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Investigating the Effects of Crooked-Line Geometry Using Seismic Modeling

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Abstract Summary

This work investigates the effects of crooked-line geometry on the seismic response through forward modeling using a horizontally layered velocity model. Straight-line and crooked-line geometry were compared using identical and conventional processing workflows. The crooked-line caused distortions in the hyperbolic events and introduced artifacts and discontinuities in the seismic horizons, based on analysis of the pre- and post-stacking data. In addition, significant amplitude irregularities were observed compared to the straight-line case, highlighting the need for specific processing strategies for crooked-line geometry.

Introduction

Land seismic surveys often face terrain-related restrictions that prevent the deployment of reasonably straight-lines. However, many processing workflows assume linear geometry as a premise, which can lead to discrepancies when this condition is not met, as in crooked-line geometries, where sources and receivers are not aligned. This inadequate alignment can compromise the data quality and, consequently, the geological interpretation of the subsurface.

In this work, a crooked-line geometry extracted from a real datas set acquired in the Taubaté Basin by the National Agency for Petroleum, Natural Gas and Biofuels (ANP) was used to investigate the effects of acquisition geometry on the seismic response through acoustic seismic simulation. The work is carried out by comparing straight and crooked geometries, applied to the same velocity model. The analysis includes comparisons of synthetic seismograms, stacked sections and amplitudes along seismic horizons, investigating the impact of geometry inflections on the continuity and coherence of reflected events.

This study is in line with works such as Nedimović and West (2003) and Du Bois et al. (1990), which emphasize the influence of acquisition geometry on seismic imaging quality.

Methodology

The seismic data was simulated using a software package called Seiswave3D, developed by the Seismic Inversion and Imaging Group (GISIS) at Fluminense Federal University (UFF), which simulates wave propagation in 3D media using the finite-difference methods. The acoustic seismic modeling as applied using a velocity model measuring 20005 m (X-axis) × 2505 m (Y-axis) × 605 m (Z-axis), sampled every 5 m in all directions and composed of four horizontally layered with velocities of 1700, 1900, 2100, and 4500 m/s from top to bottom (Figure 1).

Both surveys used a split-spread layout: the receivers were positioned along the X axis at 25 m intervals, and the sources were positioned every 50 m. Each shot used a gather of 122 channels. In total, 339 shots were simulated for the straight-line geometry and 379 shots for the crooked-line geometry, covering the entire longitudinal length of the model. A simulation with several shots was chosen in order to analyze the full extent of the acquisition geometry and to obtain stacked seismic sections. The parameters defined for modeling were: a recording time of 2 s, a sampling interval of 4 ms, a zero-phase Ricker wavelet with a cut frequency of 75 Hz.

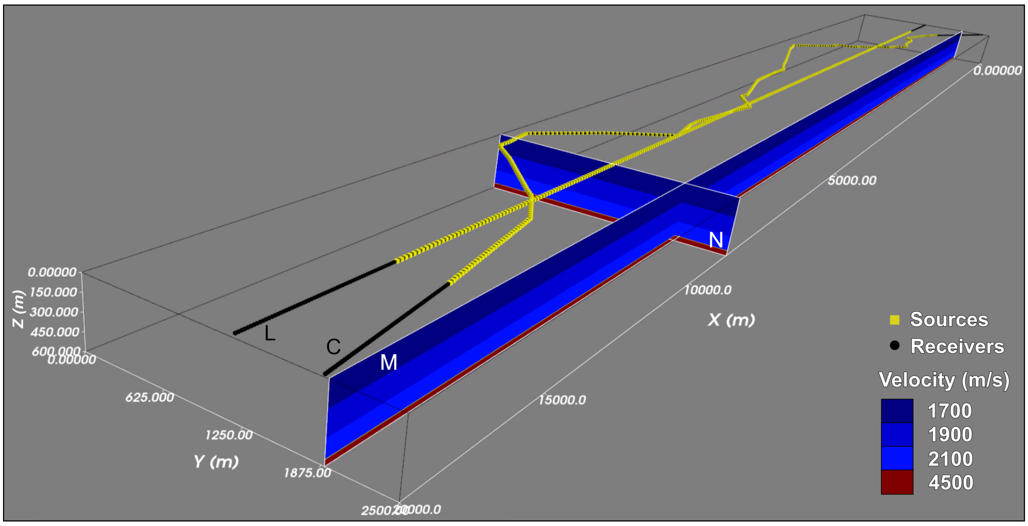

Figure 1: 3D acoustic velocity model used in the seismic simulation, with two highlighted sections: M (In-line) and N (Crossline). The acquisition geometries are indicated by L (straight-line) and C (crooked-line).

