Seismic Data Acquisition Challenges in Shallow Water & Transition Zone: Case Studies from Indian Coast

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SUMMARY:

Over the past decade, India's top oil & gas explorer, ONGC has made significant capital investments in OBC (Ocean Bottom Cable) and OBN (Ocean Bottom Node) seismic data acquisition, aiming to unlock the immense potential of India's hydrocarbon resources and strengthen the nation's energy security. However, conducting seismic surveys in shallow water and transition zones has always been a challenging and daunting task for the data acquisition crew. The current paper will discuss the key challenges faced during OBC and OBN seismic campaigns in the Indian coastal region, encompassing the entire process from survey design to field operations. The operational challenges like; strong underwater currents, fishing drag interference, inaccessible areas, and sandbars were discussed along with their solution. The paper also delves into the strategies employed to overcome these hurdles, such as improvising shot-receiver combinations during the planning and production stages. Additionally, the analysis of various quality control plots and maps played a crucial role in minimizing data gaps and achieving comprehensive full azimuth data coverage.

INTRODUCTION

The seismic exploration activities in the Indian Offshore region were initiated by ONGC in the mid-1970s, utilizing a single streamer 2D technique. Subsequently, during the 1990s, the 3D streamer method gained prominence. However, these approaches were inadequate for reservoir-scale studies. As a result, in the mid-1990s, Narrow Azimuth OBC technology was introduced in the Mumbai High production field. Over time, OBC surveys were also conducted in various shallow water fields along the West Coast of India.

The implementation of Broadband seismic technology during the mid-2010s added value to the data quality. Despite this advancement, the vintage data available at that time fell short of addressing critical production challenges effectively. To overcome these limitations, OBN surveys were introduced in 2018. Over the course of the past 10 years, ONGC has successfully acquired approximately 1100 square kilometers (SKM) of OBC and OBC-TZ (Transition Zone) data, along with more than 4000 SKM of OBN data.

This paper presents a collection of diverse case studies derived from these OBC/OBN surveys, focusing on preserving data quality while tackling the unique challenges associated with shallow water and the Transition Zone. The aim is to demonstrate the methodologies and techniques employed to overcome these challenges and ensure the reliability and usefulness of the acquired data

A. 3D OBC-TRANSITION ZONE IN GODAVARI ESTUARINE:

- **Survey Design:**

The survey area encompassed a lengthy coastline of 52 kilometers, comprising both land and shallow water regions with depths reaching up to 26 meters. Given the diverse nature of the survey area, employing the same geometry for both land and marine operations would not be an efficient approach. Cable deployment is more time-efficient for land areas, whereas firing shots is a more time-efficient method in marine environments.

To optimize the survey geometry, an orthogonal patch shooting configuration was designed, with receiver lines oriented perpendicular to the coastline and shot lines parallel to it. However, for operational convenience, the movement of the spread was chosen differently. For land swaths, the "Half-swath roll along" approach was adopted, which involved bringing receivers from the back to the front as the source fired at the middle of the spread.

But this approach would not work efficiently in marine, because multi or even a single line rolling of OBC spread will take longer time to move than the number of shots for an airgun to fire. Therefore 'patch' acquisition strategy or full-swath roll was employed for OBC to conduct more shots at shallow sea. Both approaches are illustrated in FIGURE-1 as the Unit Template of the survey. The primary objective of these strategies was to ensure adequate in-line and cross-line fold while efficiently moving the equipment throughout the survey area.

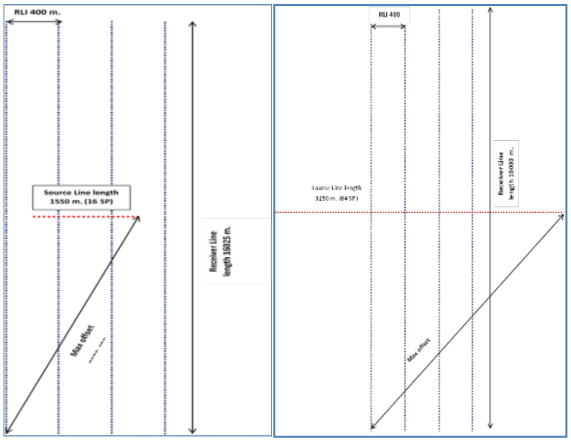

Figure 1: Unit templates; Coastal land (Left) & Marine (Right).

