



## The Epilogue of FAZ High-Density OBN Data Acquisition in India's Prominent Producing Oil Field for Unlocking New Potentials

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### Keywords

OBN, Modelling, Full Azimuth, Nodes & Source, Trace Density & Distribution, SIMOPS, Close Pass, Infill

### SUMMARY

The current paper is a comprehensive case study for Full-azimuth (FAZ) Ocean Bottom Node (OBN) seismic data acquisition in Mumbai High, the prominent oil field of India. The affordable survey geometries were optimized during the planning stage by comparing fold, trace density & distribution, and illumination maps (ray-trace modelling) to analyze the quality difference whereas resource requirement and source-node operation time were estimated for cost efficiency. The paper also contains modelling results to find the optimum configuration for a full azimuth/isotropic source and the best combination of source & node vessel counts for saving the field time. Here it was also discussed the advance planning for multiple SIMOPS to minimize the loss of operation time and infills for enhancing the fold coverage around the obstacles. An example of advance infill planning to fill the probable data loss for an anchored barge was described here by using proper SIMOPS input.

### INTRODUCTION:

Mumbai High Oil Field is located about 176 km WNW from Mumbai city in the Arabian Sea and it is contributing the lion's share of indigenous oil production for the nation during the last four and half decades. The field was discovered in 1974 through the maiden attempt of "2D seismic" exploration during 1964-67 and the next data set was acquired during the mid-1990s with state-of-art technology "Narrow Azimuth 3D-OBC" prevalent at the time. During the last 3 decades, this OBC data has been reprocessed and re-interpreted several times and was stand as the base for all exploration and production activities. However, considering the advancement of technology over the years and modern-day's E&P challenges, it was decided to re-acquire seismic data in Mumbai High Field by using the full potential of Ocean Bottom Node (OBN) technology to avails the data set having high trace density, full azimuth,

converted wave recording (PS data) and ultra-long offset for FWI.

### SURVEY OBJECTS:

The objective of the survey is to map primary producers of Mumbai high field i.e., Early Miocene L-III carbonates and deeper hydrocarbon bearing layers by both PP and PS mode of seismic data for resolving the thin multi-layered carbonate reservoirs, identifying fault/fracture network, pressure/fluid compartmentalization, reservoir facies discrimination and delineation of possible bypassed/leftover oil zones. The newly acquired OBN data would be able to impetus for integrated studies and analysis to realize the maximum value of the Mumbai High oil field and enhance the oil production and operation efficiency, and thereby increase the recovery factor of the field from the present estimate of ~28.8% to 38% by the year 2040.

### SURVEY DESIGN & MODEL STUDY:

#### 1. Offset-Azimuth & Record Length:

A numerical model was prepared based on the velocity, horizons, density and sonic logs from legacy data as input in NORSAR software and located ~35 different scattered points on the basement level for the survey independent Offset-Azimuth & Record-length estimation. Maximum offset-azimuth was chosen from PP-hit distribution and record length from PS travel-time as both PP & PS ray travel independently. After analyzing all diffraction points (FIGURE-1), it turns out that the maximum offset required to illuminate all the points of the basement to cover all the azimuths should be 4000m and the maximum record length for the same level to illuminate the PS wave should be greater than 3.5s.

#### 2. Selection of Geometry:

##### • Financial Aspect

The sufficient number of nodes (Resources) to roll the active template and the survey duration/days (Time) are the two key factors that dominate the



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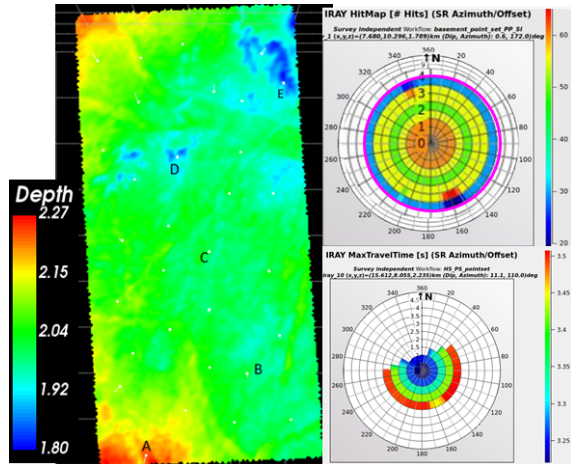


