Dip or Strike? – Complementing geophysical sampling requirements and acquisition efficiency

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Summary

Dip or strike? The shooting direction during the planning process for a new marine towed streamer seismic survey, depends on many factors. These factors include structural dip, fault orientation, survey dimension and the location of the survey area relative to no-access zones such as marine parks, international boundaries etc. Generally, the data is acquired in the dip direction to enable finer inline sampling in the dominant dip direction and perpendicular to the faults. However, in many cases economic factors override the geophysical issues and a survey is acquired in the most efficient direction. The case study presented here pertains to an area adjacent to a no-access zone, and the structural dip of interest is not aligned to the most efficient survey direction. Extensive 3D kinematic ray tracing analysis and 3D illumination studies were performed to estimate the illumination and sampling requirement for the steeply dipping fault zone. The need for optimal sampling in dip direction whilst maintaining efficiency led to data acquisition using multi-measurement streamers. This technology allows for reconstruction of the wavefield sampled equally in both inline and crossline directions, thereby achieving both operational efficiency and geophysical sampling requirement. To validate the integrity of the shooting direction decision, a swath of data was also acquired in dip direction and compared to the reconstructed data acquired in strike direction.

Introduction

Acquisition direction is one of the many decisions to be made prior to shooting a new marine streamer survey. It has a direct impact on survey economics and geophysical integrity. The geologic structural orientation and complexity, survey block size, shape, dimensions, and vicinity to no-access areas or exclusion zones, all influence the direction of acquisition and consequently the ability to meet the geophysical objectives.

The study area is located in shallow to deep water offshore Sarawak, Malaysia. The survey shape is rectangular with its longer axis in north-south direction. The proposed broadband 3D survey area has a general dominant structural dip in the east-west direction and contains a major fault running approximately north-south across the entire block (Figure 1). Furthermore, immediately to the west of the survey lies a no-access area not to be crossed during the survey.

From a geologic and geophysical standpoint, shooting east-west will align the finer sampling of the conventional asymmetric streamer acquisition bins to the dominant structural dip direction. However, the no-access zone prohibits the vessel from obtaining full subsurface coverage at the western edge of the survey. This would require shooting short east-west (E-W) sail-lines and then a number of closer spaced cable vessel passes in the north-south (N-S) direction up to the no-access zone (Figure 2a). The result would be considerable inefficiency with two directions of acquisition plus a cable reconfiguration for closer streamer spacing. To gain maximum efficiency and coverage up to the western edge of the survey boundary, the optimum acquisition direction is north-south for the entire survey (Figure 2b), but this would align the asymmetric coarser sampling along the major fault and dip direction. The main survey design considerations were: will north-south strike shooting direction cause sampling or illumination problems? Can the survey be acquired efficiently in the north-south direction, and at the same time meet the geological and geophysical objectives?
Another key question was, can some of the traditional rules of shooting direction be relaxed if symmetrical sampling of the wavefield in the inline and crossline directions can be obtained with the towed streamer acquisition and processing?

This case study describes the process which led to the first survey in Malaysia carried out using multi-measurement streamers technology which facilitates the reconstruction of the wavefield sampled equally in both inline and crossline directions using co-located hydrophones (P) and accelerometers with vertical (A\_v) and horizontal (A\_c) components (Robertsson et al., 2008). The equal sampling of the wavefield in dip or strike direction enabled the whole survey to be acquired in the efficient north-south direction without the need for a streamer reconfiguration during the survey. The acquisition is also broadband and enables true 3D deghosting, all leading to improved efficiency whilst meeting the geophysical requirements.

Furthermore, one sail line of data in the east-west dip direction was also acquired during the survey to compare it with the reconstructed data acquired in north-south strike direction to validate geophysical integrity; initial data examples are shown in this paper.

### Survey Analysis, Design and Data Acquisition

The analysis of the legacy 2D seismic data revealed steep structural dips of the order of 30°-40°. High amplitude, discontinuous shallow reflection events causing diffractions and diffracted multiples were also observed on the legacy data. These high bandwidth events have no dominant strike or dip but often have long travel times that could interfere with deeper reflections.

3D kinematic ray tracing analysis and 3D illumination studies were performed using a 3D earth model built with the interval velocity information and interpreted horizons from the legacy seismic data. Kinematic ray tracing was performed on the deepest horizon of interest at a number of locations with varying degrees of dips. The ray tracing indicated that a minimum subsurface spatial sampling of 12.5m x 12.5m is required due to steep dips in the zone of interest and also taking into consideration the shallow diffractions as well as the diffracted multiples events. The ray emergence angles at the surface were estimated to be around 15°-20° indicating significant obliquity. Furthermore, reflection points (Figure 3a) were mostly outside the source to receiver plane. These indicate that in areas of steeper dip, there is significant energy with a crossline component and signify considerable 3D obliquity on rays arriving at the receivers in either both dip and strike acquisition directions.

