Ocean Bottom Node Seismic Survey Evaluation and Design

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Abstract

Oceanic Bottom Node technology (sensors with digitization and recording instrumentation) has been and is being utilized in our industry today to acquire seismic data. In the deep-water marine environment, these four component receivers are sparsely deployed on the seafloor while a dense survey of energy generation is conducted on the surface. Basically, two simultaneous surveys are performed: the node deployment and retrieval operations, and the seismic acquisition campaign, while respecting the minimum and maximum offsets required for each deployed node. The size of the area, the node spatial sampling intervals (inline and cross-line intervals) and the min-max offsets, will dictate the number of nodes that need to be available for the project. In this paper, we established the key procedures to be executed during the survey evaluation and design phase to determine the correct node intervals, the maximum and minimum offset, the shot intervals and shot extents (halo) to optimize these parameters to best illuminate the target area. We have developed an approach to calculate the shooting polygon area by extending the node (receiver) area by the length of the desired halo. The SED can also study the feasibility of the converted-wave which is naturally acquired in the nodes survey and also determine the best parameters for this wave field.

Introduction

The new technology of Oceanic Bottom Nodes (OBN) has progressed significantly over the past decade. Surveys in oil fields with sub-sea infra structure and areas with complex geological overburdens are currently being designed using OBN because of the flexibility to deploy receiver in the vicinity of the obstructions as well as the true 3D nature of the seismic acquisition proper to illuminate deep targets under complex geological structures (Guimaraes, M.G, 2012).

Very thorough and detailed survey planning has to be conducted in order to balance survey operation efficiencies and economics. Therefore, node intervals on the seafloor has to be carefully considered in order to derive the ideal number of nodes for a survey. Illumination is very important since one has to guarantee proper illumination at the target depth with full-azimuth and large aperture.

The shooting area polygon and the maximum offset are determined during the survey evaluation and design (SED) modeling studies. The shooting area is determined once the length of the halo is decided. The Shooting area is computed by expanding the nodes area by the halo length. Khan et. al. (2009) described an interesting approach to expand polygons. We have implemented some modifications to make the algorithm more robust for different types of polygons.

After the parameters are defined by the SED, we are able to compute various operational parameters for a given survey. Initially, these are rough estimates, that are computed to estimate the survey duration, fold, etc.

Modeling

A number of forward modeling methods are available, and the choice of method generally depends on a tradeoff between the accuracy necessary and the desired computing time. In general, the type of data to be modeled, the complexity of the model, and the aspects of the data that need to be accurately modeled dictate the method that should be used.

Ray theory uses the fact that energy in the form of rays travels along minimum time paths in the model. As in optics, rays bend when velocities change, obeying the Snell's law, and are partially reflected when velocity or density discontinuities are encountered. The travel times of the reflected arrivals correspond to the times of the minimum time paths, while amplitudes are a combination of geometric spreading and reflection coefficient (Fig.1). The reflection coefficient, based on the Zoeppritz equations for elastic media, depends on the velocities and densities on both sides of the interface, as well as on the incidence angle of the ray.

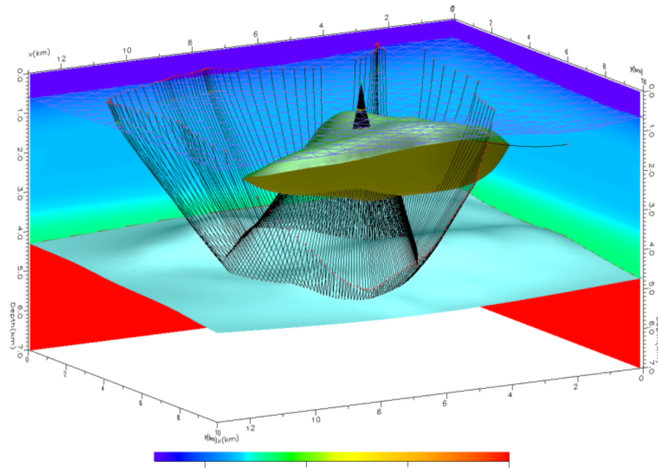


Fig. 1: In ray-tracing, the rays travels along minimum time paths in the model bending when velocities change, obeying the Snell's law, and are partially reflected when velocity or density discontinuities are encountered.