FIGURE-1: Left: Basement Depth Map with diffraction point (white dots). Survey independent PP Hit (Right-Top) and PS travel-time (Right-Bottom) map in the offset-azimuth domain for a scatter point.

survey budget/cost. Here we have calculated those 2 factors separately by analyzing the four affordable survey geometries; mentioned in Table-1 and the consideration/assumption in Table-2 for the time-motion calculation.

Table-1: Model Parameters

Mode No.	Node Interval	Node Line Interval	Shot Interval	Shot Line Interval
1	200	200	50	50
2	100	200	50	50
3	100	300	50	50
4	50	400	50	50

Table-2: Assumptions for the time motion calculation

Node Interval (m)	200	100	50
Node Deployment Speed (Knots)	1.8	1.4	1.0
Node Recovery Speed (Knots)	2.0	1.6	1.2
Line Change for Node Vessel (hrs.)	1.0		
Source Vessel Speed (Knots)	5.0		
Line Change for Source Vessel (hrs.)	0.5		
Standby	25%		

Downtime	5%
<p>Note:</p> <p>a. Number of Node Vessel: 1 and Number of Source Vessel:1</p> <p>b. Shooting Geometry Double-sided parallel or “H” Pattern</p> <p>c. Infill and deviation for Obstructions have not been accounted in the calculation.</p>	

Figure-2 represents four survey attributes; required nodes, node operation (combination of node Deployment & Retrieval) time, shooting time and minimum fold in each bin all together in a single plot. Here, it shows that all the models are node dominating (in terms of operation time) but the gap between the shooting and node operation time is huge for Model-1 & 2 due to shorter receiver line interval. Model-2 & 4 can produce higher fold as they need a huge number of nodes. After comparing all 4 geometries, Model-2 has been removed for further analysis as it will consume a huge amount of both resources and time. Whereas, Model-4 has been considered for same due to the lowest Node operation time although huge resources demand.

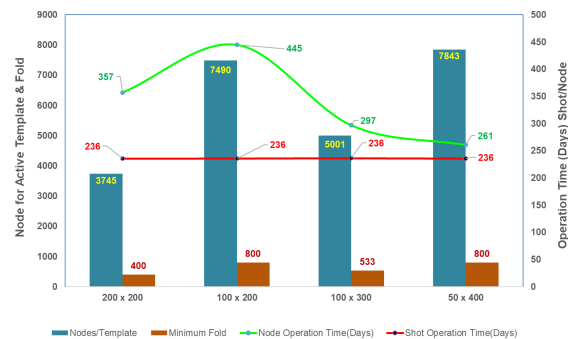


FIGURE-2: Combined Plot of; Node Requirement for an Active Template, Time-Motion (Node and Source) and Fold.

### Trace Density & Distribution:

The survey design was aimed to achieve Full Azimuth seismic data for this matured production field. Therefore, our focus was to analyze the both trace density and distribution over the azimuth in each bin for both PP and PS waves. Higher offsets (>1500m) have been excluded for this analysis as near offset can give better comparison due to the lesser traces density.

Figure-3 & 4 represent the distribution of traces over the offset-azimuth and offset-offset domain for the



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adjacent bins. It can be observed from figure-3 that Model-4 has the higher trace density and best distribution over the mid-azimuths but a huge gap can be observed near the inline direction though it has the highest fold. On the other hand, traces of Model-1 is covering all the azimuths but have very low trace density, especially for PS wave where several gaps can be observed between the traces over all the azimuths. Figure-4 also depicts that Model-1 & 4 cannot produce better trace distribution than Model-3, especially PS wave.