After seismic modeling, the synthetic data were processed using the Echos software (AspenTech). The adopted processing workflow followed the steps shown in Figure 2: trace editing (including muting of the central trace of each shot to remove high-amplitude noise), acquisition geometry assignment, normal moveout (NMO) correction using the velocity model from the simulation, and common depth point (CDP) stacking to generate seismic sections. The same velocity model, modeling parameters, and processing sequence were applied to both the straight-line and crooked-line data sets, ensuring comparability of the results.

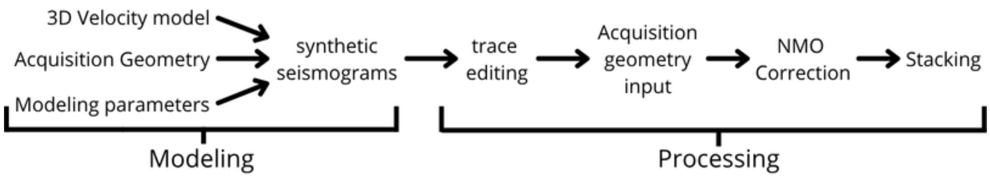

Figure 2: Processing workflow applied to both acquisition geometries: straight and crooked.

The investigation of the effects of geometry was based on a comparison between the two seismic data sets and was divided into two stages: pre-stack and post-stack. In the first stage, the synthetic seismograms were examined in relation to the acquisition geometry, focusing on the shot positions located in the regions of greatest inflection along the crooked-line. The second stage analyzed the stacked data, relating it to the complete acquisition geometry.

Results

In the first stage, the results showed that the irregularities in the crooked-line geometry had an evident impact on the seismic response, visible in reflection and direct wave events, which exhibited distortions associated with the geometry curvature (Figure 3B). In contrast, the seismogram shown in Figure 3A, acquired with a straight-line, did not present any distortions in the recorded events.

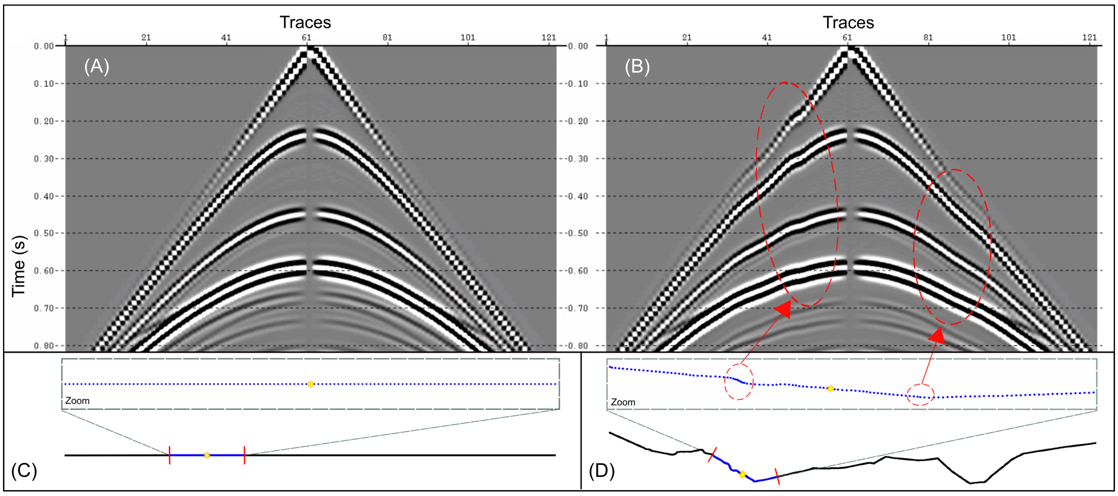

Figure 3: **(A)** Seismogram for the straight-line geometry. **(B)** Seismogram for the crooked-line geometry, with distortions in the hyperbolic events highlighted in red. **(C)** Straight-line geometry with a zoom on the central region. **(D)** Crooked-line geometry, also zoomed in, showing with red arrows the relationship between its irregularities and the effects seen in **(B)**. The blue dots represent the active receivers for the specified shot and yellow asterisk indicates the seismic source.

