Sensitivity of AVO to Coverage Gaps

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Key words

Data gaps, Interpolation, AVO

Summary

Towed streamer 3D seismic acquisition suffers from data gaps that arise due to feathering, obstructions in the survey area, etc. Even though, we are able to fill some of those gaps using processing techniques like interpolation and migration, however, the large holes present in the data affect seismic imaging and thereby deteriorate AVO analysis.

Our objective is to carry out real data analysis to demonstrate the effect of coverage gaps at various offsets with respect to AVO studies and to verify the maximum hole size that can be handled by interpolation algorithms**.** This type of analysis may help in cost effective infill management during acquisition and may reduce the burden of infill traverses.

Introduction

Coverage holes are inevitable in seismic data acquisition due to steamer feathering. Relaxation of coverage holes is critical in near offsets for shallow targets.Gaps will affect all image locations within the migration aperture, which can extend several kilometres depending on velocity and structural dip. This means that the localized geometry artefacts can extend to an areal extent much bigger than the actual gap zones.

It is well known that amplitude versus offset (AVO) phenomenon on seismic data can provide substantial exploration and development information. But, the presence of data gaps may provide erroneous results during AVO studies.

In order to evaluate the effect of data gaps on AVO attributes, the data gaps of sizes 100m, 200m, 300m & 500m had been deliberately created (Figure 1) to determine the sensitivity of amplitudes for coverage gaps. As per the current industry practice, before migration the input seismic data volume is regularized and interpolated for data redundancy and gaps, however the possibility of filling the gaps depends upon the size of the gaps.

For that, 3D interpolation using Fourier reconstruction in F-Kx-Ky domain was tested for all data gaps and subsequently sensitivity of AVO was analysed**.**
As part of this study, following Aki and Richard approximation to Zoeppritz equation is considered for generation of AVO attributes

$$R(\theta) \approx A + B \sin^2 (\theta)$$

where,
A is the intercept of AVO,
B is the AVO gradient and
θ is the angle of incidence.

Both the estimated intercept and the gradient volumes are used in locating anomalous zones. Sensitivity of intercept and gradient attributes with missing offsets was studied.

Our study area shows Class-III AVO in shallow unconsolidated sands that played a significant role in identification of prospects.

Data Preparation

Data considered for this study is from Indian offshore basin. Area for creating holes was selected by considering geological and geophysical aspects like structure, amplitude variation with offset and fault focusing etc. In the present study, main focus was on shallow amplitude anomaly showing Class-III AVO.

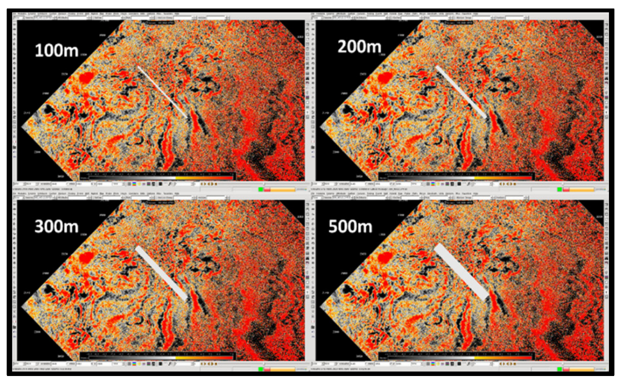

Figure – 1: Display of different sizes of holes created in the data.

The input data was Kirchhoff Pre-Stack time migrated gathers followed by noise attenuation and multiple elimination (SRME). This data is considered as reference gathers for further comparative analysis.

Then the data gaps of various sizes (100m, 200m 300m & 500m) as shown in Figure 1 were created in all offset classes and the workflow shown in Figure 2 was carried out for further AVO studies.
Two datasets were created; one was the pre-stack migrated gathers with holes in each offset class and second was the corresponding interpolated gathers.

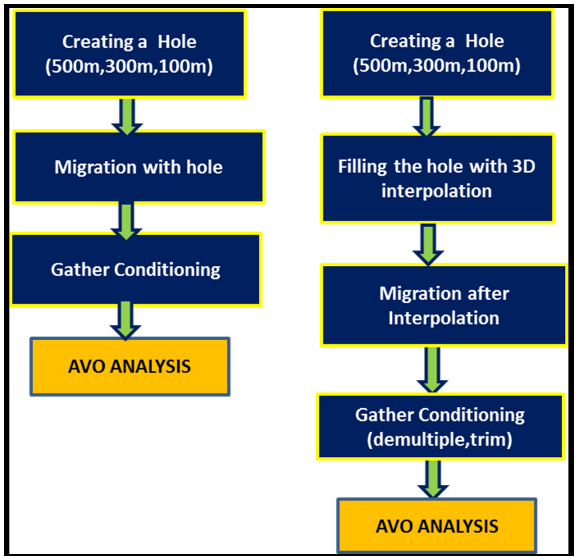

Figure – 2: Data Preparation Workflow

Data Analysis:

Basic AVO analysis was carried out on both the data with gaps as well as the interpolated datasets, and the results were compared with the reference gathers. Basic attributes viz., Intercept (RO) and Gradient (G) were generated for different data sets as defined earlier and following analyses had been carried out to examine the effect of data gaps on AVO.