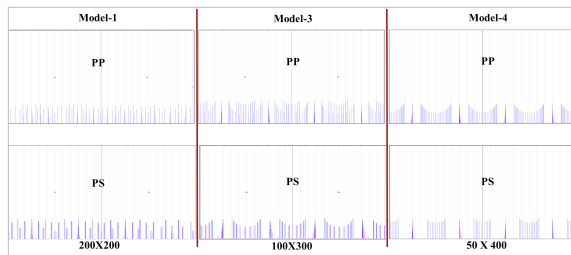


FIGURE-3: Offset-Azimuth distribution for adjacent two bins. X-axis: azimuth; grid interval  $30^\circ$ , Y-axis: scaled offset w.r.t bin dimensions.

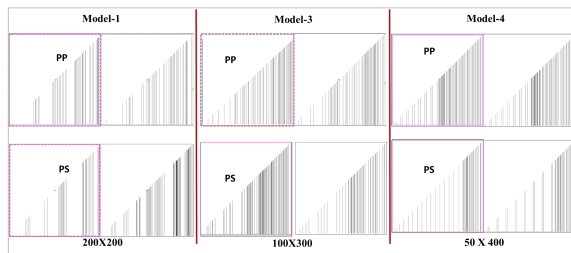


FIGURE-4: Offset-Offset distribution for adjacent two bins. X-axis: trace separation, Y-axis: scaled offset. Both X & Y scaled w.r.t bin dimensions.

After analyzing both the financial and quality aspects, Model-3 has been selected for the Mumbai High Full-Azimuth OBN survey as it would be time efficient than Model-1, resource-efficient than model-4 and quality efficient than both Model-1 & 4.

### 3. Model Study:

As Mumbai High is the oldest and highest oil-producing field from offshore in India, the survey campaign is going to face more than 100 restricted locations associated with surface installations and other production related activities. Therefore, it was considered a 200m exclusion (blue circles in Figure-5

left) for each obstacle where all Shots & Receivers were muted for fold calculation during the survey design to observe the maximum fold loss. The velocity cross-section in Figure-5 represents the input model for the Ray-Traces Illumination study.

The Illumination map of Figure-6 depicts that the higher hit count is reflected by higher trace density. Therefore, Model-4 has better illumination than the other two but it has been characterized by lots of fold stripping due to asymmetry in the node grid. Finally, Model-3 has been optimized for data acquisition as it was supported by earlier observations in geometry selection as well as illumination study.

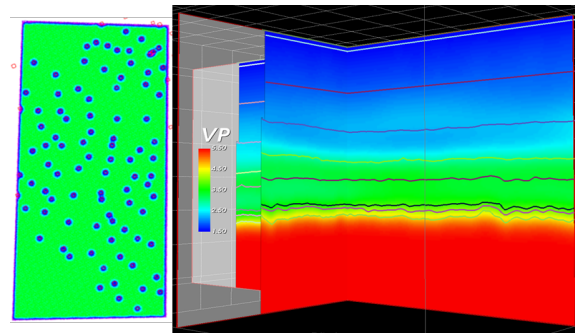


FIGURE-5: Left- Area for Model study with platform locations (blue circles). Right- Velocity Model with all the horizons for Illumination study.

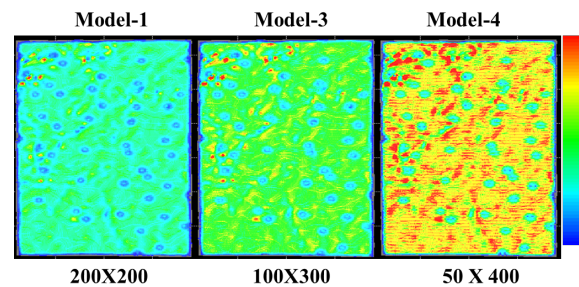
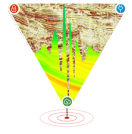


FIGURE-6: Comparison between Near Offset Illumination Map generated by Ray-Trace modelling for the Model-1,3 & 4.