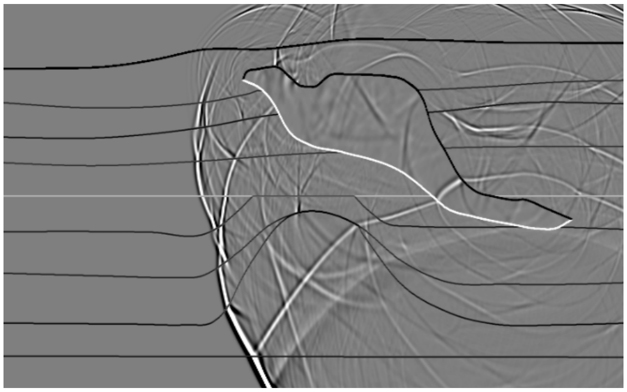


Fig. 2: Wave-equation acoustic model.

Ray methods usually give very accurate travel times and accurate amplitudes for geometric arrivals if the model is sufficiently smooth. These methods are efficient, and computing time is low to moderate. However, such ray-tracing techniques are not able to handle rapid velocity-structure variation and requires instructions to the wave-field which contributes to understand the origin of each reflection.

Wave-equation methods solve the propagation problem over the entire model, rather than performing local solutions as in ray methods. Two commonly used wave methods are the Kirchhoff method and the finite difference method. Finite difference methods can provide very accurate results even in the most complex media (Fig.2). These methods provide exact numerical solutions and can include all wave phenomena, such as diffractions, multiples, and ground roll. The only limitations on finite difference methods are imposed by computing time, which is high in two dimensions and very high in three dimensions. This effectively limits grid size and hence the resolution obtainable. However, these are still the methods of choice for highly faulted complex models for which amplitude accuracy is important. Wave-equation techniques are more precise since it generates the actual propagation field and can handle complex geologic structures.

Node surveys are requested because of the 3D full azimuth nature to acquire data mainly because the presence of complex geologic overburden such salt domes, over thrust faults, etc. Such geologic situations are not well handle by ray-tracing technique alone and wave-equation methods are required to carry out the forward modeling study.

Forward modeling is the most important phase of the survey evaluation and design because defines the main acquisition parameters such as *X* and *Y* node intervals, node area, shot halo, and the shot interval and shot line interval. If one is concerned about the adverse effects of loss of nodes, maximum space node, missing near offset data, end-on verses split-spread, or other aspects of a particular survey design, working with a synthetic data set that has been properly decimated or sorted can help answer the question about these survey designs. In the Fig. 3, we show a simple example of an acoustic wave-equation modeling on a 3D salt model for a node geometry. Up-coming (direct) and Down-going (mirror) nodes gather are generated for the areal shooting on the surface. Figure 4(a) shows the up-coming gather migrated and Fig. 4(b) the down-going (mirror) migrated.

Figure 5a shows a migrated in-line (direct + mirror) of all nodes throughout the 3D model. The images are summed to generate the full fold image of the sub-surface. Decimation of nodes exercises can be done to evaluate the illumination in different levels. Figure 5b shows the same migration but decimating nodes by four in the whole survey. This exercise can also indicate an acceptable node failure tolerance during the data acquisition.

Another important parameter to be studied in the modeling is the maximum offset. Node survey happen to be very expansive because of the duration to perform the carpet of shots on the surface. Larger offsets, extend the carpet to assure the maximum offset.