I. *Pick Analysis (At the Target Horizon)*
II. *Cross Plots – AVO Attributes (around the Channel)*
III. *Amplitude Variation with Offset (RMS) (1000ms Time Window)*
IV. *Time Misalignment*

Results

I. Pick Analysis

Normally, variation in reflection amplitude as a function of incidence angle is analyzed to detect the changes in elastic properties of reservoir rocks such as Poisson's ratio. This may suggest that the change in the ratio of P-wave to S-wave velocities further imply the change in fluid saturation within the reservoir rocks.

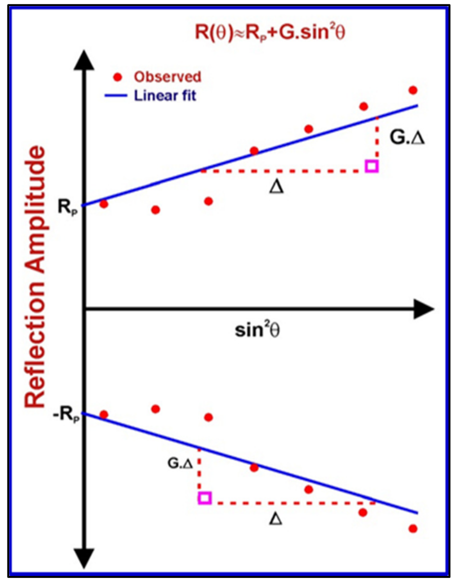

Figure – 3: Theoretical representation of amplitude variation with offset

The Aki-Richards approximation predicts a linear relationship between these amplitudes and Sin$^2\theta$. Regression curves are then calculated, to get Intercept (A) and Gradient (B - slope of the regression) values for each time sample.

Figure 3 is a classical representation of the linear regression trends used to fit the amplitudes picked for Class – III AVO. Loss or missing of amplitude points because of data gaps deviate the trend thereby giving incorrect Intercept and Gradient results. Supporting that, the same regression analysis is carried out for reference, gapped and interpolated data at the shallow target horizon as shown Figure 4.

Yellow curve represents the pick analysis for the reference data. Green, Magenta, Blue and Red bold curves represent the gapped data with 100m, 200m, 300m & 500m and dotted curves show the corresponding interpolated versions. Interpolated data of smaller holes (100m & 200m) could be able to match with the reference trend but 300m and 500m could not retrieve the reference trend.

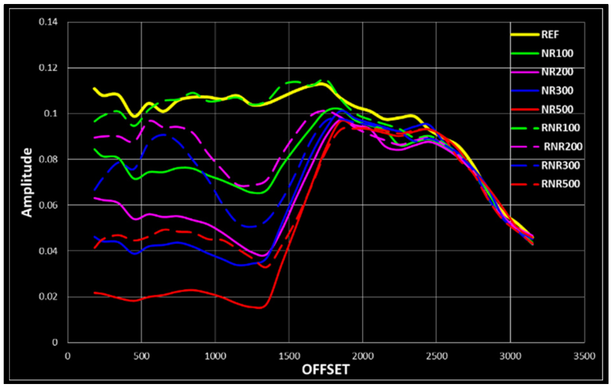

Figure – 4: Comparison plot (gapped vs interpolated) of pick analysis for different hole sizes.

From the regression analysis of above curves, intercept and gradient values were measured and the same are plotted as Histograms (Figure – 5)

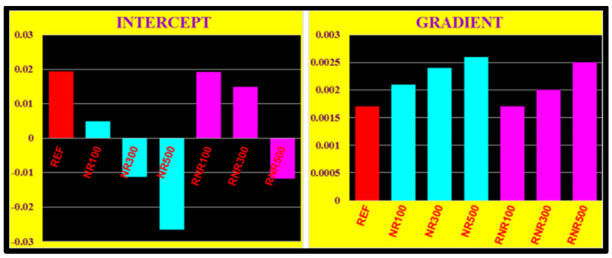

Figure – 5: Comparative study of intercept and gradient values of data before (Cyan) and after Interpolation (Magenta).

