A novel marine survey configuration for the Sarawak Basin: Combining a wide-tow triple source with a non-uniform streamer spread

Martin Widmaier, Carine Roalkvam, Okwudili Orji, and Ashish Misra, PGS*

Summary

New and innovative survey design solutions for marine towed streamer acquisition were recently introduced by Widmaier *et al*. (2019). One of the key technical elements was the concept of wide-tow multi-sources, i.e., the distribution of multiple sources along the front of a streamer spread. All the wide-tow source case studies acquired in recent years have made use of uniform multi-source and multi-streamer spreads (i.e., regular streamer and source separations), thus following the same industry standards as in marine seismic surveys with the typical narrow source configurations. However, uniform configurations may not always be feasible or optimal due to operational or geophysical constraints. In this article, we revisit the basics of the wide-tow multi-source method and make the step from a uniform to a non-uniform design. The first seismic survey using this novel method has recently been acquired in a challenging area offshore Malaysia.

Introduction

Marine towed streamer survey designs with novel source and streamer geometries were launched in commercial projects only a few years ago. The concepts were described in publications by Widmaier *et al*. (2017) and Widmaier *et al*. (2019). A main technical element was the introduction of wide multi-source spreads, i.e., the distribution of multiple sources along the front of the streamers. The wider tow of multi-sources was introduced as a smart alternative to the traditional marine survey design method of reducing the streamer spread width. The latter is commonly used to decrease the distance between the sources and the outermost streamers and improves near-offset coverage. A narrower streamer spread means also a reduced sail line separation, and thus lowers turnaround and increases cost. Widmaier *et al*. (2020) presented a series of case studies that illustrated how wide-tow sources enabled higher streamer counts, and thus higher survey efficiency, without comprising the near offset coverage.

The wide-tow multi-source projects acquired until recently have all made use of uniform multi-source and multi-streamer spreads. This means that streamers as well as sources were configured with regular spacing and followed the same industry standards as applied in seismic surveys with narrow source geometries. However, uniform configurations may not always be feasible or optimal due to operational or geophysical constraints. In the following section, we revisit survey design fundamentals of both the standard narrow source geometry and of the alternative wide-tow multi-source method. We then make the step from a uniform to a non-uniform design with a survey recently acquired in the Sarawak Basin offshore Malaysia as the first case study example.

Best practice survey design for wide-tow multi-sources

Seismic sources have traditionally been towed in front of the two innermost streamers of a streamer spread. The standard source separation for a towed streamer survey is commonly defined by dividing the streamer separation L by the number of sources S. A typical example with a triple source and a 12 x 75m streamer spread is shown in Figure 1A and the key parameters are given in Table 1. The sail line separation or the size of the areal common midpoint (CMP) coverage per sail line is usually defined as a function of the streamer spread, i.e., 0.5*number of streamers*streamer separation. The areal CMP coverage per sail line is sometimes referred to as the 'CMP-brush'.

A wide-tow source separation is typically an integer multiple n of the standard source separation. Note that some values of n need to be excluded to ensure uniform 3-D CMP coverage. E.g., the rule $n \neq S$ keeps the wide-tow source separation from equaling the streamer separation. This combination would generate duplicate fold for some CMP lines and lead to zero-fold for others. Wider tow of sources extends the areal CMP coverage per sail line, i.e., the 'CMP-brush' becomes wider. However, the number of CMP lines or sublines acquired per sail line is equal to the product of the number of sources S and the number of streamers N. Thus, the wider 'CMP brush' that results from a wider source separation is the result of partially sparser spatial sampling in crossline direction, and not from acquiring additional data. Figure 1B shows a 12-streamer spread with a wide-tow triple source with a source separation factor $n=4$. The source separation increases from 25m for the standard triple source (example A) to 100m for the wide-tow triple source (example B). This is an increase of 75m between each source (see Table 1). With the increased 'CMP brush' generated by the wide-tow triple source, one may consider increasing the sail line separation by 75m from 450m (example A) to 525m (example B) without increasing the streamer count. The efficiency increase comes however at a cost. As predicted above, the CMP coverage modelled for example B (Figure 2B) shows CMP lines with zero-fold.