### 4. Full Azimuth Source Configuration:

The source configuration was decided by using the same philosophy of full azimuth source as described by the author in the paper "Challenging Full-Azimuth 4C-3D OBN Survey in Congested Oil Fields of India", Ghara, et.al. 2020.

The 2-string source configuration (Figure-7A) having a dimension of 15mX8m and the larger gun in the



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middle was chosen for smooth mobility near or between the platform/installations crowd. The source configuration of 8m string separation was selected for the full-azimuth survey due to more coherency in azimuthal signature and spectrum (Figure-7 C&E) than the nearby combinations.

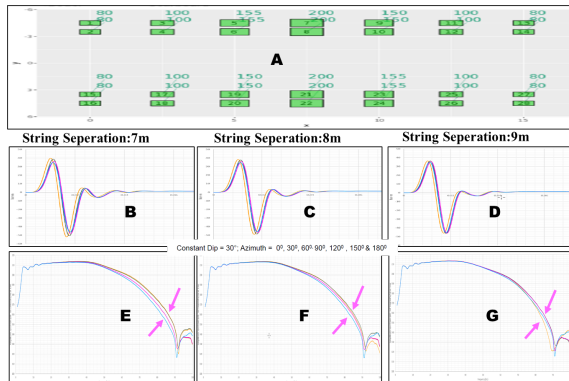


FIGURE-7: Full Azimuth Source Configuration. A: Source Layout, B, C & D: Source Signature and E, F & G: Amplitude Spectrum for the 7m, 8m & 9m string separation. The colors of the signature and spectrum represent every 30<sup>o</sup> azimuths for a constant dip of 30<sup>o</sup>.

### OPERATION PLANNING & RESOURCE DEPLOYMENT:

During the pre-mobilization stage, it was planned to deploy more resources and spend lesser time in the field which can save chances of huge time loss from SIMOPS interference.

To achieve that aim, the vessel counts have been modelled taking the same time duration for 100mX300m node grid geometry from Figure-2 to estimate the actual survey duration which has been presented in Table-3. It clearly shows that the addition of 3<sup>rd</sup> node vessel will make the project as source dominating from node dominating and there will be a better balance between both node and source operation. Therefore, the last option; 3 node and 2 source vessels were decided to deploy for the Mumbai High OBN survey. During the production, it has been observed that the third vessel was very useful to manage the operation delays associated with SIMOPS interference and receive repositioning.

Table-3: Time & Motion calculation with vessels

No. of Node Vessel	No. of Source Vessel	Node Operation Time (Days)	Shooting Time (Days)	Survey Duration (Days)
1	1	297	236	297
2	2	148	118	148
3	2	99	118	118

It was also planned to deploy around 8000 nodes to engage enough spear instead of the requirement for 6600 (total requirement for the active template, daily retrieval, battery recharging, data download & pre-deployment testing) nodes to roll the template which can provide 30% forward patches always get ready for shooting well in advance.

### DATA GAP & INFILL:

The following two major steps were taken for the entire survey to minimize the data gap and enhance the fold.

- **Node Deployment by ROV:**

As the Mumbai oil field is the highest congested oil field of India, it was the most challenging task of the survey to place nodes around the infrastructures for achieving the targeted fold coverage. Therefore, 2 node vessels, additionally equipped with ROV (Remote-Operating-Vehicle) facility were deployed in the field along with the requirement of NOR (Node-On-Rope) node deployment facility to place the nodes as close as possible to the installations and pipelines safely. Also ROV was very useful to place the out-positioned nodes within the specs of half bin size from preplot.