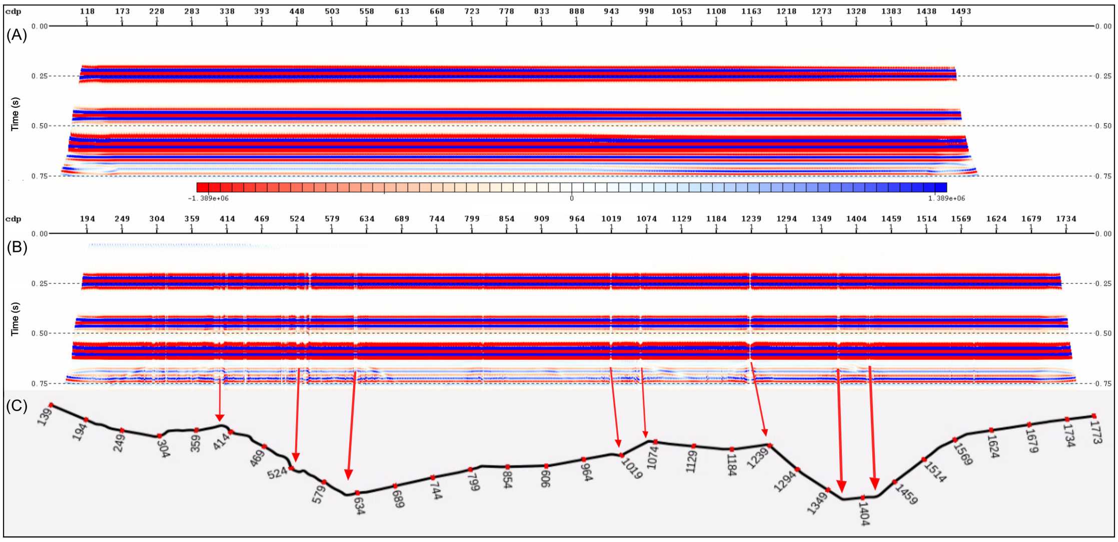

Figure 4: **(A)** Stacked section with straight-line geometry. **(B)** Stacked section with crooked-line geometry, showing discontinuities in the horizons compared to **(A)**. **(C)** Crooked-line geometry with CDPs along the seismic line; arrows indicate the correspondence between line inflections and the discontinuities seen in **(B)**.

In the second stage, it was noted that the straight-line geometry preserved the reflectors without structural alterations (Figure 4A), while discontinuities and amplitude-related noise were identified in the reflectors, coinciding with the inflection zones along the crooked-line geometry (Figure 4B). The distribution of the CDPs is consistent with these structural variations observed in the stacked section (Figure 4C), highlighting the influence of acquisition geometry on the continuity and quality of the reflected events.

The amplitudes for the three seismic events in the stacked section were examined in detail. First, the amplitudes of the straight-line geometry (Figure 5A) are more consistent and exhibit minimal variations. In contrast, Figure 5B reveals highly irregular amplitudes for the crooked-line geometry, especially at CDP positions corresponding to the seismic line inflections. This demonstrates that the crooked-line introduces significant data distortions even under the same subsurface model.

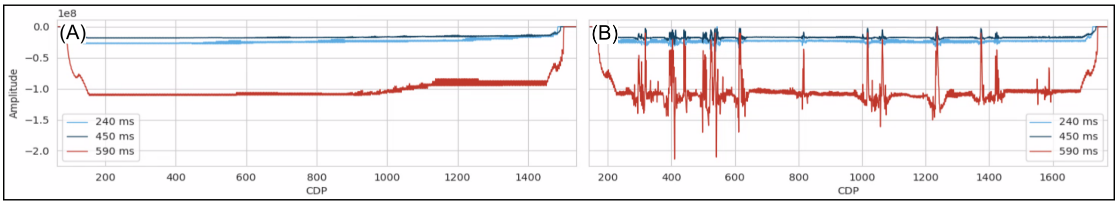

Figure 5: Amplitude analysis for each seismic interface. **(A)** Amplitudes for the straight-line geometry, showing a more uniform distribution. **(B)** Response for the crooked-line geometry, exhibiting significant amplitude variations associated with the irregularity of the seismic geometry.

Conclusions

Forward modeling with crooked-line geometry showed that inflections along the line significantly impact the seismic response, even in simple models such as horizontally layered. Distortions and loss of coherence were observed in the hyperbolic events on the pre-stack data, along with discontinuities and artifacts in the interfaces of the stacked section, and strong amplitude variations (Figure 5), all of which compromise data quality.

These results reinforce the need for specific processing techniques when dealing with irregular geometries, such as adaptive binning, CDP repositioning, dip-moveout (DMO) correction, cross dip-moveout (CDMO) correction and 3D prestack migration.

Future work will focus on the development and testing methods to attenuate these effects and improve seismic imaging and geological interpretation.

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