Challenging Full-Azimuth 4C-3D OBN Survey in Congested Oil Fields of India

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SUMMARY:
ONGC has conducted its first full azimuth 4C-3D dense grid OBN seismic data acquisition in the two important oil fields; D1 and Neelam-Heera during 2018-19 using double sided parallel geometry with full azimuth source and simultaneous source shooting. This paper is a case study focusing on the operational challenges in the congested oil fields, fold recovery plans for achieving seamless coverage, the importance of First Break Positioning (FBP) for underwater receiver positioning and receiver indexing, the effect of simultaneous shooting and deblending in removal of interference noise and other QC aspects to maintain the data quality.

INTRODUCTION:
The modern-day subsurface imaging challenges like complex nature of geology, anisotropic behavior of the reservoir, thin layer resolution or the lack of new data for the surface obstruction can’t be mitigated by conventional streamer seismic data because of its limitations in terms of frequency bandwidth, azimuth and offset. The growing demand of new technology motivated the oil industry towards seafloor based geometry with multi-component recording system. The concept of multi-component was developed in middle of the last century but practical application started in 1990s when geophysicists started the use of vertical geophone with hydrophone, co-located in seafloor based cable. But, the use of horizontal geophone started in the year of 2000 when the industry realized the benefits of shear wave to resolve complex geological challenges. Now, the seismic industry has two types of multi-component seafloor based acquisition systems; cable free and cabled which have been named as “Ocean Bottom Node” (OBN) system and “Ocean Bottom Cable” (OBC) system respectively. OBN is preferable to the industry as it is not restricted by offset or azimuth and bathymetry. Node technology also has its own journey from free-fall deployment to ‘ROV’ to ‘rope-on-node’ with increasing the efficiency and reducing the cost during last 10 years.

Advance seismic data has been in high demand in both D1 & Neelam-Heera fields in order to resolve the production issues, anisotropy mapping, reservoir development, thin pay mapping and basement fracture detection which can be fulfilled by full azimuth dense grid 4C-3D Ocean Bottom Node seismic.

SURVEY GEOMETRY:
As the main objective of this survey was to resolve complexity and anisotropy of the subsurface, it required full azimuth & dense grid survey geometry. The feasibility study suggested 5000m of full azimuth offset, (25m x25m) of bin size and (200m x 200m) of node grid for the survey. The nodes were deployed on the seafloor with 200m station interval (inline stagger 100m for every alternative line) and 200m line interval whereas 4 salvos of source lines with source interval 50m and line interval 50m in flip-flop mode were fired.

Figure 1: Active patch of double sided parallel geometry with 25 receiver lines.
Challenging Full-Azimuth 4C-3D OBN Survey in Congested Oil Fields of India

It was for the first time in ONGC when double sided parallel geometry (Naranjo et al., 2018) was implemented where a patch of 25 receiver lines was active and two sets of shots; primary (receivers active below the source line) and secondary (receivers active above the source line) were fired on either side of the patch (Figure 1). The benefit of double sided parallel geometry over conventional geometries is simultaneous shooting by multiple independent vessels and hence reducing the acquisition time.

FULL-AZIMUTH SOURCE:

The conventional marine sources are usually front loaded (large volumes guns in the front) which is not sufficient to distribute energy equally in all azimuths (Figure 3 A & C). The idea (Hopperstad et al., 2001) was to design an azimuthally isotropic source which can generate equal amplitudes in all azimuths, therefore a centrally loaded source (large volume guns in center) was introduced which had lower volume than the previous one but higher far-field amplitude (Figure 2 C & D) and uniform energy distribution in all azimuths (Figure 3 B & D).

CHALLENGES:

1. Node Position Accuracy & Productivity:
Node positioning accuracy (half the bin size) was the main challenge in beginning of the project which was affected by unpredictable underwater currents, ultimately hampering the productivity (shots/day) tremendously as the deployment speed was very slow. To improve the production, several changes were adopted in deployment strategies like; a. Use of heavy chain link in receiver station b. Flexibility of rope length in between the stations c. Deployment of dummy line before start of line to know the nature of localized currents d. Selection of patches for redeployment (Figure 4) or additional deployment of nodes.
2. **Surface installations & Fold Coverage:**

The aim of OBN survey was to achieve seamless fold coverage near the installations. Survey was designed and planned accordingly, but the movement of several simultaneous operators like barges, diving operations, rigs and other pipeline maintenance work hampered the smooth production as well as coverage for their huge buffer (~1.5Km radius) restriction.

The advantage of cable free node system is that the recovery shots and receivers are flexible to position in any direction to cover foldage gap. Therefore, fold recovery plans were dynamic and synchronized with movement of the obstacles.

The use of additional nodes and shots targeting the gap, modification of template for existing shots or receivers, deployment of snake line or the infill nodes with the preplot lines for faster recovery and hazard free operations, holding of back spread during secondary shooting, time sharing basis operations with the other operators etc. were the common practices in fold recovery program. Two different complicated cases from Neelam-Heera area are presented below to achieve near offset (1-1250m) coverage inside the restricted buffer zone.