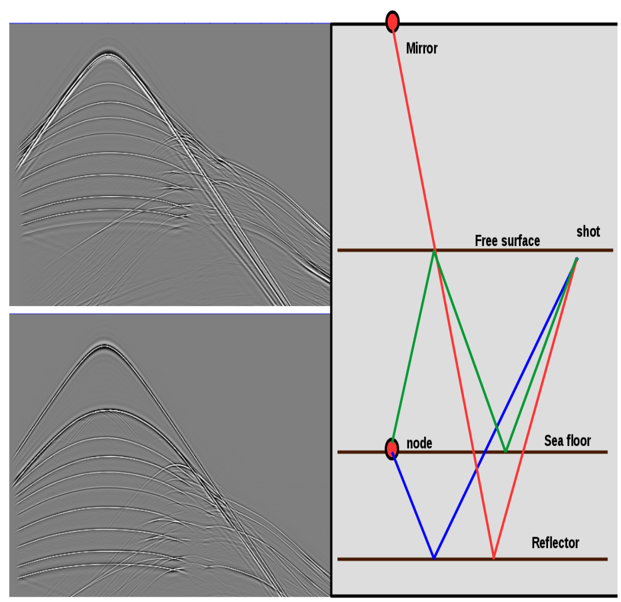


Fig. 3: At left, up-coming/direct (ray in blue) and down-going/mirror (ray in green/red) common node gathers generated by a full acoustic wave-equation modeling.

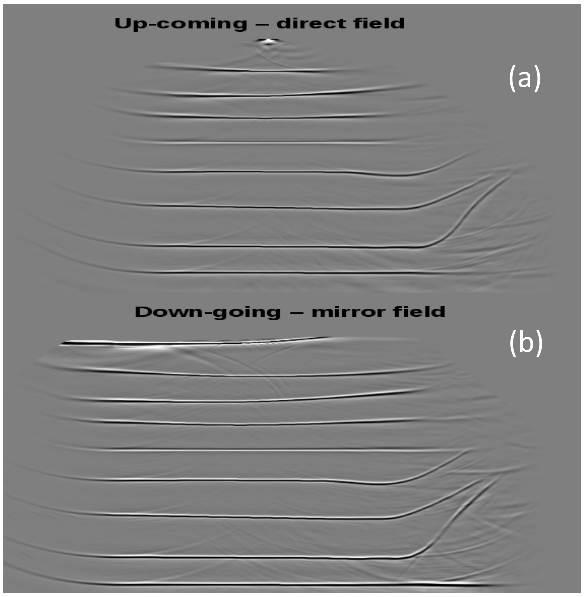


Fig. 4: Shot-record migration applied for each field. Notice the difference of the seafloor image and the lateral extent in the illumination of each field.

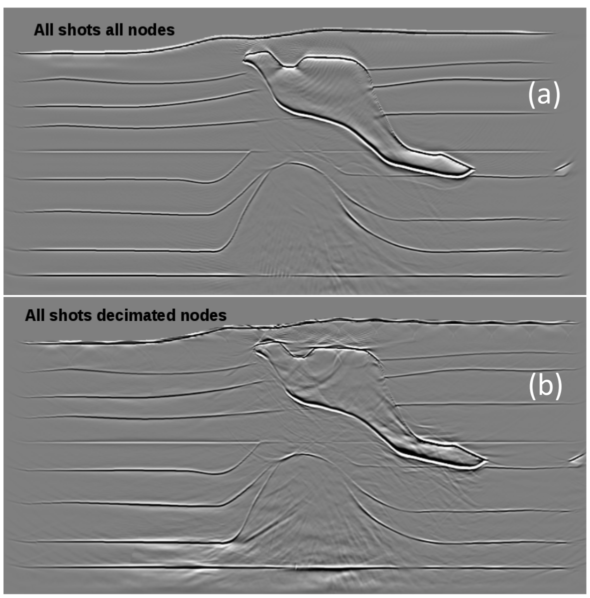


Fig. 5: 3D PSDM final volume composed of direct + mirror fields with all nodes and shots. **(b):** 3D PSDM final volume composed of direct + mirror fields with all shots and nodes decimated by four.

Once the maximum offset and the nodes area are defined, one has to determine the shooting area which is just the extension of the nodes area by either the length of the maximum survey offset or the desired halo around the nodes area. As most of the polygons are those surrounding the geological area, they can be either concave or convex with multiple sides which makes more difficult the expansion approach.