- **Source & Receivers:**

For the land portion of the survey, explosives with an average weight of 3.5 kilograms were detonated at a depth ranging from 35 to 40 meters below the surface. In the shallow sea, a tuned 'air-gun array' was utilized as the energy source, with the volume of the array varying based on the bathymetry of the specific location, as indicated in Table-1

Table-1: Marine source parameters

Parameters	**Type I**	**Type II**	**Type III**
Water Depth range	>=7	<7	3-7
Source Depth(m)	5	2.5	1.5
Pressure (psi)	2000	2000	2000
Volume (cu. In.)	1500	1240	390

During the field operation, four types of receivers were deployed, as illustrated in FIGURE-2. In the sea, dual-sensor (2C) receivers were used. Single-component hydrophones were employed in rivers and channels, while SM-24 geophones were utilized on land. In submerged water-logged areas, marsh phones were planted as receivers for data acquisition. Each receiver type was selected based on its suitability for the corresponding environment encountered during the survey.

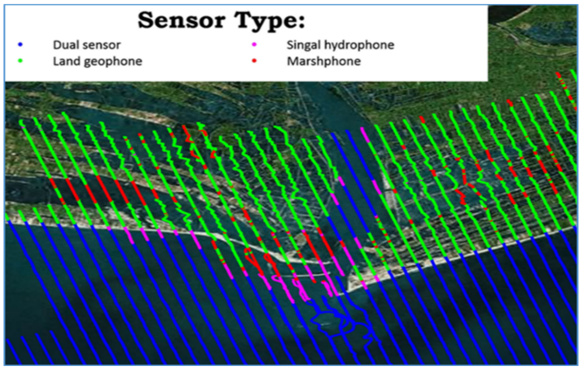

Figure 2: Multiple Receivers Layout with proper index (Top) & Shot Gather with amplitude spectrum for different types of receivers (Bottom).

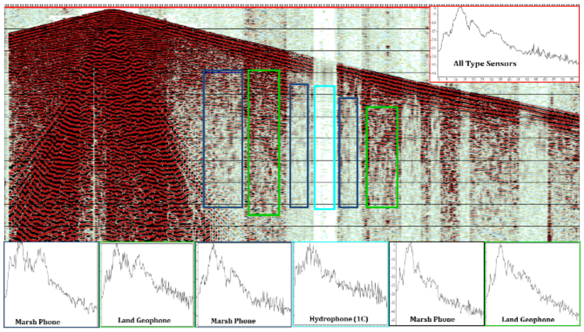

Figure 2: Shot & Receiver Layout (Left). Near Offset Fold Map; Without (Right Top) and with (Right Bottom) additional Shots & Receivers

- **Dynamic Fold Coverage:**

The primary challenge encountered in transition zone seismic surveys was maintaining adequate fold coverage from the coastline to a very shallow surf zone, where the water depth was less than 4 meters. Within this area, which spanned approximately 600-1000 meters, traditional shooting methods were not feasible. Compounding the challenge, the prospect area was in the estuarine region of the Godavari River, necessitating the crossing of high currents and shallow river mouths twice.

To address these challenges, an initial approach was devised to achieve a 128-fold coverage instead of the originally planned 64-fold coverage. However, while this approach fulfilled the overall fold requirement, it did not adequately address the near or near-mid offset ranges. In response, two major steps were implemented during production to enhance the fold coverage and improve data quality.

1. ***Small Infill Receiver Line:***

During production, an Infill Receiver Line (around 50 geophone stations) was added between the pre-plot lines in the land area (FIGURE-4) along the coastline. This was done to address the significant near-offset fold drop observed in the surf zone, ensuring improved fold coverage and data quality.

2. ***Shallow Draft Vessels:***

To overcome the challenge of shooting in shallow water areas, a new small volume and shallow draft source vessel was incorporated during production. This vessel was planned ad hoc and proved essential in covering the wide range of the shallow water surf zone and the river mouth (FIGURE-5). Operating parallel to the coastline, the small vessel employed a half of the existing shot-grid to enhance the near-offset trace density. Its inclusion helped overcome limitations and recover fold losses, ensuring comprehensive data acquisition in challenging environments.

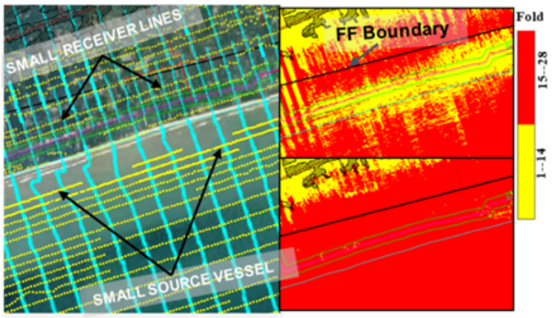

Figure 4: Shot & Receiver Layout (Left). Near Offset Fold Map; Without (Right Top) and with (Right Bottom) additional shots & Receivers.