**CASE-I:**

During the primary shooting, no shots and receivers (Figure 5A) were allowed inside the buffer (radius ~1.5 km) of the barge. Therefore, it was attempted to deploy additional receivers outside the buffer but a huge fold gap (Figure 6A) was created inside the buffer. During the secondary shots, all shots were taken (Figure 5B) inside the buffer along with two active receiver lines and all active receivers outside the boundary (holding of back spread). But, the combined fold map (Figure 6C) still showed a little gap which was covered (Figure 6D) by a separate work plan (Figure 5C) at the end of the survey with two crossline receivers.
CASE-II:
It was a case where two barges were operating during the production period; barge - 1 & 2 restricted around 13 SKM & 3 SKM of area respectively. During the first two days of primary production (Figure- 7A) barge-1 was moving from west to east therefore shots and receivers were not allowed inside the big buffer. Next day, the area was accessible, therefore skipped receivers were deployed and shots were taken (Figure- 7B) but the small buffer of barge-2 was allowed only for shooting for the next two days, therefore additional receivers were deployed at the periphery of the small buffer. Rest of the primary shots (Figure- 7C), two crossline recovery shots (Figure- 7D) and all the secondary shots (Figure- 7E) were taken with all active receivers in-and around both the buffer zones. In spite of all the efforts, there was a big near offset data gap (Figure- 8B) inside the small buffer as there was no receiver. Therefore, a separate recovery plan was designed (Figure- 7F), limited by a half day time span at the end of the project to fill the gap (Figure-8C).

3. Accurate Receiver Positioning & FBP:
The only way to know underwater node position for ‘node-on-rope’ deployment technology is the pinging method. Dependency of sound velocity profile of the water column and loss of pinging signal are the main disadvantages of this method to locate the accurate underwater node position. Also, it was observed that ~5% of nodes were unpinged due to the transponder (attached with the node) loss or error. Therefore, First Break Positioning (FBP) was an essential solution to ascertain the accurate node position and it was made mandatory for all the receivers.

Figure 7: Six phase recovery plan to recover the near offset fold inside the buffer of two barges. JD: Julian Day

Figure 8: Fold development for the offset range of 1-1250m inside the buffer of barge-1 & 2.

Figure 9: Rectification of node position by FBP correction for the corresponding nodes.

It was observed in D1 area that about 30% of nodes have a position shift of 5-10m from the pinging
location. FBP not only improves the receiver location but also rectifies the location of wrongly positioned (Figure-9) or dragged nodes.

4. **Multiple Dragging and Receiver Indexing:**
Neelam-Heera field was near the coast and suitable choice for fishing activities which caused receiver dragging from its original drop location on several occasions. The lines were dragged in different parts which were identified by re-pinging during the production period. It was a challenging task for the onboard geophysicists to find the different drag locations (named as receiver indexing) of the same receiver by filtering the corresponding shot points. For indexing the multiple receiver locations, the offset for First Break analysis was chosen as 3000m to accommodate more data points and filter out shots by identifying the drag timing from the three components (Northing, Easting & Vertical) of tilt vector plot for three orthogonal geophones (Inline, Crossline & Vertical). One example with two distinct drags and three indexes has been shown in Figure 10 by using the FBP technique.

**Figure 10:** A, B & C are the panels to determining the three node positions from First Breaks. D is the Tilt vector plot to detect the drag date & time.

**OTHER QC ISSUES:**

**Same Polarity for Inline & Crossline Geophones:**
There were a few nodes where the amplitude of inline geophones was recovered after tilt-orientation correction to the raw data (Figure- 11 A & B). The gather analysis couldn’t clarify the issue, but First Break RMS amplitude maps clarify that orientation (energy accumulation) of the inline and crossline geophones was parallel instead of perpendicular to each other. Those nodes were separated out from production and flagged for processing.

**Figure 11:**
A. Receiver Gather Before Tilt-Orientation correction
B. Receiver Gather After Tilt-Orientation correction
C. RMS Amplitude Map Before Tilt-Orientation correction
D. RMS Amplitude Map After Tilt-Orientation correction
Challenging Full-Azimuth 4C-3D OBN Survey in Congested Oil Fields of India

**Figure: 11** Receiver gathers (A & B) and First Break RMS Amplitude Maps (C & D) for inline and crossline geophones before & after tilt-orientation correction. The RMS map (D) after the correction showed the parallel orientation of energy accumulation for both the horizontal geophones.

**DEBLENDING:**

It was the first blended acquisition in ONGC where two dual-source vessels shot simultaneously and independently with coordination between the sources (to avoid the blasts at same time) and allowed to record two types of seismic interferences; self-interference from the same vessel within the cycle time and crosstalk interference from other source vessel. Simultaneous source shooting (Abma et al., 2012) is a modern-day shooting technology to reduce the acquisition time and enhance the shot density therefore a suitable choice for node based acquisition. The hybrid deblended scheme (Robert To et al., 2018 and Zhuang et al., 2017) was used to remove the interference noises and recover the signal (Figure 12).

**CONCLUSION:**

The main objective of the OBN survey was to acquire full-azimuth seismic data which was achieved by using double-sided parallel geometry and centrally loaded full azimuth source. The changes in node deployment strategies increased the node position accuracy as well as productivity. The restricted zones by simultaneous operators hampered the aim to achieve seamless coverage which was fulfilled by flexible and dynamic fold recovery plans synchronizing with their movement. First Break Positioning (FBP) was the most effective tool to identify the actual underwater node position and index the receiver locations for dragging. First Break RMS amplitude map is a tool to resolve the receiver orientation anomalies. Finally, the interference noises recorded by the blended acquisition with use of simultaneous source shooting could be effectively removed by hybrid deblended scheme.

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