We started with Khan *et. al.*, 2009 to create an algorithm to expand such polygons. We realize that their algorithm failed for some polygons so we developed the following approach that can be used in such polygons.

Let δ denote the value of offset, and (x_i, y_i) the coordinates of the original polygon to be expanded, expressed clockwise direction. Note that for the polygon of N sides, the coordinates for $i = 0$ coincide with the coordinates for $i = N$ to complete the cyclical nature of the polygon. The coordinates of the expanded polygon (X_i, Y_i) can be calculated through the following routine:

$$\emptyset_i = \tan^{-1}\left(\frac{x_i - x_{i-1}}{y_i - y_{i-1}}\right) \quad (1)$$

$$\alpha_i = x_i - \delta.\sin(\emptyset_{i-1}) \quad (2)$$

$$\beta_i = y_i + \delta.\cos(\emptyset_{i-1}) \quad (3)$$

$$X_i = \frac{-\alpha_i.\tan(\emptyset_{i-1}) + \alpha_{i+1}.\tan(\emptyset_i) + \beta_i - \beta_{i+1}}{\tan\emptyset_i - \tan\emptyset_{i-1}} \quad (4)$$

$$Y_i = \frac{(\tan\emptyset_{i-1}\tan\emptyset_i).(\alpha_{i+1} - \alpha_i) - \beta_{i+1}.\tan\emptyset_{i-1} + \beta_i.\tan\emptyset_i}{\tan\emptyset_i - \tan\emptyset_{i-1}} \quad (5)$$

For the area calculation, let (x_i, y_j)denote the coordinates of the polygon for which we wish to calculate the area, expressed clockwise direction. Note that for the polygon of N sides, the coordinates for $(i = 0)$ coincide with the coordinates for $(i = N)$, to complete the cyclical nature of the polygon. The area can be calculated through the following routine:

$$\xi_i = x_i.y_{i+1} \quad (6)$$

$$\eta_i = y_i.x_{i+1} \quad (7)$$

$$S_{polygon} = \frac{1}{2}\left|\left(\sum_0^N(\xi_i - \eta_i)\right)\right| \quad (8)$$

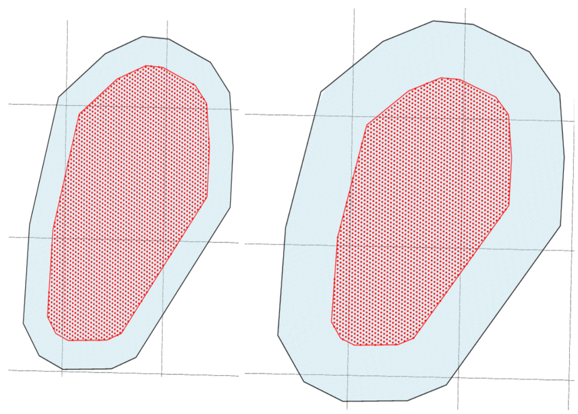
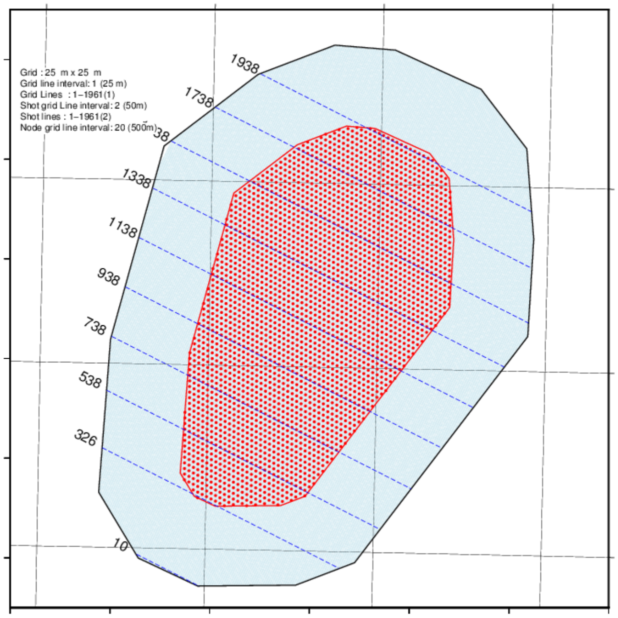


Fig.5: Expansion of polygon which represent the computed nodes area (red) to generate the shooting polygon (light blue). At left the expansion used was 4 Km and at right 8Km.