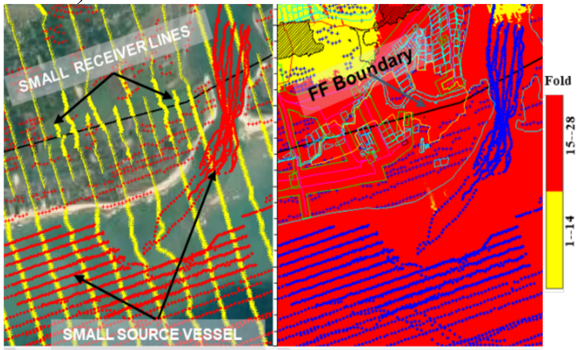

Figure 5: Shot & Receiver Layout (Left) in River Mouth. Near Offset Fold Map (Right) with additional shot & Receivers.

B. TYPICAL CHALLENGES OF SHALLOW WATER OBN SURVEY ON THE WEST COAST:

STRONG CURRENT & PRODUCTIVITY:

During the initial phase of OBN data acquisition in the western part of Mumbai Offshore, a strong and unpredictable south-westerly underwater current from Gujrat Offshore presented significant challenges. This current's erratic nature, combined with varying water depths, severely impacted productivity (shots /day) and node position accuracy (radial offset +/-12.5m from the preplot). To address these challenges, several dynamic node deployment strategies were implemented. This included the use of a heavy chain link in the receiver stations (FIGURE-6), the flexibility of rope length between the stations, deployment of a dummy line before the start of the line to know the nature of localized current, selection of patches for redeployment (FIGURE 7) or additional deployment of nodes. These measures impacted doubling productivity by achieving node position accuracy of ~95% per line with significantly higher node deployment speeds.

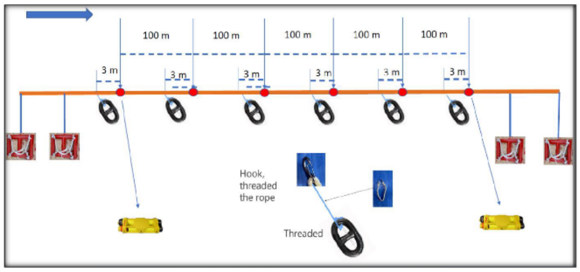

Figure 6: Node Configuration with heavy Chain Links attached with rope.

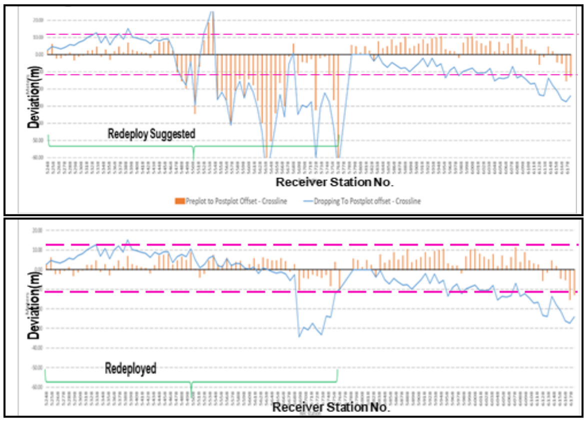

Figure 7: Crossline deviation (from preplot) histogram of a nodes line. Deviations before redeployment (Top) after redeployment (Bottom). The

position accuracy increased by 20% after redeployment. Pink dotted lines indicate the limit of deviation. (Source Ghara et.al 2020).