A sail line separation of 525m is the natural separation of a 14 x75m streamer configuration. Adding the two "missing" streamers to example B results in the configuration shown in Figure 1C and a uniform CMP coverage without gaps

10.1190/image2022-3748986.1

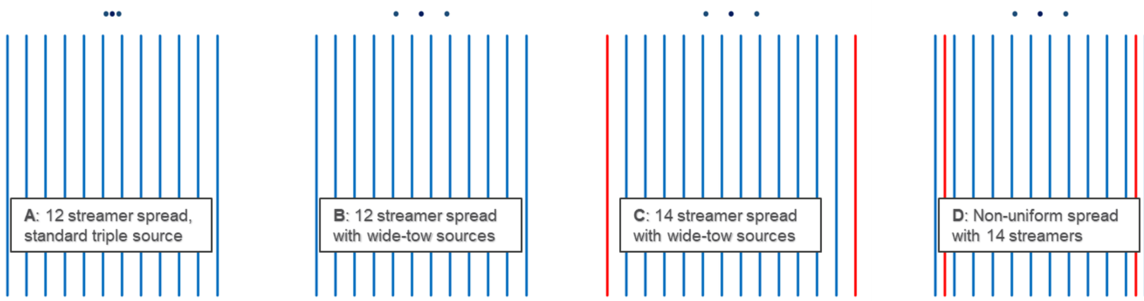

Figure 1 *Illustrations of the 4 triple source acquisition configurations as summarized in Table 1. The additional streamers (highlighted red) can either be added in the standard way to extend the spread-width (C) or can be interleaved resulting in a non-uniform streamer spread (D).*

configuration example	description of configuration	number of streamers N	streamer sep. L [m]	number of sources S	sail line separation [m]	source sep. scalar n	source separation [m]	total source spread width [m]	normalized efficiency (sailline separation)
A	12x75m streamer spread, standard triple source	12	75	3	450	1	25	50	100%
B	12x75m streamer spread, wide-tow triple source	12	75	3	525*	4	100	200	117%
C	14x75m streamer spread, wide-tow triple source	14	75	3	525	4	100	200	117%
D	12(+2)x75m non-uniform spread, wide-tow source	14	75	3	525	4	100	200	117%

Table 1 *Description of the configurations A, B, C, and D as shown in Figure 1. The nominal CMP line spacing for all examples is 12.5m. *) Note that the sail line separation in B is based on 14 streamers while the streamer spread comprises 12 streamers only. Consequently, B generates a coverage with empty CMP lines as shown in Figure 2B.*

(Figure 2C). The uniform CMP coverage is possible, as the 'CMP brushes' generated by example C overlap in a complementary manner for adjacent sail lines. Overlapping 'CMP brushes' do not occur for traditional configurations as represented by example A.

In summary, it is best practice to plan and acquire towed streamer surveys with uniform coverage and regular spatial sampling. When combining standard streamer spreads with wide-tow sources, regular sampling can be achieved by means of overlapping the 'CMP brushes'. More detailed introductions to wide-tow multi-sources can be found in publications by Widmaier *et al*. (2019), Widmaier *et al*. (2017), and Long (2017).

Non-uniform geometries with wide-tow multi-sources

Wide-tow multi-source configurations and wide streamer geometries can bring new challenges and in certain scenarios may require solutions alternative to the best practice approach. E.g., the maximum achievable towing width on both the source and receiver side is typically constrained by a seismic vessel's towing capacity or its deflector size. In shallow water, the length of the umbilicals and lead-ins can be a limiting factor as these define the deepest point in a towing configuration. In some environments, steering for coverage with overlapping 'CMP brushes' may be challenging. In special cases, it may also be desired to limit the crossline distance between the sources and the outermost streamers. We have developed a method based on non-uniform source and/or streamer separations which can overcome such challenges. Spreads with non-uniform streamer separations have been used in the past like for example in compressive sensing-based marine survey designs (Mosher *et al*., 2017), or in a Fresnel zone-driven configuration with increased streamer separations for outer streamers (Hager *et al*., 2015). The method introduced here mainly relies on geometrical considerations. Streamers (or sources, or both streamers and sources) are re-arranged from a uniform configuration to a configuration with non-uniform separations while aiming for the same nominally uniform or close-to-uniform 3-D coverage and without sacrificing efficiency relative to the best practice solution.