1 – Nodes area (500x500): 729.808899
2 – Shot area 1782.57922
3 – Nodes 500x500 /km2: 3.97912383
4 – Total nodes per line (500x500): 29.
5 – Total number Nodes line (500x500): 99
6 – Total number of 500x500 nodes: 2904
7 – Number of shots/line (avg) 618.988586
8 – Shot Line Length average (m) 30949.4297
9 – Number of shot lines 1141.
10 – Total number of shots – survey 706266.
11 – Total Km Shots survey 35313 35313
13 – Turns: 570.
14 – Vessel speed (Km/h): 7.03760004
15 – Sailine length (Km): 30.9494305
16 – Turn time / line (hrs): 0.5
17 – Total sailtime/line(hrs): 4.89772511
18 – Sail(Sequence) lines/day: 4.90023422
19 – Total source lines/day: 9.80046844
20 – Days to shot: 116.423004
21 – Source km/day : 303.318909

Fig. 6: operation create the shooting polygon (light blue). At left the expansion used was 4 Km and at right 8Km.

Once the shots and nodes areas are defined, the maximum offset in both directions, shot and shot line space, nodes spaces, nodes available for the survey, battery life, ROV deployment and pick up time, shooting vessel time, shooting line changes time, surface obstructions, sub-sea infrastructure, and some other physical parameters like currents, etc. Thus the statistical of the survey is computed (Fig.6). Another option is to use a software package similar to *SEAFLOOR PLANNER* which is able test several motion and time scenarios for the survey.

The Figures 7 shows a survey design in area with obstructions for shooting on the surface. After respecting the exclusion zone the up-coming + down-going field fold is computed. The Figures 8-10 shows the total fold for different apertures: Fig.8 offsets of 0-2000m, Fig. 9 offsets of 0-4000m and Fig.10 offsets 0-6000m.

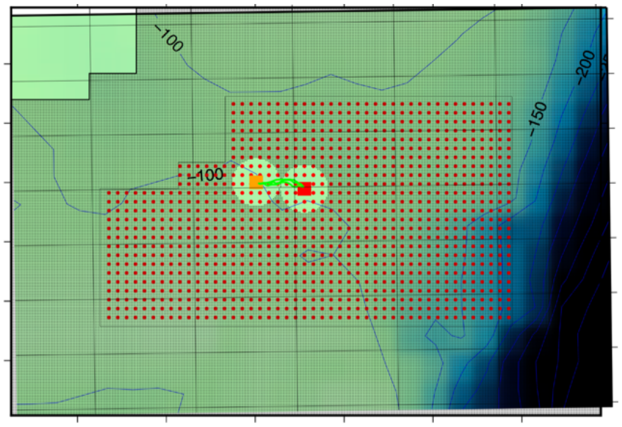


Fig. 7: Survey design with the expanded shooting polygon and the nodes area. In the vicinity of the platforms shots are excluded so the correct fold can be computed.

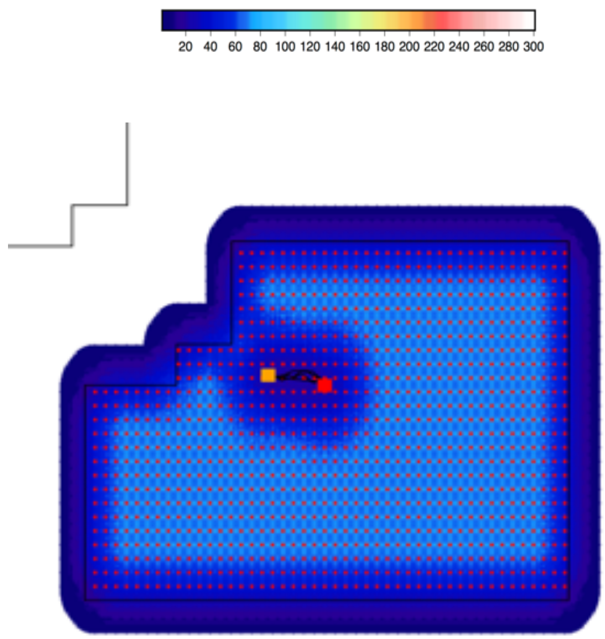


Fig. 8: Direct + mirror fold limited by the offsets 0-2000m.

