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Triple-Source Simultaneous Shooting (TS3), A Future for Higher Density Seismic?

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SUMMARY

The use of triple-sources in marine seismic streamer acquisition has been tested in the past, but with no significant commercial success compared to dual-source acquisition. With the introduction of new and better low noise streamers, in addition to the ability to record and deblend simultaneous source data, it is time to revisit the use of triple-sources in marine seismic exploration for decreased crossline bin-size leading to better spatial resolution. The data from the triple-source configuration flip-flop-flap sequential firing mode, is similar in quality compared to flip-flop conventional dual-source acquisition mode. When firing off the triple-sources in simultaneous mode, giving reduced shot-point interval, the results appear to be better than for dual-source flip-flop mode mainly due to increased fold and less aliasing of pre-stack gathers. A triple-source configuration can find its application in shallow and deeper water areas for imaging of targets where reduced crossline spacing and higher fold may be required.

Introduction

The use of triple-sources in marine seismic streamer acquisition has been tested in the past, but with no significant commercial success compared to dual-source acquisition. The main hurdle was that the increased shot-point interval for each sub-surface line, when using three sources in sequential mode, did not favour a good signal-to-noise ratio due to decreased fold. However, with the introduction of new and better low noise streamers, in addition to the ability to record and deblend simultaneous source data, it is time to revisit the use of triple-sources in marine seismic exploration for decreased crossline bin-size leading to better spatial resolution.

The marine seismic business has since the introduction of multiple streamer acquisition strived to increase resolution and fill in the gaps between the streamers. In connection with exploration surveys the trade-off between being efficient and thereby reduce time and cost of a survey can sometimes push the resolution of the seismic data to the limit. The distance between sensors within a streamer is defined as a group interval of 12.5 m for most streamers available today. So, along the streamers, and in the shooting direction, the sampling is usually more than adequate when shot-point intervals can vary between 12.5m to 50m for different geophysical objectives. However, the sub-surface sampling between the streamers is usually a lot more sparse. Distance between streamers in commercial seismic exploration can vary from 50m and possibly up to the extreme case of 200m. In a standard configuration, two sources are usually fired sequentially in so-called flip-flop mode.

With a given number of streamers, the sub-surface line sampling between (crossline direction) is doubled by the use of two sources, but this will be at expense of the number of traces in each bin along the sub-lines (inline direction). This implies that the fold will be reduced for each sub-surface line when going from a single source, fired at let's say 25m, compared to 25m shot-point interval in flip-flop mode (50m between shot-points within each sub-surface line).
In order to increase the sampling, and thereby the resolution between the streamers, solutions of utilizing multiple sensors (geophones/accelerometers in addition to hydrophones) in towed streamers have been proposed (Robertsson *et al*., 2008 and Lu *et al*. 2011). These techniques, are based on wavefield reconstruction in the crossline direction and to utilize the surface-related multiples, respectively, for finer sampling between the streamers, but require hardware solutions which are not presently available to all industry contractors.
The introduction of simultaneous sources in both ocean-bottom (Abma *et al*., 2012) and streamer acquisition (Beasley *et al*., 1998 and 2012) has been motivated by a desire for more efficient acquisition, increased sub-surface spatial sampling and increased fold, which will again lead to increased signal-to-noise ratio of a given dataset.

Finer crossline sampling with conventional streamers can be achieved either by reducing separation between the streamers, or by additional seismic sources. A test of configuring a dual-source into a triple-source setup was performed during a commercial multi-client exploration survey. The main purposes were to operationally test the configuration, investigate how easy it would be to split and operate available sub-arrays in three seismic sources, in addition to analyse the acquired data for quality and compare the triple-source data to the base case data acquired in conventional dual-source mode.

Test overview and acquisition

The data was acquired in June 2014 during the TGS West of Shetland acquisition campaign. The main acquisition parameters were, 12 streamers of 6km length, with a slant tow between 12m–30m depth, separation of 100m. The source size was 3480 cu.in. in dual-source mode (flip-flop) at depth of 7m and separation of 50m between centre source. Shot-point interval was 18.75m during the base case survey. Continuous recording was used during the acquisition campaign. The water depth at the test area varied between 700m-800m. Table 1 summarizes the different test sequences. When going from a dual-source to a triple-source setup the natural crossline bin size will decrease.