- **Additional Nodes Near Isolated Platforms:**

During the production, it was observed that there was a huge chance for fold loss (Figure-8B) in the near offset (1050m) range around the isolated platforms. It was caused due to the "Cat Eyes" distribution of the shots (restriction for 150m metal-metal distance) to take safe turns near the platforms (Figure-8 A&B) though nodes were placed properly in their preplot locations by ROV. It was also observed that most of the platforms in this area were isolately located and there were good chances for placing the nodes closer to the platforms. Therefore, a fold test (Figure-8B) was conducted by adding 3 infill nodes (inbetween the preplot nodes) on either side of the platform to

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enhance the near fold. This small effort was time efficient as the infill nodes were attached in the *same rope* for preplot nodes but it added a very little amount of node inventory as a whole. Statistically (calculate for a box of 1Km X 1Km for each platform), this infill plan improved near offset fold by 10% for 90% bins by adding only 3.5% nodes for each platform. When it was estimated the impact on the whole inventory, it was found that maximum 1.4% additional nodes to be needed for the active patch at the most crowded part of the block.

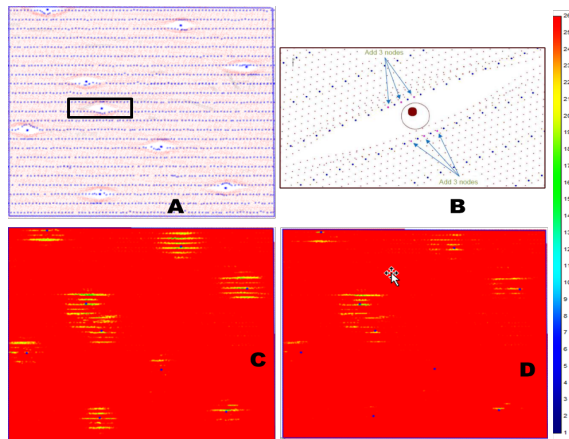


FIGURE-8: Infill Plan for Isolated Platforms. A: Source & Receiver distribution, B: Zoom plot with 3 infill nodes on both sides of the platform. Near Offset Fold before (C) and after (D) infill.

### OPERATION CHALLENGE: SIMPOPS & CLOSE-PASS:

The herculean task of placing the nodes around the dense grid platforms, with associated infrastructure and underwater pipelines, was achieved by ROV after reviewing side scan images to ensure a hazard-free operation. But, the data acquisition campaign was mainly affected for multiple times by different SIMOPS operations and the majority of them were diving operators (around 52 locations) to support the nonstop oil production. But, it was well managed to achieve more than 6000 accident-free close-passes during the whole project. Sometimes more than 2 or 3 SIMOPS operators worked together (Figure-9A) over the active OBN patches, having their different schedules with different objectives. But, the proactive & dynamic look ahead planning by inputting the operation schedule of associated stakeholders like;

allowing node operation within the diving zone, allowing ROV operation closer to the anchors, synchronization of multiple SIMOPS operations schedule, allowing shooting within the diving zone for a small time window to complete the consecutive patches (Figure-9C), etc. drove this acquisition campaign towards an efficient time-sharing operation between the SIMOPS and seismic operations. As a result (Figure-10), the seismic operation has been affected by only 6% of the total SIMOPS operation time and most of this is from the initial days of the survey.

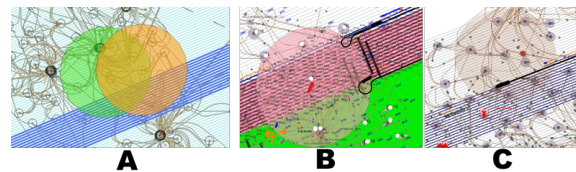


FIGURE-9: 3 cases of SIMOPS activities. A: two different SIMOPS Operators were working together over the Active Patch. B: The source vessel (black) broke the production line at the safety buffer for the diving operation. C: The diving operator allowed (time sharing) for passage of source vessels (black) inside their restriction zone to complete the shooting for pending the patch retrieval.

