Exploring the Benefits of Streamer Overlap Shooting for 3D and 4D Seismic Surveys

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Summary

The goal of any time lapse 3D (4D) seismic survey is to detect the changes in the reservoir (pressure, fluid saturation, movement of fluid contacts, temperature etc.) due to production effects on the reservoir state. It is therefore essential to minimise differences in the seismic data due to acquisition and processing differences, environmental differences etc. One of the key factors in minimising differences between successive 4D surveys is the ability to record traces with identical source-receiver azimuths for both base and monitor surveys (i.e. with high repeatability). We will show that an extremely high degree of repeatability is possible by acquiring overlapping coverage between adjacent sail lines. We will also consider the benefits of overlap shooting in minimising primary and/or secondary infill requirements.

Introduction

Streamer overlap is a robust method to maximize the repeatability of azimuths at sail line boundaries for timelapse 3D (4D) applications. It is most effectively applied when the vessel is sailed along the pre-plotted sail line track.

It is typically observed that overlap shooting has a simultaneous benefit of reducing primary infill requirements. A question naturally arises regarding the potential suitability of streamer overlap shooting in exploration or appraisal 3D surveys to reduce infill shooting requirements, and the following discussions address the applicability of streamer overlap shooting for both 4D and infill objectives. Note that "primary infill" refers to additional vessel passes to the planned sail lines which are acquired during the "prime" acquisition phase, and "secondary infill" refers to additional sail lines to fill in remaining coverage holes acquired after the "prime" acquisition phase.

Streamer Overlap Fundamentals

Any streamer spread will have a nominal sail line separation equivalent to 0.5 x no. of streamers x streamer separation in metres. Streamer overlap involves additional streamers being towed but with the same nominal sail line separation, providing additional CMP traces in a broad zone along each sail line boundary (Figure 1). Typical overlap configurations are one or two streamers, e.g. 10 or 12 streamers on an 8 streamer pre-plot.

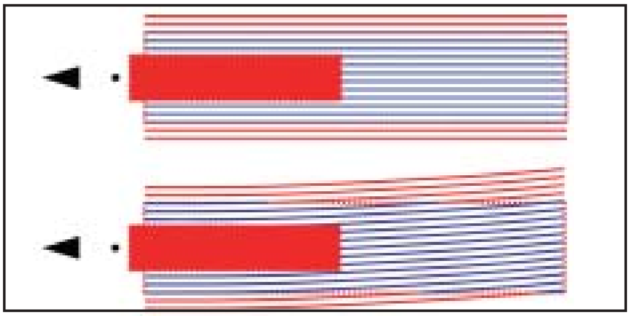

Fig. 1: Demonstration of CMP binning with streamer overlap. The "live" area of CMP bins populated during acquisition is highlighted in solid red. For zero feathering the "excess" overlap streamers are plotted in red also. In the event of streamer feathering the overlapping streamers contribute to CMP binning, as seen in the lower part of the figure.

These additional streamers contribute to the 'live' CMP coverage only when currents cause a lateral deviation of the streamer spread (known as feathering). In this case the additional streamers move across to the undisturbed position of the 'prime' streamers, ensuring the same CMP coverage as was the case without feathering. When there is no feathering these additional traces do not contribute to the 'live' coverage, and are removed in data processing.

The additional CMP coverage provided by this overlap has the benefits of:

- Minimising the requirement to reduce the nominal sail line separation in order to maintain acceptable CMP coverage.

In other words, overlap shooting reduces the primary infill requirements in the case of variable streamer feathering between adjacent sail lines.
- Maximising 4D repeatability; in conjunction with appropriate acquisition & processing strategies, by ensuring azimuthal repeatability between traces from base and monitor surveys.
- Optimising cross-line data processing operations such as 3D interpolation, 3D regularisation, and 3D SRME.

Acquisition of data using streamer overlap (typically in 4D mode) is clearly most effective when many streamers can be deployed; the more streamers that can be towed, the lower the cost and the greater the flexibility.

Application of Streamer Overlap Shooting to 4D Surveys

It has been demonstrated (Widmaier et al, 2003) that a successful strategy for marine 4D acquisition comprises:

1. Shot point repetition,
2. Streamer overlap shooting,
3. Dense streamer configurations, and
4. An appropriate CMP binning strategy in data processing.

A recent 4D survey acquired by PGS is a compelling example of this 4D acquisition strategy yielding outstanding source-receiver azimuth repeatability (Figure 2). Consequently, the acquisition imprint on the 4D signal was minimised.

