First full-azimuth towed-streamer survey offshore Brazil - An acquisition and survey design case study

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Abstract

In geologically complex areas, the limited azimuth range associated with single-vessel straight-line acquisition can result in the target reservoir being poorly and/or randomly illuminated by the deployed surface spread. While the source wavefront propagates in all directions, only a small proportion of the reflected wavefront is captured by the surface receiver spread.

Driven primarily by the need to improve subsalt illumination in the Gulf of Mexico, the industry experimented with a number of multivessel geometries; most recently, coil shooting has been deployed over a number of complex geologies worldwide. The first coil shooting survey offshore Brazil was recently acquired with the goal of improving the imaging of the pre-salt target reservoirs for an exploration project. Coil shooting is a technique in which a single towed-streamer vessel shoots a circular "line". This circular line is repeated inline and crossline to build up fold, offset, and azimuth distribution. This paper will present the survey design process and results, and additionally, present some of the challenges involved in planning and acquiring this unique geometry.

Introduction

Most seismic surveys are still acquired by single towed-streamer vessels sailing along straight lines. This type of acquisition geometry produces datasets with a very limited range of azimuths that could result in a poor illumination of the reservoir, particularly in geologically complex areas. In an effort to improve the illumination of the reservoir in these complex geologies, the industry has deployed new acquisition geometries including multiazimuth (MAZ) and wide-azimuth (WAZ) geometries. More recently still, coil shooting has been deployed to solve some very challenging imaging problems efficiently.

Coil shooting is a step forward in which a full range of azimuths are acquired by a single towed-streamer vessel sailing along a set of circles. The circles are geometrically arranged in the inline and crossline directions and continuously covered by the seismic vessel (Moldoveanu, 2008). The concept of circular shooting was originally proposed by French (1984). Two decades later, many of the challenges inherent in circular geometries were overcome with the introduction of the point-receiver acquisition system for noise cancellation and the streamer control system for improved cable positioning. Two coil shooting tests were performed in the Gulf of Mexico and in the Black Sea in 2007 before the commercial deployment of the technique offshore Indonesia in August, 2008 (Ross, 2008).

In early 2010, the operator was looking for an opportunity to evaluate the coil acquisition technique as a tool to improve imaging of subsalt targets. It was decided to implement the technology in a large ultra-deepwater oil and gas field located in the Santos basin. The signal-to-noise ratio at the reservoir level is very poor on existing seismic data from the area, with poor illumination resulting from a complex overburden including a complex top-salt horizon. In addition, strong surface and interbed multiple energy interfere with primary information at the reservoir level. These are the main geophysical challenges that led to adoption of the coil shooting technique in this field.

The survey was originally planned to cover the area indicated on Figure 5 (top left) but, due to the sudden arrival of a drilling rig on its central portion prior to the beginning of the seismic survey, the area was moved approximately 10 km towards the northeast around the location of a future well. The new survey area was carefully selected with the objective of using the full-azimuth seismic dataset to optimize the well drill planning.

Survey design and acquisition planning

During the planning phase of the seismic program, a survey design study was performed to evaluate the potential uplift of the coil acquisition solution and optimize the surface geometry.

The study consisted of 3D acoustic finite-difference modeling of several acquisition geometries. The coil geometry was compared to a full-azimuth areal geometry based on nodes and shots spaced by 400 m and 50 m, respectively, and two narrow-azimuth geometries with 16 streamers of 6 m and 8 km separated by 50 m. The modeling was followed by a processing effort that included a common-shot wave-equation migration. The study results indicated an improved signal-to-noise ratio, better attenuation of the multiple energy, and better continuity of the horizons in favor of the full-azimuth geometries. In addition, it was verified that the coil full-azimuth dataset benefits from a larger number of nearoffset traces than the areal geometry, and as a consequence, better multiple energy attenuation is expected from this dataset during the processing phase. A ray-tracing effort was also performed using the coil geometry to validate the design and assess improvements in reservoir illumination.