The base case acquisition was a line from the standard survey (Sequence 69). Thereafter, the dual-source configuration of the six available sub-arrays was reconfigured into three sources where two sub-arrays formed one full source (Sequence 111). This lower the available volume of the sources to 2495 cu.in. for the port and starboard sources and to 1970 cu.in. for the centre source. The reason for not having three equal sources was due to limited test time available and operational constraints. Different total source volumes will not hamper the main purpose of the test of using three sources and firing these off in simultaneous mode. The first triple-source tests (Sequence 111) was to fire the sources in sequential flip-flop-flap mode, repeating a portion of the Sequence 69. When firing the sources in this mode, the shot-point interval was 12.5m. Thereafter, the approximate same line segment was repeated, firing the triple-sources in simultaneous mode using a time dither of +/- 300ms (Sequence 112).

Sequence	Type	Sim Ops	Source size [cu.in.]	SPI [m]	Record length at 4.5 knots	Natural Bin Size - Inline	Natural Bin Size - Crossline	Natuaral fold	Comments
69	Dual source, flip-flop	None	2 x 3480	18.75>37.5	8.1s	6.25m	25m	80	Conventional acquisition
111	Triple source, flip-flop-flap	None	2 x 2495, 1 x 1970	12.5>37.5	5.4s	6.25m	16.66m	80	Reduced crossline bin size
112	Triple source, flip+flop+flap	Dithered	2 x 2495, 1 x 1970	12.5>12.5	5.4s	6.25m	16.66m	240	Reduced crossline bin size, increased fold

Table 1 *Overview of different test sequences that are discussed in the triple-source test.*

Results and discussion

Since this initial test only allowed for single sail lines, not covering a full area for 3D imaging, the main analysis of the data is focused around the quality and similarity of gathers and stacks, hence, comparing the sail lines of triple-source data fired in flip-flop-flap and simultaneous source mode to the data from the same sail line when operating the sources in conventional dual-source flip-flop mode. An example of a brute stack from the same CDP's when firing the sources in flip-flop versus in flip-flop-flap mode is shown in Figure 1. The main difference which can be noted when comparing the spectra is due to the fact that there was a difference in source volumes, 3480 cu.in. for Sequence 69 and 2495 and 1970 cu.in. for Sequence 111. Since the shot point interval of Sequence 69 was 18.75m, this will give a shot-point interval of 37.5m (2 x 18.75m) for each sub-surface line, which will be the same for Sequence 111 sub-surface lines, where shot-point interval was 12.5m (3 x 12.5 m). As expected, we observe from Figure 1 that the stack responses are similar.