As an alternative to extending the streamer spread from 12 to 14 streamers in the standard way (Figure 1C), the additional two streamers can also be interleaved as illustrated in Figure 1D. The resulting non-uniform configuration with 14 streamers has the same physical spread width (i.e., the distance between the two outermost streamers) as the 12-streamer configurations shown in Figure 1A and 1B. The corresponding 3-D coverage is shown in Figure 2D. While the nominal crossline sampling achieved is not strictly uniform when compared to coverage for the standard 14-streamer solution (Figure 2C), one can observe that it is close-to-uniform and provides good crossline sampling for all practical purposes. Figure 2D also shows that the "CMP brushes" from adjacent sail lines do not overlap as in the best practice wide-tow source acquisition approach (Figure 2C). Note that the example discussed here is a straightforward and pragmatic implementation of a non-uniform streamer configuration, but many permutations are possible including non-uniform

10.1190/image2022-3748986.1

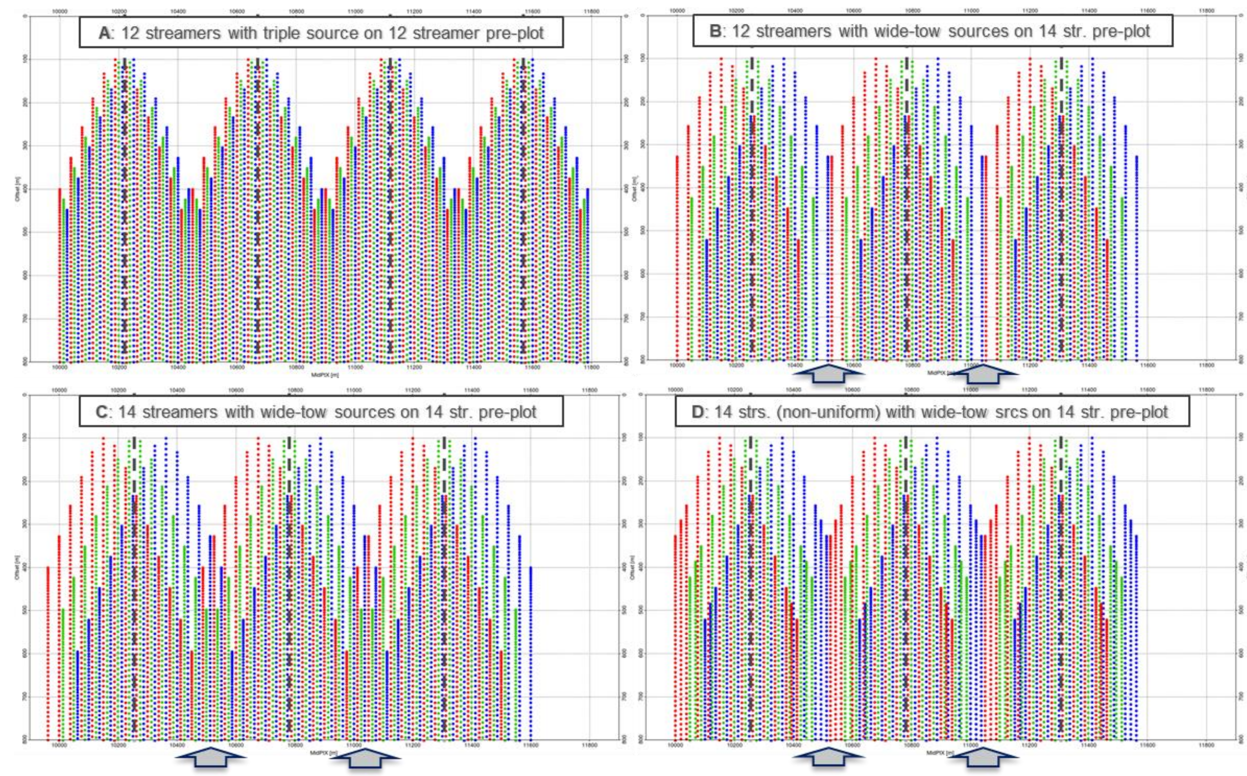

Figure 2 *CMP coverage comparison for the 4 acquisition scenarios described in Table 1 and Figure 1. The x-axis is crossline direction, and the y-axis is offset. The black dashed lines represent the sail lines. The colour coding (red, green, blue) of the CMP lines identifies the source that populates the subline. Example A is based on a 12-streamer pre-plot. Examples B, C, and D are based on a 14-streamer pre-plot which provides 17% higher efficiency. The grey arrows point to the sail line boundaries for the 14 streamer pre-plots. The differences in the coverage provided by configurations B, C, and D for this zone can be observed.*

source spacing. The more sources and streamers are available, the larger the solution space for the non-uniform alternatives becomes.