Based on the results of the study, it was decided to adopt an acquisition geometry with 78 circles of 6.25-km radius over a total area of 25 km x 25 km. In an effort to make the acquisition geometry slightly less regular, the coil centers were randomly distributed within a predefined tolerance (Moldoveanu, 2010). Two squares covering 15 km x 15 km and 2.5 km x 2.5 km were defined (Hill, 2009) for quality control purpose to identify the areas in which the seismic data would have at least 180° and 360° of azimuthal distribution (Figure 1).

The acquisition configuration was based on 10 streamers separated by 120 m towed at a depth of 12 m and two source arrays of 5085 in^3 spaced by 60 m deployed at a depth of 10 m (Table 1).

The survey was planned such that the sources towed by the vessel would follow a sequence of predefined sets of circles, also called coils or swaths. A swath is represented on Figure 5 by a line joining the centers of the predefined set of circles. The original design of the survey pre-plots was based on nine swaths (of around eight or nine circles) all oriented along the 0° or 180° directio ns.

Table 1: Survey parameters

Number of streamers	12
Streamer length	8000 m
Number of sources	2
Source size	5085 in^3
SP interval	37.5 m
Streamer depth	12 m
Streamer separation	120 m
Record length	12 s
Source depth	10 m

Data quality control

Based on experience acquired during the previous coil projects, a number of non-conventional acquisition QC products were generated by the seismic crew or by the acquisition supervisors based ashore.

A simple approach was put in place to generate the onboard brute stack sections in a way that the receivers and sources were regularly distributed along the planned circle of a 6.25-km radius. Higher levels of turn noise identified on the online shot gathers and brute stack sections indicated the need for an enhanced noise attenuation flow; this subject is covered in the last section of this paper (Figure 6).

The source and receiver positions were transferred ashore on a line-by-line basis to generate near-real-time source location plots, fold of coverage, and illumination maps. The real or post-plot source locations were assessed against the planned or pre-plot source positions on a daily basis (Figure 1).

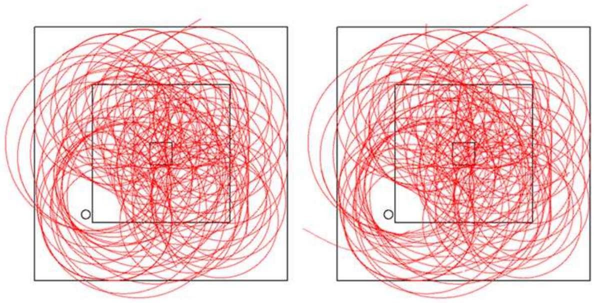

Fig. 1 - Source positions: planned (left) and actual (right). The planned source positions are based on the last pre-plot version. The external polygon represents the survey area boundary; the inner polygons represent the 180° and 360° azimuth areas. The drilling rig location is indicated by the black circle.

In addition to the total fold (Figure 2), it was decided to produce a set of offset-azimuth restricted fold of coverage plots. In a similar way, the real and modeled coverage plots were compared on a daily basis for QC purposes (Figure 3).

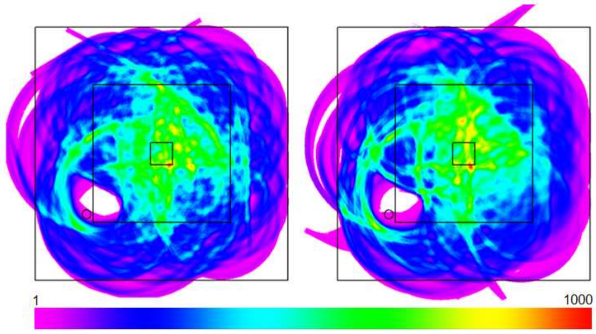

Fig. 2 - Total fold of coverage calculated on 25-m x 25-m bins: planned (left) and actual (right). The planned source positions are based on the last pre-plot version.

A number of ray-tracing analyses were performed as the acquisition progressed to assess the illumination on the selected target horizon. The analyses consisted of a direct comparison between the illumination achieved from the real and planned surface positions (Figure 4). This exercise was replicated by the operator's E&P office in Rio de Janeiro in an effort to confirm any decisions on potential infill requirements.