The above plots exemplify how the intercept and gradient values change dramatically because of the presence of gaps in the data. Here, reference data with intercept value of 0.02 was gradually reducing to -0.025 (500m gapped data) with increase of hole size leading to polarity change. Similarly, gradient value of reference data 0.0017 is increasing gradually to 0.00224 (for 500m data) by increasing hole size. So, loss or missing of amplitudes at any of the offsets misleads the trend distinctly thereby giving incorrect results of AVO.
Thus, Table – 1 emphasizes the size of the gaps that can be relaxed during acquisition

Hole Size	Near Offset 0-1500m	Near Mid 1500-3000m	Far Mid 3000-4500m	Far Offset 4500-6000m
100m	✓	✓	—	—
200m	✓	✓	—	—
300m	✗	✗	—	—
500m	✗	✗	—	—

Table – 1: Comparative study through Pick Analysis resulting the maximum hole size that can be relaxed at different offsets during seismic acquisition.

II. Cross Plots (AVO Attributes):

Cross plots of AVO attributes define the type of AVO present in the data. Variation in background trend is the resultant of changes in Vp/Vs
As part of our study, AVO attribute (Intercept & Gradient) cross plot was generated for 100ms time window at the target to see deviation of the anomalous points from the background.

Cross plot of reference data (Figure 6) shows that the anomalous points falling in the 3rd quadrant which represents Class – III anomaly in the target. However, comparison of cross plots generated for all four hole sizes (100m, 200m, 300m &500m) exhibit the increase of missing or disorienting of anomalous points and subsequently changing the background. This will delude the basic interpretation incurred from reference data (Figure 7)

Nevertheless, crossplots of interpolated data ((Figure 8) demonstrate that the missing or disorienting anomalous points had been retrieved back for smaller holes but the problem still persisted with gapped data of sizes 300m and 500m.