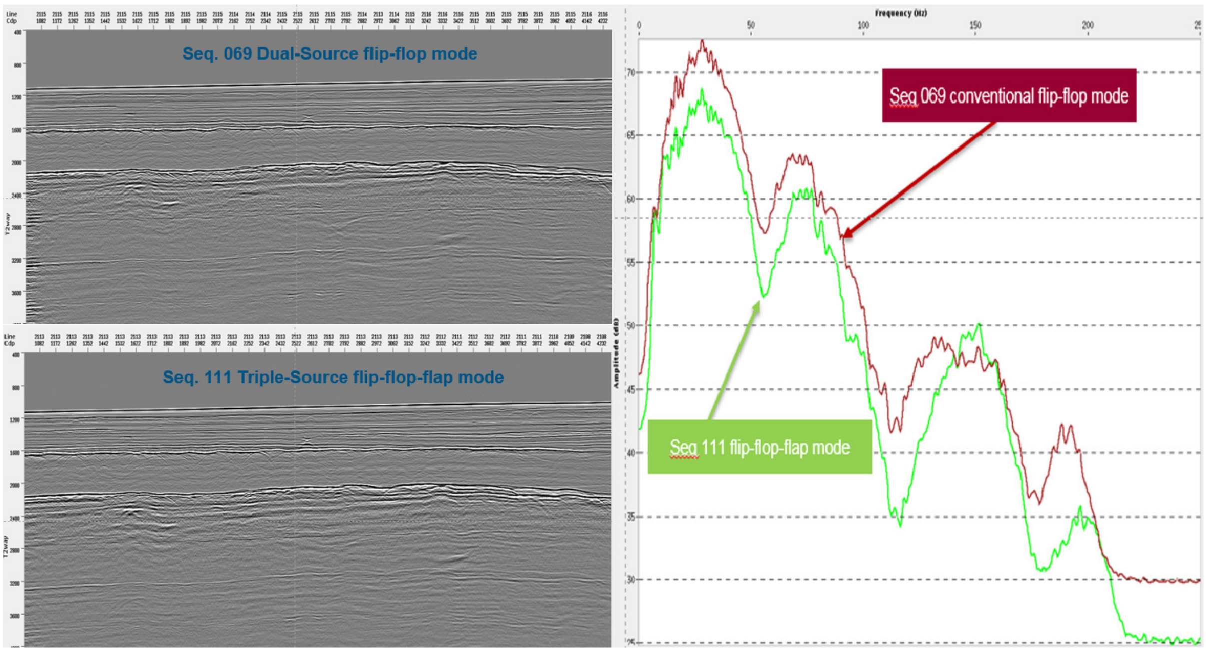

Figure 1 *Stacks from the conventional acquisition mode (Seq. 69, upper left) and the flip-flop-flap mode (Seq. 111, lower left) and the corresponding spectra (right). The difference in amplitude strength is due to the difference in source volumes, Seq. 69: 3480 cu.in. and Seq. 111: 2495 cu.in.*

Data from the Sequence 112 needed to be deblended. An enhanced adaptive subtraction (EAS) method was used to separate the data from this Sequence (Liu *et al*., 2014 and 2015). Figure 2 shows gathers from a CMP before and after EAS deblending method, the difference gather and for comparison the same gather from dual-source mode (sequence 69). Figure 3 shows stacks from Sequence 112, together with a stack from the dual-source sequence 69. One significant difference between the data is that when using triple-source, and firing in simultaneous mode, the fold is increased by a factor of 3, i.e. shot-point interval is 12.5m for each sub-line compared to 37.5m of the reference (Sequence 69). As observed, this will also reduce aliasing in the pre-stack data significantly.

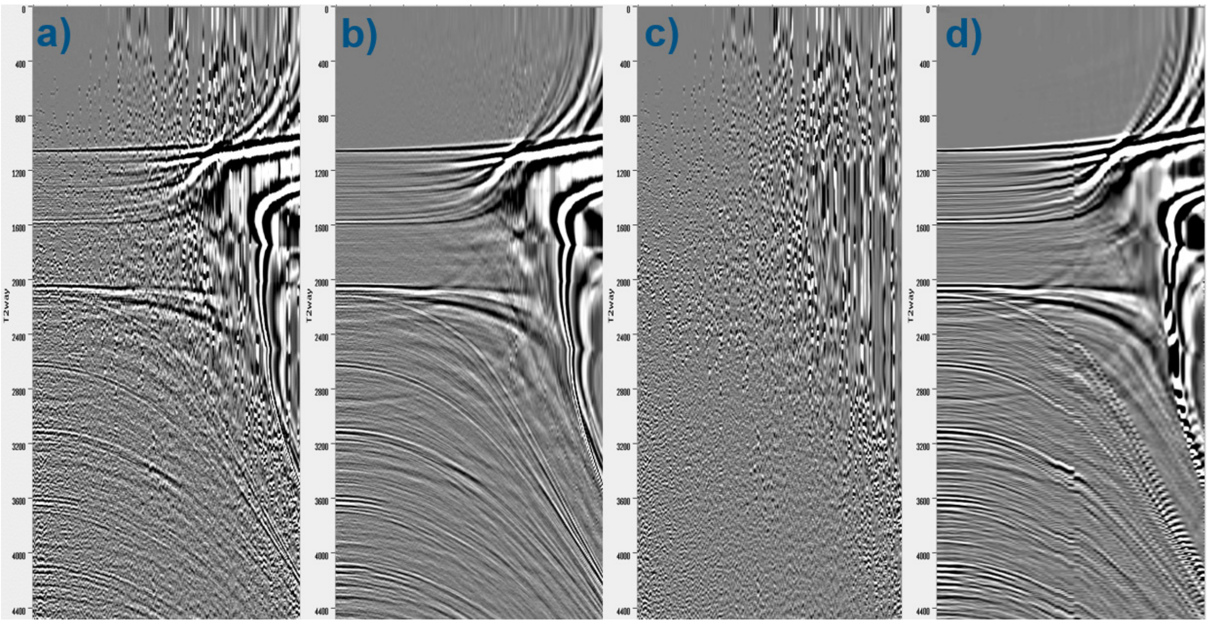

Figure 2 *a) CMP gather from triple-source test (Sequence 112) before deblending; b) after deblending; c) difference between a) and b); d) CMP gather from dual-source Sequence 69.*