Streamer Overlap Strategy for Reduced Infill

Intuitively, overlapping streamers to minimise coverage holes between adjacent vessel passes should also reduce infill in many instances. However, is this really the case? There are essentially two approaches to steering the vessel during acquisition:

1. Steer the vessel along the pre-plotted sail lines, using a sail line separation corresponding to the nominal number of streamers.

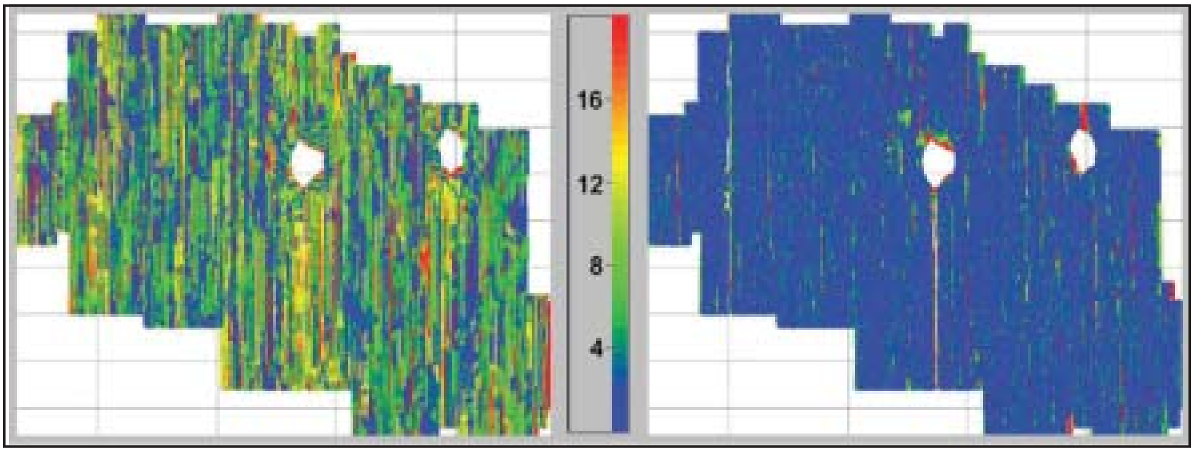

Fig. 2: Source-receiver azimuth difference plots between t_0 and t_1 4D surveys (left), and between the t_1 survey and a subsequent HD3D- 4D t_2 survey (right). The colour maps display azimuth differences from 0 (blue) to 20 (red) degrees. Data courtesy of Shell E&P

For example, if the nominal streamer configuration is 8 streamers at 100m separation, and 2 additional streamers in overlap mode are to be used (i.e. 10 streamers towed on an 8 streamer pre-plot), the sail line separation will be 400m. As introduced earlier, this approach is strongly recommended for 4D acquisition, as shot point repetition is the first component of a successful 4D acquisition strategy. This is also the easiest approach operationally.

Unacceptable holes in coverage are recovered by secondary infill, i.e. by acquiring additional lines to fill the coverage holes. PGS global experience consistently. These additional streamers contribute to the 'live' CMP coverage only when currents cause a lateral deviation of the streamer spread (known as feathering). In this case the additional streamers move across to the undisturbed position of the 'prime' streamers, ensuring the same CMP coverage as was the case without feathering. When there is no feathering these additional traces do not contribute to the 'live' coverage, and are removed in data processing.

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Unacceptable holes in coverage are recovered by secondary infill, i.e. by acquiring additional lines to fill the coverage holes. PGS global experience consistently demonstrates that this approach typically yields low infill rates, however in areas with extremely variable currents (and therefore streamer feather), significant amounts of secondary infill may still be required.

A key issue that arises are the criteria used to establish the nominal sail line separation; and if there is no geophysical constraint upon the maximum acceptable sail line separation, the largest separation (and streamer spread width) should clearly be pursued in the name of optimum efficiency and reduced cost.

2. Steer the vessel for CMP coverage based upon the nominal streamer configuration.

Take again the example of a nominal streamer configuration with 8 streamers at 100 m separation, plus 2 additional streamers in overlap mode. If overlap shooting is being considered in the pursuit only of reduced infill, then a question arises: Why not use the additional streamers for acquisition with 500 m nominal sail line separation and no streamer overlap? It is quite likely that about 20% extra survey efficiency would be obtained using 10 streamers instead of 8. However if there is a geophysical limit of 400 m maximum sail line separation, then a possible case for overlap shooting arises – if a vessel capable of towing a 900 m wide streamer spread is available. We must then consider whether the resulting decrease in infill justifies the operational effort of deploying the additional streamers.

If a vessel is steered for ‘conventional’ CMP-based coverage, how should the additional overlapping streamers be used? Is it likely in our 10 streamer example that the trace contributions from the two outer streamers will be duplicates and largely rejected in processing? In this case, does the additional effort of towing two additional streamers have a detrimental overall effect upon survey efficiency and cost?