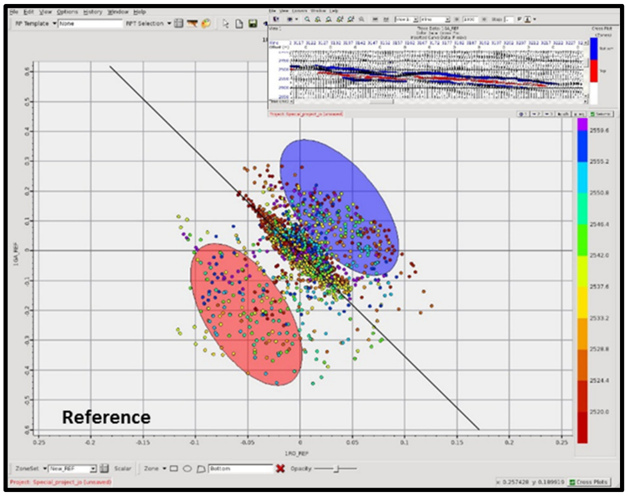

Figure – 6: Intercept and Gradient crossplot generated for Reference gathers

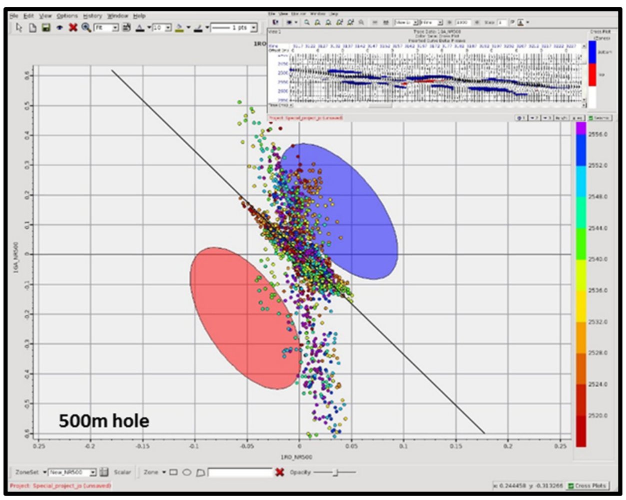

Figure – 7: Crossplot of gathers with 500m gap

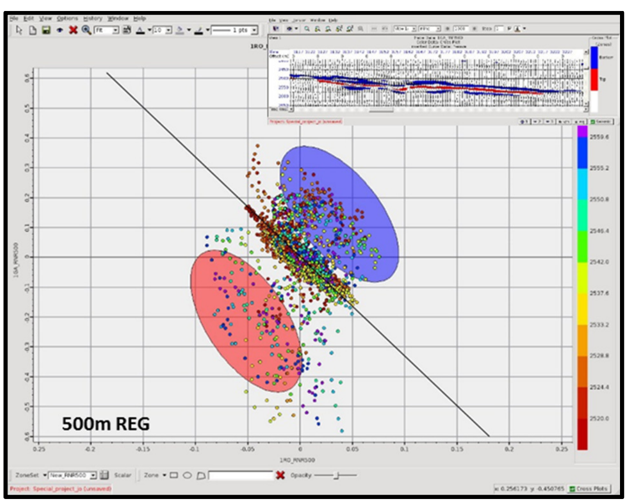

Figure – 8: Crossplot of gathers after regularizing 500m gap

Series of Crossplots of data with coverage gaps (Figure 9a) and after interpolation (Figure 9b) are shown below to demonstrate how the anomalous points and background trend vary with increasing hole sizes

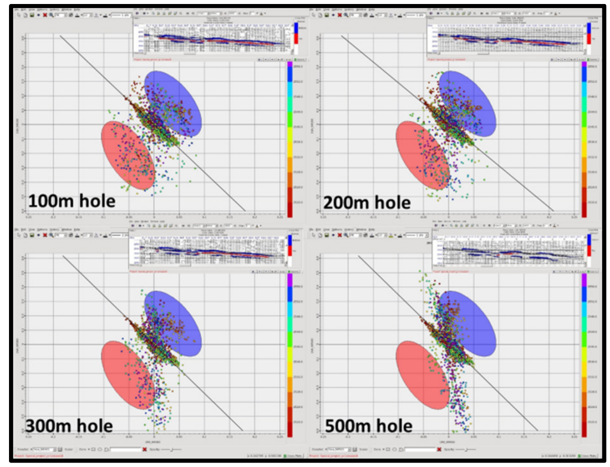

Figure – 9 (a): RMS windows of gapped gathers: data referred to from left to right – 100m hole, 200m hole, 300m hole and 500m hole each

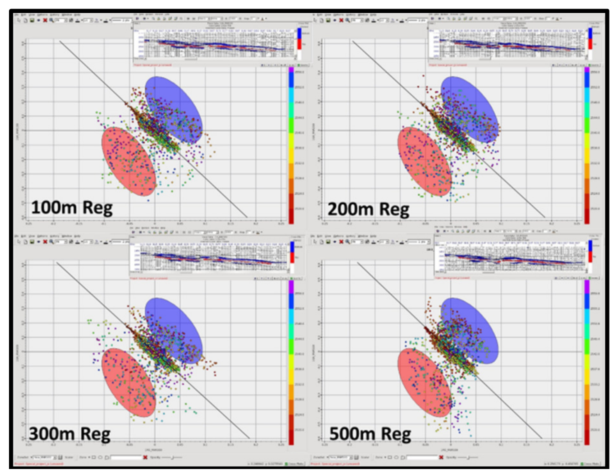

Figure – 9 (b): RMS windows of interpolated gathers: data referred to from left to right – 100m hole, 200m hole, 300m hole and 500m hole each

Following table summarizes the results achieved from crossplot analysis. Hence, this study also illustrate the maximum gap size that can be relaxed for shallow targets.

Hole Size	Near Offset 0-1500m	Near Mid 1500-3000m	Far Mid 3000-4500m	Far Offset 4500-6000m
100m	✓	✓	—	—
200m	✓	✓	—	—
300m	✗	✗	—	—
500m	✗	✗	—	—

Table – 2: Comparative study through Cross plots showing the maximum hole size that can be relaxed at different offsets during seismic acquisition

III. Amplitude Variation with Offset

AVO is analyzed over a window of 1000ms to see the RMS trend for both sets of data. Outputs are compared with RMS trend of reference gathers as shown in Figure 10.

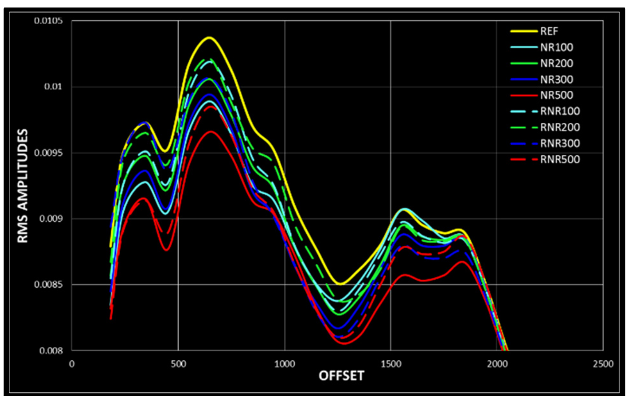

Figure – 10: RMS amplitudes graph depicting the amplitudes of Reference data, gapped data (Bold lines) and Interpolated data (dotted lines)

This study is carried out to understand the amplitude variation with offset in the background data. It also supports that there would be deviation of background with increasing hole size as mentioned in crossplot analysis.