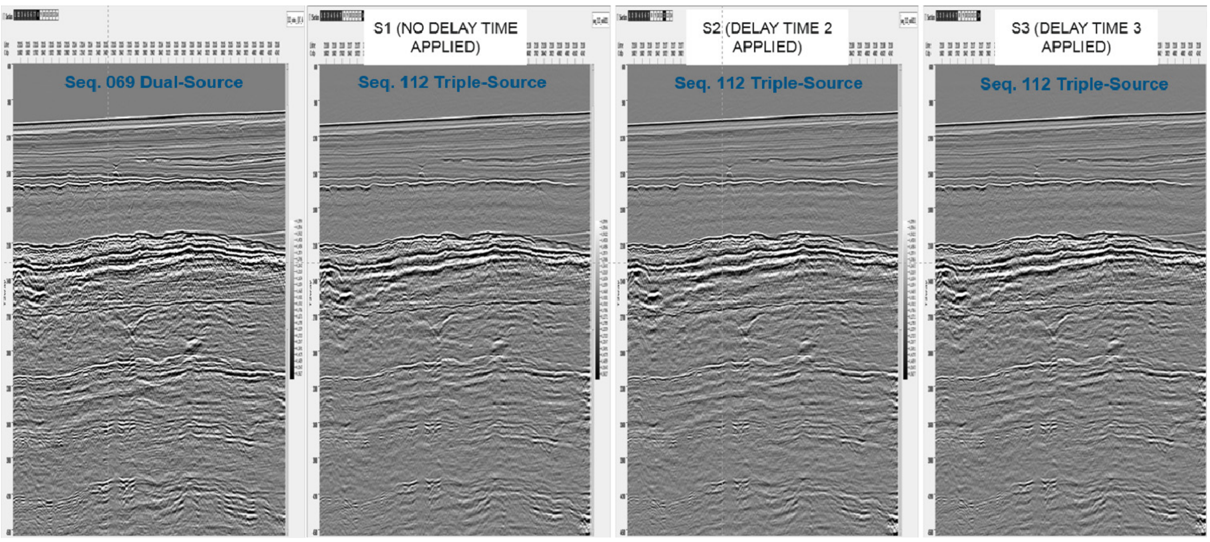

Figure 3 *Stack from subline 11 of dual-source (left, 3480 cu.in.) to be compared with deblended data from the triple-source simultaneous test, S1 (mid-left, 2495 cu.in.), S2 (mid-right, 1970 cu.in.) and S3 (right, 2495 cu.in.). The fold is 3 times higher for the triple-source simultaneous mode data.*

One difference between the dual-source (each with three sub-arrays) and the triple-source acquisition (each with two sub arrays), is that the total gun volume of the sources are different. However, for 3D streamer acquisition in shallow waters, when imaging shallow plays and targets, it should not be a problem to allow for a reduced source size and only two sub-arrays. Radiation pattern will of course be different for a three- versus two sub-array source, but this may not serve as a show stopper in connection with a narrow azimuth streamer survey. The advantage of having a significantly reduced shot-point interval, giving higher fold, in addition to reduced crossline bin spacing in 3D cubes, clearly outweighs the effect of reduced source strength. In preparation of future triple source acquisition, the sub-arrays can of course be balanced in size giving a total source volume of around 2000 cu.in. each. Most high-tech 3D streamer vessels available may be able to cope with such source volumes and have sufficient compressor capacity in charging all three sources ready for firing every 12.5 m even in simultaneous mode while keeping the pressure close to the standard of 2000 psi.

Conclusions

A test of using triple-source instead of dual-source in marine seismic streamer acquisition has been conducted. Ultimate goal for the triple-source configuration is to reduce the crossline bin-size when using conventional hydrophone streamers in a standard spread without reducing the streamer separation. The reconfiguration of the three sub-array dual-source into a two sub-array triple-source was straightforward. The data from the triple-source configuration flip-flop-flap sequential firing mode, is similar in quality compared to flip-flop conventional dual-source acquisition mode. When firing off the triple-sources in simultaneous mode, giving reduced shot-point interval, the results appear to be better than for dual-source flip-flop mode mainly due to increased fold, leading to reduced aliasing. A 3D survey of an area using a triple-source configuration (TS3) can deliver a higher density dataset, with increased inline and crossline sampling, especially in shallow water areas and for shallow targets and structures.

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