Case study from Sarawak Basin offshore Malaysia

The new concept of combining wide-tow multi-sources with a non-uniform streamer separation was deployed for the first time in a seismic exploration project in the Sarawak Basin offshore Malaysia. The survey area has relatively shallow secondary targets that benefit from denser sampling of the near offsets. Wide-tow multi-source solutions can deliver an improved near offset coverage without compromising efficiency and turnaround (e.g., Widmaier *et al*., 2021). The survey area is divided in two polygons with one in moderate to shallow water depths and one in very shallow water (20m). Pre-survey planning and risk assessments for the very shallow polygon concluded that wide-tow sources and streamer spread widths beyond 12 x 93.75m would operationally not be feasible. To maximize efficiency and to avoid a reconfiguration between the two polygons, the 12-streamer spread has been complemented by 2 “interleaved” streamers as explained conceptually in Figure 1D. Note that interleaving the 2 streamers has not increased the spread width beyond operational feasibility. However, combined with wide-tow sources the 12 + 2 configuration enables acquisition on a 14-streamer pre-plot in the polygon with moderate water depth. The reconfiguration effort between the polygons is reduced to a source-side modification from a wide-tow to a standard narrow triple source configuration. As acquisition in the very shallow area is done with a standard triple source, the corresponding pre-plot is based on 12 streamers only with the interleaved streamers being redundant in a nominal sense. The acquisition of this unique survey combining a wide-tow triple source with irregular streamer spacing has recently been completed by Ramform Sovereign. Figure 3 shows the novel source and streamer configuration just after deployment and the seismic vessel literately getting ready for the first acquisition sequence of the survey.

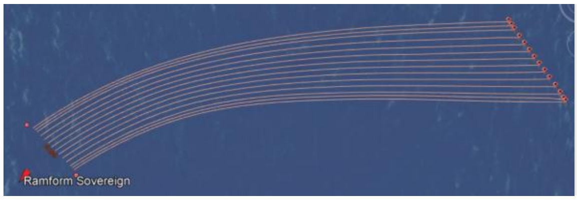

Figure 3 *The Google Earth snapshot shows Ramform Sovereign preparing for the acquisition start in the Sarawak Basin/Malaysia. The streamer spread is non-uniform and consists of a 12 x 93.75m spread plus 2 interleaved streamers. The source separation is 125m and the total source spread width is 250m.*

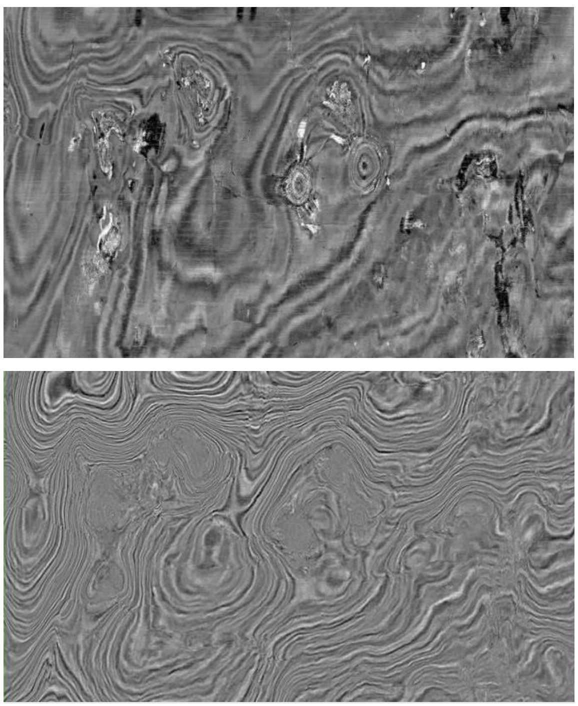

Figure 4 *Time slices (top: 500ms TWT; bottom TWT: 1500ms) from a near trace QC stack as generated onboard the seismic vessel while acquiring with a configuration comprising a wide-tow triple source and a non-uniform streamer spread as shown in figure 3.*