IV. Time/Phase Misalignment:

In addition, it is observed that there is a time shift in the data because of increasing coverage gap. This can be explained from Figure 11. Target event is picked at the peak in the reference data as shown in Figure 11 (A). Data points can be seen above the zero crossing line for comparison. This means that the data points of near and near-mids are in positive section. However, 500m hole in the near offset data as shown Figure 11(B) is coercing the data points of further offsets towards negative section by causing time misalignment of ~5ms. But after 3D interpolation, this problem is reduced to ~2ms. So, Interpolation is able to handle the misalignments as shown in Figure 11(C) and can further be minimized by present robust processing workflows.

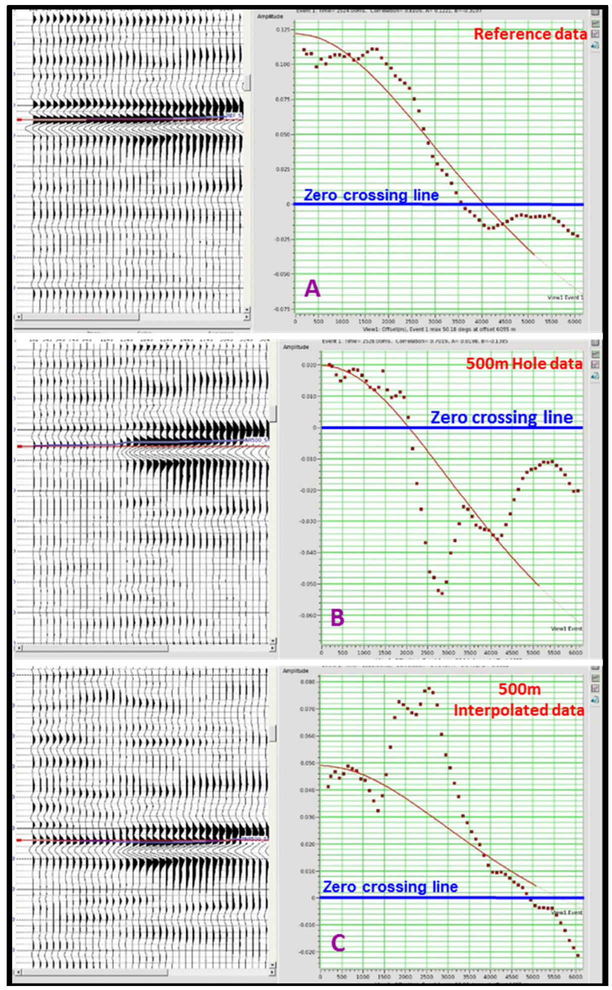

Figure – 11: Time misalignment and amplitude loss comparison among reference (A), 500m gapped (B) and 500m regularized (C) datasets

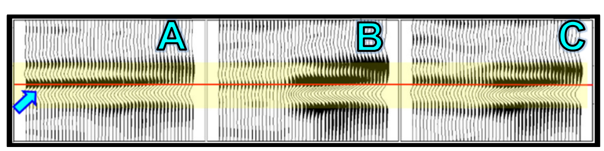

Figure – 12: Time misalignment highlighted in Reference (A), 500m gapped (B) and 500m Regularized (C) datasets

Images shown below emphasize the misalignment of data from near to far as the 500m gap created at near offset (as shown in Figure 12). Thus, loss of data leads to misalignment of time or phase in the gathers from near to far offsets which increases with respect to gap size

However, present day robust AVO algorithms can handle this type of obstacles. But, it is recommended to give attention for checking the presence of coverage gaps prior to AVO studies.

Conclusions

Based on our study, the following conclusions are arrived:

- Sensitivity of AVO to coverage gaps depend upon the size of the hole.
- AVO response for the smaller holes can be handled by 3D interpolation schemes whereas for the larger holes, AVO response could not be retrieved.
- 3D interpolation schemes can retrieve the background trend, but not the AVO effect if the hole size is larger
- This type of analysis may help in cost effective infill management during acquisition and may reduce the burden of infill traverses.
- This study also assist as a pre-check in terms of data gaps in gathers before starting the geophysical analyses.

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