3D ray tracing was performed to evaluate the illumination at the deepest target. Firstly, for dip (east-west) acquisition direction with a north-south edge “patch fill”, a combination of conventional spread geometry of 10 x 8km at 100m cable spacing for the east-west lines and 10 x 8km at 50m cable spacing for the north-south patch were used. Secondly, for the complete strike (north-south) direction acquisition, a spread of 20 x 8km at 50m cable spacing was used to simulate an effective subsurface sampling of 12.5m.

The second design assumes that multi-measurement streamers would be employed that could reconstruct the pressure wavefield between the streamers, in this case for cables spaced at, for example, 100m spacing creating 6.25m x 6.25m wavefield sampling in both inline and crossline directions (Ozbek et al., 2010). The illumination maps at the target horizon (Figure 3b) showed that the east-west acquisition shooting design displayed variable illumination even in less rugose parts of the dipping surface. The east-west design plots also showed fine scale illumination stripes due to azimuth change from inner to outer cables during up-dip and down-dip shooting. North-south shooting direction, while taking into account the higher data density, displayed more consistent illumination both in gentle and more rugose parts of the dipping surface.

### Figure 3:

(a) Reflection points plot showing obliquity 3D effect.
(b) Illumination ray tracing hitmaps showing variable illumination with E-W direction shooting, but more consistent illumination with N-S direction with finer cross cable sampling (marked with white circles and arrows).

Based on the above analysis, data acquisition was carried out in the north-south strike shooting direction using the multi-measurement streamer acquisition technology. The crossline wavefield vector information from accelerometers oriented in the cross cable direction (A\_c) enables a full 3D wavefield reconstruction to obtain finer virtual cable crossline sampling and application of a true 3D deghosting algorithm. Variable currents and marginal weather posed a significant challenge during data acquisition, but deeper streamer tow depth (18m) and stringent quality control measures ensured good data quality throughout the survey.
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It should be noted that when shooting data in a predominantly strike direction, it is possible that the range of subsurface reflection angles sampled by the surface receiver spread is reduced; consequently it may impact the velocity analysis sensitivity. In this project, the mitigation for this effect was to acquire as long offsets as possible (~ 8.0 Km) within the logistical constraints.

**Data Examples – Sampling Perspective**

Initial data examples show encouraging results from several perspectives. The \( A_y \) component data shows useful shallow primary reflections and multiples as well as some deeper, out of plane diffractions and coherent events (Figure 4). These data are used in the joint interpolation and deghosting process to reconstruct the full pressure wavefield at a fine un-aliased sampling for further processing (Figure 5).

The seabed surface map extracted from the initial stack volume reveals high correlation with detailed features observed on the multibeam echo sounder data from the survey area (Figure 6). This demonstrated that detailed imaging is achievable from the finely spatial sampled marine seismic data for use of shallow hazard analysis.

**Data Examples – Dip vs Strike Shooting Direction**

Initial comparison of the data acquired in dip and the strike direction and processed through identical flows shows close similarity in terms of seismic imaging and frequency content (Figure 7). Minor differences observed could be attributed to the difference in illumination of the geologic features through two shooting directions (Figure 8a and 8b), validating the survey design and modelling analysis. The improved imaging in the marked areas could also be due to the additional illumination from the cross cable energies recorded in the crossline component sensors.

**Conclusions**

Fine sampling of the wavefield in both the inline and crossline directions enables rethinking on the conventional rule of finer spatial sampling in the dominant dip direction. In this case, the orientation of shooting along the longer axes of the survey was made possible, achieving efficiency without compromising the geological and geophysical
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objectives. The acquired data provide un-aliased crossline subsurface sampling of 12.5m (or finer if necessary) but with 100m streamer spacing. The steep dips and/or rugosity of the target horizon cause obliquity effects, which requires a true 3D deghosting and pre-processing workflows. This is possible to achieve with the output from 3D joint interpolation and deghosting process.

Initial comparison of the data acquired in dip and strike shooting directions shows close similarity, the steep dipping events are not degraded despite the strike direction data being acquired with an efficient 100m cable spacing design. In fact at this early stage we observe some improved illumination in the strike shooting direction. This validates the decision on shooting direction and also meets the objective of achieving efficiency without compromising on geophysical integrity.

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Figure 7: Dip (E-W) vs Strike (N-S) – frequency octave panels show similar data quality irrespective of the shooting direction.

Figure 8a: An inline PrSTM stack from E-W dip shooting direction. One sail line was acquired in the dip direction to compare to the acquired production data with wavefield reconstruction to validate the geophysical integrity of the process (compare to Figure 8b).

Figure 8b: A reconstructed crossline PrSTM stack from N-S strike shooting direction, extracted at the same location as the inline from dip shooting direction shown in Figure 8a. Comparison shows similar imaging irrespective of the shooting direction. The strike direction shows improved illumination in some areas (marked in white circles in Figures 8a and 8b).
REFERENCES