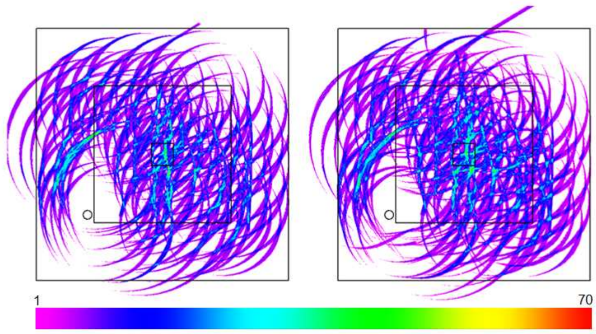

Fig. 3 - Azimuth-offset restricted fold of coverage (0°-60° plus reciprocal azimuth range, 750- to 1250-m offset range): planned (left) and actual (right). The planned source positions are based on the last pre-plot version.

In general, the coverage and illumination plots generated throughout the duration of the survey were very comparable with the ones resulting from the modeled geometry. Based on these QC plots, it was decided to modify the pre-plot geometry on a couple of occasions by adjusting the location and radius of a few planned circles because of the drilling rig on the southwestern side of the prospect area.

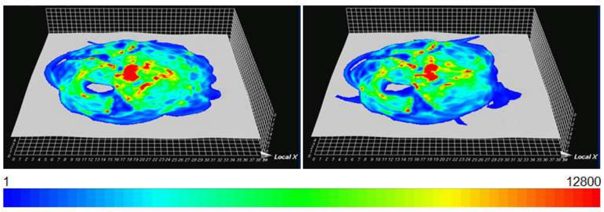

Fig. 4 - Target illumination map (hit count) calculated on 25-m x 25-m bins: planned (left) and actual (right). The planned source positions are based on the last pre-plot version.

Acquisition implementation and operational challenges

Acquisition started during the last week of November, 2010, and was expected to last 33 days. However, due to the combination of several operational factors (time share with another seismic program, fast barnacle infestation, and periods of very bad weather), the survey was extended by 30 days. The time spent in line changes accounted for only 13% of the shooting time, or 4% of the total duration of the survey. With conventional race-track acquisition of a survey this size, line changes often represent the largest portion of the survey duration. Table 2 summarizes the main operational statistics.

Another challenge experienced during vessel mobilization was the unexpected arrival of the drilling rig at the central portion of the original survey area. This sudden event required a very dynamic planning effort involving both operator and contracted parties that resulted in the adjustment of the survey area. As a consequence of this collaboration effort, the arrival of the rig resulted in no down time. However, the modification of the survey area location meant that the northern portion of the predefined swaths fell outside the environmental permit area, forcing the technical coordinators to modify the shooting plan. The swaths originally oriented along the east-west direction were rotated by 90° and shortened to accommodate two new east-west swaths in the northern portion of the survey area. These two swaths were covered at the end of the survey once the extension of the environmental permit was approved.

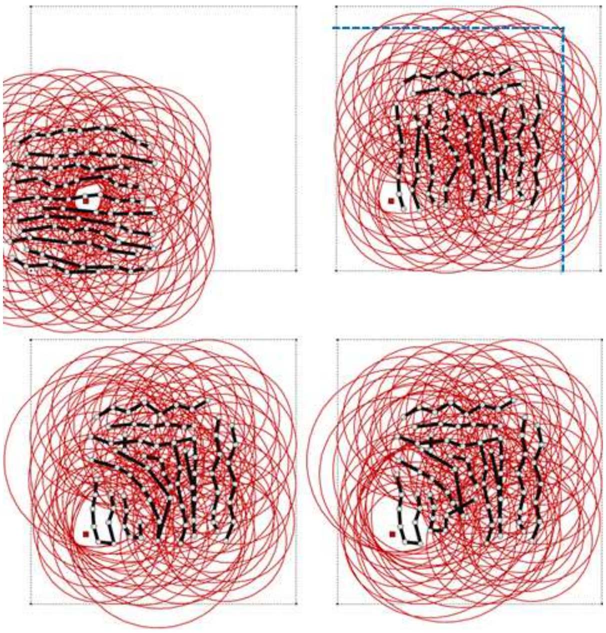

Fig. 5 - Acquisition planning maps (pre-plots): original (top left), first modification (top right), second modification (bottom left), last modification (bottom right). The red circles represent the source planned locations. The black line represents the circle centers along each swath. The blue dashed line shows the extension of the original environmental permit area on the north and east sides of the survey area. The drilling rig location is indicated by the red square.