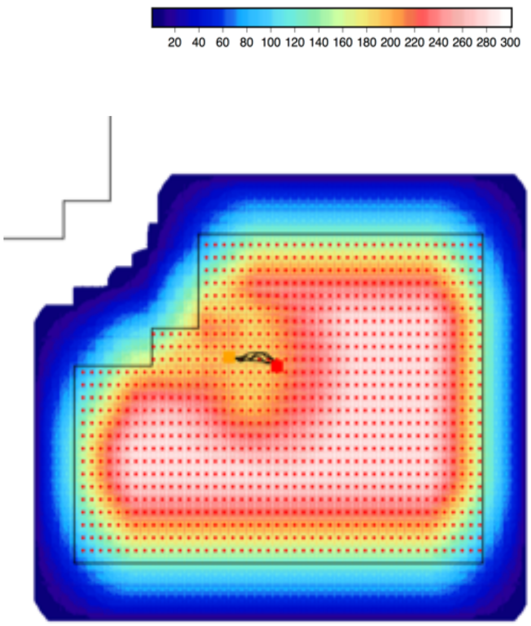


Fig. 9: Direct + mirror fold limited by the offsets 0-4000m.

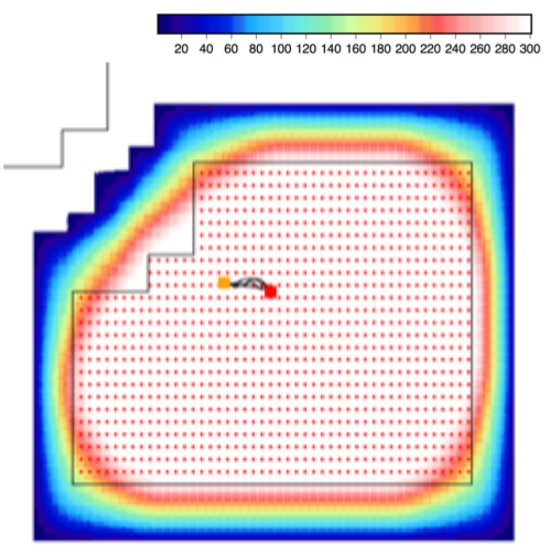


Fig. 10: Direct + mirror fold limited by the offsets 0-6000m.

Conclusions

We present in this paper the most important tasks of the survey evaluation design for deep-water oceanic nodes. The numerical modeling plays an important role to define the node spacing and the node area surrounding the geological target area. The maximum offset and the halo are also defined in the modeling study. In summary, the numerical modeling defines the number of nodes positions to be used in the survey and the maximum offset to illuminate the targets.

Once the maximum offset is defined, we developed an algorithm to expand the nodes area by the length of the desired halo to define the shooting area. The shooting area along with the maximum offset define the template to acquire the whole survey given a number of nodes available by the company. Depending on the size of the nodes area, nodes should be retrieved to download data and recharged batteries. Then they are re-deployed ahead. Knowing the maximum number of nodes available, the maximum offset and the shooting area one can compute precisely the turnaround time to perform the whole survey. Parameters such as shooting vessel speed, ROV deployment and pick up speed, line change time, stand by, etc., are used in this computation.

The survey evaluation and design can also use to study the feasibly of the converted waves. The study can show the potential advantages of the converted wave for the survey. The forward modeling with elastic wave-equations will guide the definition of all the specific parameters necessary for converted-wave imaging.

Acknowledgments

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