DOUBLE PING STRATEGY:

In the shallow water environment, ensuring accurate positioning of underwater nodes during recording posed a significant challenge due to the node dragging possibility, caused by intense fishing activities or strong underwater currents. To address this, two separate acoustic ping runs were conducted: one after node deployment and another before node retrieval. These runs helped to identify any node movement that occurred during the production phase. By comparing the results, as shown in the comparison chart (FIGURE-8), instances of dragged nodes could be easily determined from the difference plot. The positions of these dragged nodes were then included in the fold calculation to assess the potential loss of fold or the need for additional fold recovery measures prior to the node retrieval

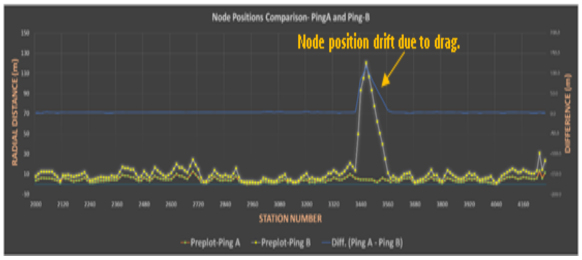

Figure 8: Comparison of node's radial drift from preplot between post-deployed ping (Ping-A) and pre-retrieval ping (Ping-B). (Source Ghara et.al 2022).

IMPORTANCE OF FIRST BREAK POSITIONING:

The underwater node position for 'node-on-rope' deployment can only be determined through the pinging method. However, the accuracy of pinging depends on various factors such as underwater current, sound velocity in the water column, vessel speed, seabed topography, and siltation over the nodes. Therefore, the ping position can only be used for operational control, while the ultimate solution for determining the final position is the data-driven approach called "First Break Positioning" (FBP). FBP is the only method to determine multiple locations for drag nodes. FIGURE-9 is a case that demonstrates the fixing of the drag node position using a separate index.

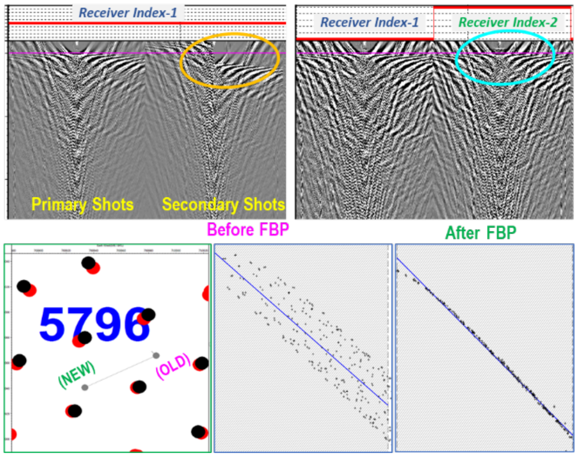

Figure 9: Inline LMO (Top) before and after FBP for secondary shots. Interactive FBP Panel (Bottom) to find the drag node location. (Source Ghara et.al 2022).

CROSSLINE LMO TO DETECT THE INTERMITTENT DRAG:

Inline LMO provides receiver location information for only two indexes (beginning and end of the spread), while intermittent drag can only be detected in crossline LMO as it represents the closest shots of each shot line. FIGURE-10 illustrates two examples showcasing intermittent line drag observed in Crossline LMO and the corresponding actions taken to address them.

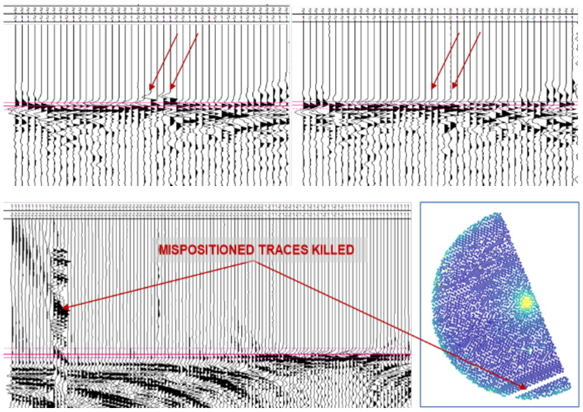

Figure 10: Top- Crossline LMO before (left) and after (right) position correction for intermittent drag. Bottom- Traces killed for intermittent drag which cannot be determined due to insufficient near traces for FBP.

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CROSS-CURRENT& FISHING ACTIVITY:

The Tapti field, situated (refer to FIGURE-11) in the south Gulf of Khambhat of the Gujrat Coast in the Arabian Sea, is characterized by the water depth ranging from 10-30 meters. Due to the convergence of five major rivers of western India into this Gulf, a strong south-westerly water current (>4 knots) was consistently present in this area. Additionally, the typical fishing structure of western offshore, called "Stake Net" (attached with iron poles fixed on the seabed) was expected to be oriented randomly along 60°-70° azimuth, further adding to the complexity. To minimize interference from Stake Nets and cross-currents, the line direction for both shots and receivers was chosen parallel to the same azimuth range.