The rig located at the extreme southwestern edge of the final survey area presented an obstacle to acquisition. As a consequence, the shooting plan was again modified on several occasions with the objective of improving the coverage around the obstruction. The turn radius and the location of a few circle centers were adjusted along the survey. Figure 5 shows the events that illustrate the successive adjustments applied to the pre-plots and to the arrangement of swaths. These changes were dictated by the magnitude and direction of the currents as well as the extension of the exclusion zone around the obstruction. The circular geometry made these operational adjustments relatively easy to implement. As a result of the modified shooting plan, the vessel acquired a few more than 92,000 shots, as opposed to the original design of nearly 87,000, while the total number of circles covered by the vessel (77) was slightly less than the number of circles originally planned (Table 2).

Table 2: Survey operational statistics

Line change time (% of production time)	~13 %
Infill (% of prime production kilometer)	~0.4 %
Technical downtime (% of survey duration)	~1 %
Number of shots per km^2	~130
Average fold within 180°az. area (25x25m bin)	~400
Maximum fold within 360°az. area (25x25m bin)	~1000
Number of circles (original design)	78
Number of circles (acquired)	77
Number of shots (original design)	86703
Number of shots (acquired)	92258

The surface obstruction inevitably resulted in a large hole in surface coverage as detailed on Figure 2. After completion of the seismic survey, a 3D VSP acquisition was successfully conducted at the rig location. There is a plan to merge the surface and borehole seismic datasets to generate a more contiguous single dataset. It is expected that the VSP data will contribute with some coverage in the area of poor surface seismic coverage resulting from the surface obstruction.

Preliminary processing steps

A customized noise attenuation sequence was performed offshore to address the high level of turn and sea noise identified on the field data. By taking advantage of the point-receiver data sampled with single sensors at 3.125-m intervals, most of the turn noise present on the raw shot gathers was removed (Figure 6) using a series of data-adaptive filter algorithms. The filters were applied in cascade after a period of parameterization tests conducted onboard.

The data were shipped ashore in March 2011 after having been through the noise attenuation sequence, digital group forming, and a first stage of signal processing including wavelet processing. The data will then go through a multiple attenuation effort including state-of-the-art 3D general surface multiple prediction (Dragoset and Moore, 2008), earth model building, and final imaging using reverse-time migration. Based on the current plan, the initial time images will be available in August, 2011, with more advanced products delivered in December.

Conclusions

This paper describes the acquisition aspects of the first coil survey implemented in Brazil. The acquisition planning, the particularities of the QC products, and the preliminary steps of the processing sequences were discussed. On the operational side, despite high levels of standby associated with barnacle cleaning and time sharing, it was demonstrated that coil shooting remains more efficient than a conventional race-track acquisition.

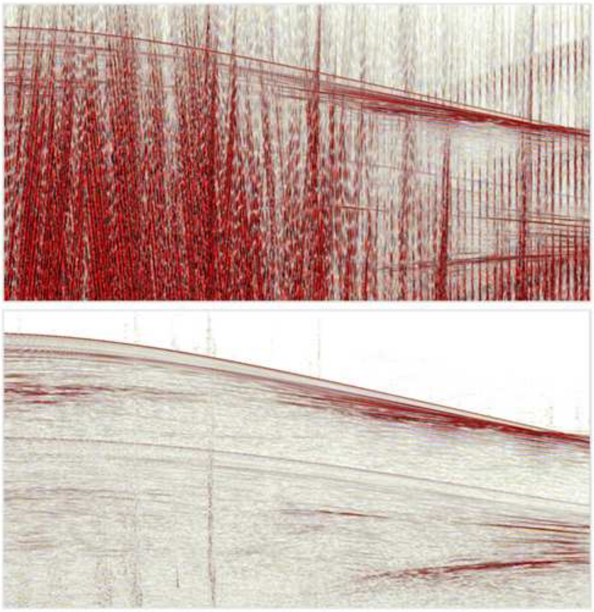

Fig. 6 - Shot gathers: raw (top) and after onboard noise attenuation (bottom).

Acknowledgments

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