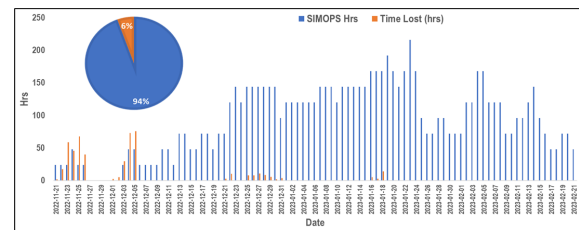


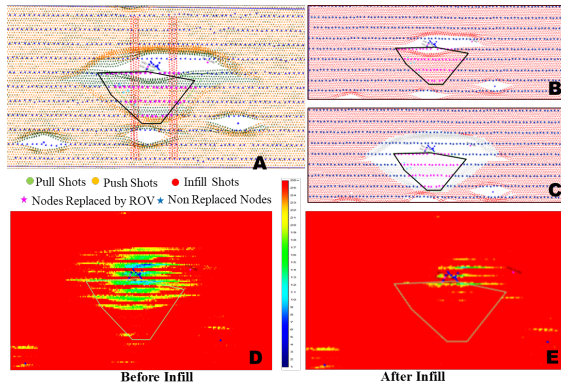
FIGURE-10: SIMOPS operation time vs loss of seismic operation time in date-wise Bar and Pie chart.

### MOST CRITICAL CHALLENGE:

At the end of December 2022, one barge came to the prospect and shared its anchor pattern (Polygon in Figure-11) and it was just the middle of the active patch. It has been given for 2 days time-window to clear the anchor area. The seismic crew has reviewed the whole situation and replaced all the nodes with a new one within the anchor pattern zone by ROV for safer retrieval in the future. The purpose of fresh deployment by ROV was to secure the data till date and use the maximum potentiality of battery life of the fresh node in viewing the longer work schedule of

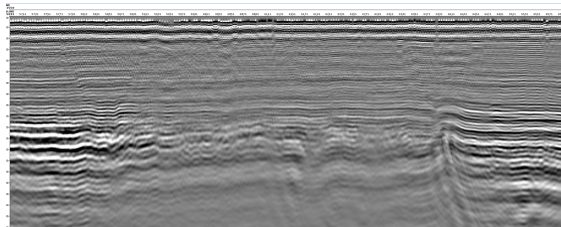
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the barge. Shooting for remaining push shots was also focused to fill the probable gap for the anchored barge in advance for achieving the full-azimuth data target. It was a most efficient and effective challenging example in this project where the probable data loss was well managed and data safety was preserved by using the proper SIMOPS inputs.



**FIGURE-11:** Source & Receiver distribution; without A) All the shots; Pull, Push and Infill over the Anchor Barge. B) All active Pull shots inside the anchor before. C) All probable switch off push shots inside and nearby the anchor barge. Near Offset Fold without (D) & with (E) Push & Infill shots.

### STACK SECTION:



**FIGURE-12:** Field generated Inline Raw 2D-Stack for Hyrophone data to depict the data quality.

### CONCLUSION:

The following conclusion can be drawn from this case study:

- The survey geometry 100x300 node grid was finalized for the Mumbai High OBN survey as it was optimum in terms of quality, cost/time and resource requirement.
- The data quality for the full azimuth survey was analyzed not only by fold but also trace density and distribution over the bins and observed to be high quality.

- Source signature and spectrum was coherent in all azimuths for the Mumbai high Full-Azimuth OBN survey.
- The survey duration was modelled in the planning stage with different source & node vessel combinations targeting to save the field operation time and minimized the SIMOPS interference and found to be very efficient during the survey.
- Two major Infill planning; the use of ROV for node placement closer to the platform and 3-3 infill nodes on either of the isolated platforms impacted a huge to enhance near offset fold coverage.
- Multiple SIMOPS were well managed by dynamic planning and good support from other stakeholders which ultimately save a huge operation time for seismic operation.
- The successful utilization of well planned SIMOPS inouts in advance allowed the crew to maximize their capabilities, ensuring full azimuth data coverage inline with complex operator e.g. anchor barge.

### ACKNOWLEDGEMENT:

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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.

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