Considering previous experiences indicating the presence of a couple of shallow sandbars (5-8 meters water depth), the provision of small boat operations was incorporated during the planning stage. A dedicated bathymetry survey was conducted well in advance to identify these sandbars for safe operations. However, it was discovered that the sandbars exhibited dynamic in nature, differing from previous maps (refer to FIGURE-12). As a result, the shallow boat operation plan had to be adjusted accordingly to accommodate the changing sandbar locations.

An unexpected challenge arose from rapid siltation occurring primarily near the shallow regions, leading to significant node loss initially (refer to FIGURE-12). However, by avoiding the use of chain links in shallow areas, the number of node losses was reduced.

Figure 11: Satellite map Tapti field, Gulf of Khambhat in North-East direction.

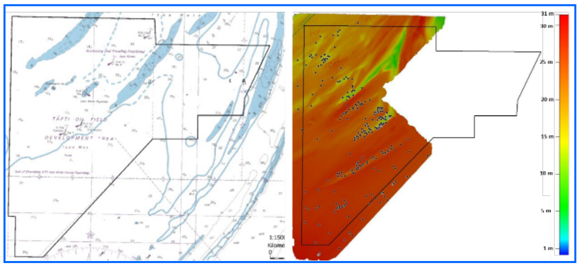

Figure 12: Previous Bathymetry Map (Left) and current Bathymetry map (Right) with lost node locations (black dots).

FULL-AZIMUTH INFILL PLANNING:

In seismic surveys, infill plays a crucial role in filling data gaps caused by field obstacles. However, for a full azimuth survey, the infill plan should focus not only on fold build-up but also on filling the offset gaps in different azimuths. The case study shown in FIGURE-13, the NE part of the Panna area experienced drag of several node lines due to a northward strong current along with Stake Net activities, resulting in a significant fold gap across different Offset-Azimuth ranges. The infill plan prioritized filling the offset-azimuth gap along with achieving desired fold coverage.

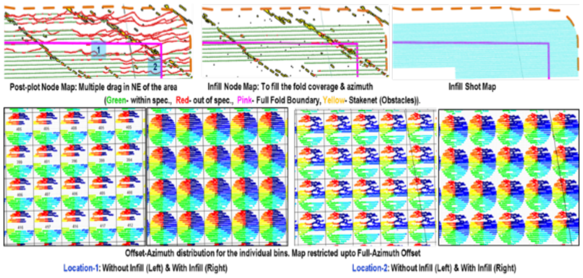

Figure 13: Case study of Full Azimuth Infill recovery plan to fill the Offset-Azimuth gap as well as to enhance the fold counts, caused by node drags. (Source Ghara et.al 2022).

CONCLUSION:

The survey geometry and fold recovery in the Transition Zone (TZ) area should be planned with operational convenience in mind. Double pinging strategy, First Break Positioning, and both Inline and Crossline LMO serve as vital quality control tools for identifying and rectifying the node positions, especially for drag cases caused by fishing activities or strong currents. Topographical and logistical inputs

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play a crucial role in survey planning as well as the execution of OBC/OBN seismic operations in shallow water environments. The ultimate aim of a full azimuth survey should always be focused on achieving the desired full azimuth coverage, from survey design to infill planning.

Overall, the OBC and OBN operations in the shallow water and TZ areas of the Indian coastal region were challenging tasks in terms of surface approachability, strong water currents, sandbars, and fishing drags. However, efficient measures and dynamic planning at all stages during operation preserve the acquired data quality.

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*Views expressed in this paper are that of the author(s) and may not necessarily be that of Oil and Natural Gas Corporation Ltd.

REFERENCES:

Hopperstad, Jon-Fredrik, Johan-Fredrik Synnevag and Peter Vermeer, 2001, An azimuth-invariant source array: SEG Technical Program Expanded Abstract. https://doi.org/10.1190/1.1816668

Ghara, Sudip., Prakash, Deepak., Payra, Saikat., Parasher, Deepak., 2020, Challenging Full-Azimuth 4C-3D OBN Survey in Congested Oil Fields of India, 13th Biennial International Conference and Exhibition, Society of Petroleum Geophysicists.

id-280-challenging-full-azimuth-4C-3D-OBN.pdf (spgindia.org)

Ghara, Sudip., Prakash, Deepak., Payra, Saikat., Parasher, Deepak., Pal, Vijay, 2022, QC Measures for Ocean Bottom Seismic Data Acquisition: Case Studies from Mumbai Offshore Region, 5th South Asian Geoscience and Conference Exhibition.