 m. The offset-distribution plots are color-coded by seafloor reflection angles. The offset corresponding to 45°, roughly the maximum useful offset for a flat reflector with a 50% stretch mute, is indicated. Although WPS and WHS have similar efficiency, WHS achieves ~44% higher trace density due to two additional streamers and an extra source (Table 1). The crossline gap analysis shows similar distributions for both configurations (Figures 1c and 1d), indicating comparable spatial resolution, though the flatter WHS curve suggests slightly better achievable resolution. The maximum gap sizes stay below the Fresnel zone radius (Monk, 2010) for 1800 Hz at the water-bottom to well below 5 m offset. This is a significant contribution to successful near-offset interpolation and regularization. Interpolation of near-offset gaps is also improved for WHS, which has ~53% higher trace density up to the maximum minimum offset compared to WPS (Table 1; Figures 1c and 1d). However, at the same shot-point intervals and identical vessel speed, WHS yields a shortened clean record length.

Figures 2a and 2b show two configurations with higher acquisition efficiency. Both utilize 14 streamers and a wide penta source. Option 2 (14 × 12 m WPS) with 12 m streamer separation is 20% more efficient than Option 1 (14 × 10 m WPS). Conversely, Option 1 provides ~20% higher amplitude density, better

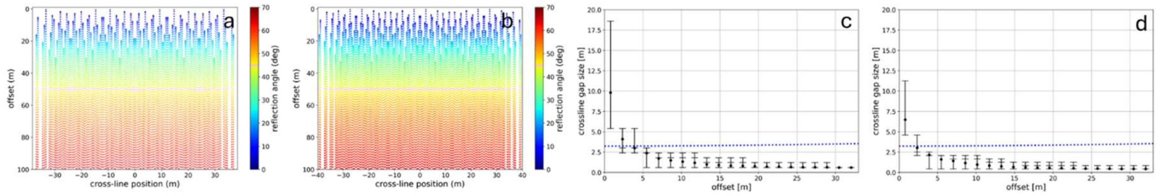

Figure 1 *Offset distribution plots (left panels) and crossline gap analysis (right panels) for very dense seismic acquisition solutions: 8 x 6 m WPS (a and c), and 10 x 5 m WHS (b and d).*

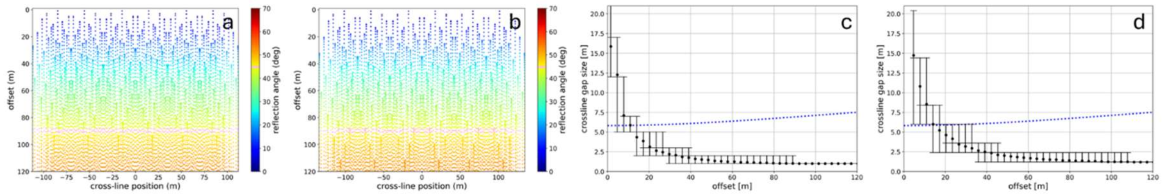

Figure 2 *Offset distribution plots (left panels) and crossline gap analysis (right panels) for more efficient acquisition solutions: 14 x 10 m WPS (a and c), and 14 x 12 m WPS (b and d).*

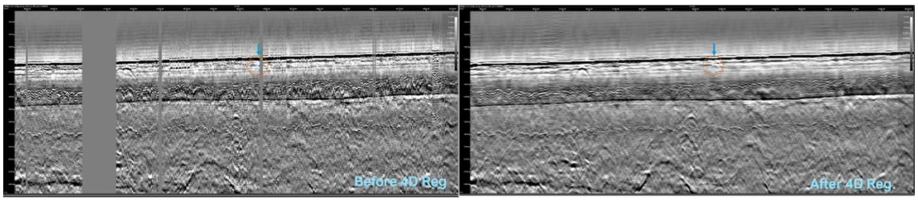

Figure 3 *Very near offset stack from 8 x 6m WPS before (left) and after (right) regularization.*

sampling, and a smaller minimum offset. Crossline gap analysis shows that Option 1 will likely deliver better image quality (see Figures 2c and 2d). The more efficient configurations are designed to meet slightly relaxed resolution requirements compared to the denser configurations, indicated by the approx. 6 m Fresnel radius at 1000 Hz for 45 m water depth.

Comparing the average gap size curves for all four configurations illustrates their clear difference for near offset coverage. Nevertheless, each configuration remains well-suited for its intended survey objectives. Well-designed configurations that ensure adequate target sampling in relation to physical constraints (Fresnel zone sizes) facilitate effective reconstruction of data in near-offset gaps during processing. This is illustrated in Figure 3, which shows a near-offset example with well-interpolated results. The data was acquired with the 8 x 6 m WPS configuration described above.

Conclusions

Wide-tow multi-source solutions even out near-offset sampling and enable fit-for-purpose image quality and more cost-effective acquisition. Site characterization surveys for offshore wind focus on the shallow subsurface from the seabed to about 100 m below, often in very shallow water environments. Meeting Fresnel zone-based sampling criteria in a cost-effective way is challenging. We have outlined how modern ultra-high resolution 3D seismic solutions for offshore wind can be designed to meet sampling and resolution requirements with high acquisition efficiency.

References

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