After the completion of the first sail line in the survey, there will be a strip of CMP coverage computed using the navigation-based positions of all 10 streamers. What is the value of the outer 2 streamers? One possible approach is to steer for coverage using all streamers, but using real-time binning to reject coverage that falls outside geophysically determined cross-line offset limits. However the 2 overlap streamers will result in more regular CMP coverage along the sail line seam, and consequently the trajectory of the 2nd sail line can be steered a larger distance from the 1st sail line than would be the case if the overlap streamers were not used. This system is then repeated for all remaining sail lines required to complete the total 3D survey area. The net benefit is that the overlap streamers result in fewer total sail lines being required to complete the survey, and the total infill percentage is less (refer to Figures 3 and 4). How much less is not easily quantified prior to the survey, and a risk and operations analysis must be uniquely applied to each new survey location.

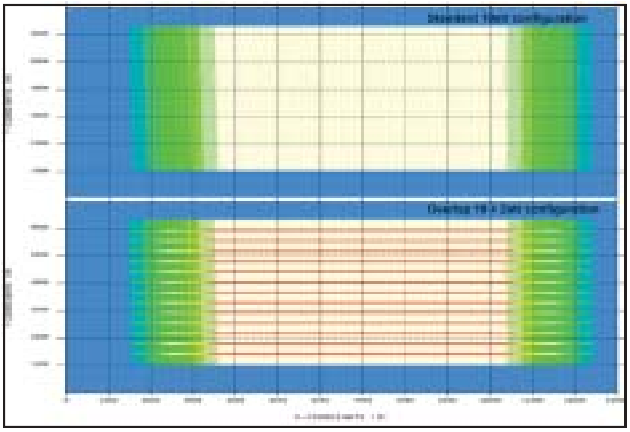

Fig. 3: Pre-plot navigation data analysis of streamer overlap shooting for a 10 streamer configuration applied to a 10 streamer pre-plot with no feathering (upper), and a 12 streamer configuration applied to a 10 streamer pre-plot with no feathering (lower). The bands of excess CMP coverage in the lower part of the figure correspond to the streamer overlap zone at each sail line boundary. These excess traces would contribute nothing to infill rates in this scenario if there was no feathering variability between sail lines.

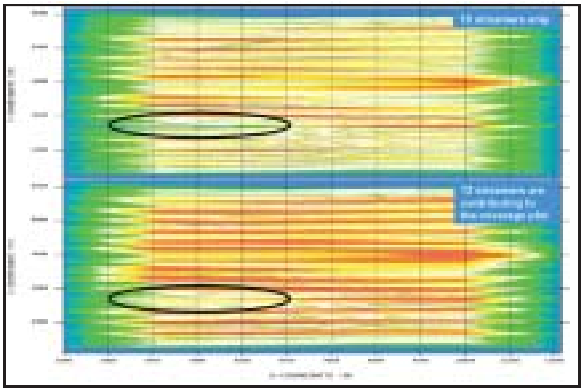

Fig. 4: Real navigation data analysis of the actual CMP coverage for the two streamer scenarios in Figure 3. A large hole in CMP coverage along a sail line boundary (circled) is recovered by the use of the overlap streamers; however, the duplicate CMP coverage everywhere else is of no value to reduced infill! Note that the "red" zones of excess CMP coverage must have duplicate trace rejection applied in processing prior to the pre-stack imaging step. There is more incentive to increase sail line separation in the pursuit of increased efficiency in this case, rather than use the overlapping two streamers to reduce infill.

As a general case, the availability of a vessel with the capacity for towing high streamer counts will typically encourage the pursuit of the largest practical streamer spread (and sail line separation) in the name of higher efficiency, unless a credible geophysical constraint upon sail line separation can be made. In that case, streamer overlap may be a cost-effective way to reduce primary infill, and may provide a useful platform for certain highend processing algorithms.

Steering by CMP coverage in both non-overlap ('conventional') and overlap mode is more demanding in terms of onboard QC than simply steering by the preplotted sail lines (option 1 above).

Conclusions

Unless a strict geophysical criterion such as the pursuit of 4D source-receiver repeatability, or an upper threshold upon maximum streamer spread width is being applied, it will generally be the case that the maximum logistically practical streamer spread should be used in acquisition – without streamer overlap shooting. Streamer overlap shooting is a fundamental requirement for 4D applications, and is increasingly beneficial to high-end processing steps such as 3D SRME and 3D data regularisation schemes. However in specific cases where operational and risk factors are known, it can be demonstrated that streamer overlap can reduce primary and/or secondary infill requirements.

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