Onboard QC and preliminary processing

The non-standard vessel configuration shown in figure 3 was thoroughly assessed and de-risked related to geophysical sampling, 3-D coverage, and image quality at survey planning stage by seismic modelling and infill prediction. Nevertheless, onboard geophysicist and navigators have given special focus to monitor coverage and seismic integrity during the survey to spot any artifacts potentially caused by operating with this new and non-uniform configuration. Although many lessons were learned and new experiences gained during the survey, no showstoppers were identified. E.g., the near offset quality-control (QC) stacks that were generated during the survey resulted in brute seismic images of good quality with only mild hints of geometry related acquisition footprints typical for the shallow overburden. Time slices from the near offset QC stacks at 500ms and 1500ms two-way traveltime (TWT) are shown in figure 4.

Processing of the seismic data has only just started. Pre-processing workflows for wide-tow multi-source data include a regularization process which benefits from the improved near offset sampling. The regularization will mitigate remaining acquisition footprints and compensate for the slightly irregular spatial sampling as predicted in Figure 4D.

Conclusions

The wide-tow multi-source method has gained a lot of attention in recent years as it enables higher streamer counts, and thus higher survey efficiency, without comprising the near offset coverage. So far it has been standard industry practice to design and acquire wide-tow multi-source surveys with regular source and streamer separations. In certain scenarios, e.g., in the presence of either operational or geophysical constraints, the combination of wide-tow sources with non-uniform streamer configurations may be an interesting alternative. If optimally designed, this new approach can deliver uniform or close-to uniform sampling and matches the efficiency of the equivalent best practice solution. The first seismic survey using this novel method was designed for a challenging area offshore Malaysia. The corresponding seismic acquisition has been completed earlier this year. The processing of the seismic data is ongoing.

This case study represents a pragmatic combination of a wide-tow triple source with a non-uniform streamer configuration. Many other permutations are possible also comprising non-uniform source spacing. The more sources and streamers are available, the larger the solution space for the non-uniform alternatives becomes.

Acknowledgements

We thank PGS for the permission to present this work. Special thanks to the crew of Ramform Sovereign as well as our colleagues in Operations and R&D who made this novel acquisition configuration possible. The survey has recently been acquired in the Sarawak Basin on behalf of a seismic consortium comprising PGS, TGS and Schlumberger (WesternGeco); with exclusive multi-client rights awarded and approved by Petronas MPM.

10.1190/image2022-3748986.1

REFERENCES

Hager, E., M. Rocke, and P. Fontana, 2015, Efficient multi-source and multi-streamer configuration for dense cross-line sampling: 85th Annual International Meeting, SEG, Expanded Abstracts, 100–104, doi: https://doi.org/10.1190/segam2015-5857262.1.

Long, A., 2017, Source and streamer towing strategies for improved efficiency, spatial sampling, and near-offset coverage: First Break, **35**, 71–74, doi: https://doi.org/10.3997/1365-2397.35.6.89459.

Mosher, C., C. Li, F. Janiszewski, L. Williams, T. Carey, and Y. Ji, 2017, Operational deployment of compressive sensing systems for seismic data acquisition: The Leading Edge, **36**, 661–669, doi: https://doi.org/10.1190/tle36080661.1.

Widmaier, M., D. O'Dowd, and C. Delarue, 2017, Strategies for high-resolution towed-streamer acquisition and imaging of shallow targets: 87th Annual International Meeting, SEG, Expanded Abstracts, 186–190, doi: https://doi.org/10.1190/segam2017-17783497.1.

Widmaier, M., D. O'Dowd, and C. Roalkvam, 2019, Redefining marine towed-streamer acquisition: First Break, **37**, 57–62, doi: https://doi.org/10.3997/1365-2397.2019035.

Widmaier, M., R. Tønnessen, J. Oukili, and C. Roalkvam, 2020, Recent advances with wide-tow multi-sources in marine seismic streamer acquisition and imaging: First Break, **38**, 75–79, doi: https://doi.org/10.3997/1365-2397.fb2020093.

Widmaier, M., C. Roalkvam, O. Orji, and A. Misra, 2021, Maximizing quality and efficiency with wide-tow multi-source configurations: First Break, **39**, 75–80, doi: https://doi.org/10.3997/1365-2397.fb2021086.