3D curvature analysis of seismic waveform and its interpretational implications

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Outline

• Motivation
• Waveform curvature vs. geometric curvature
• Interpretational implications
• Application to horizon modeling
• Limitations
• Conclusions
Motivation

• Curvature analysis is useful for measuring the reflector geometry to depict the surface morphology and highlight the potential faults and fractures caused by anticlinal bending (e.g., Roberts, 2001);
• The reflector geometry is only partial information offered in a seismic cube, and the reflection waveform is also of significant importance for interpreting the seismic signals;
• What if applying the curvature analysis to the reflection waveforms?
Curvature

\[ k_{2D}(x, z) = \frac{z''}{(1 + z'^2)^{3/2}} \]

\[ k_{3D}^{\text{max}}(x, y, z) = \text{MAX}(k_{3D}^\varphi(x, y, z), \varphi=[0^\circ, 360^\circ]) \]

\[ k_{3D}^{\text{min}}(x, y, z) = \text{MIN}(k_{3D}^\varphi(x, y, z), \varphi=[0^\circ, 360^\circ]) \]

where

\[ k_{3D}^\varphi(x, y, z) = \frac{1}{\left[1 + A_1^2 + A_2^2\right]^{1/2}} \cdot \frac{(B_1 + B_2 \tan^2 \varphi + 2B_3 \tan \varphi)}{\left[(1+A_1^2)+(1+A_2^2)\tan^2 \varphi + 2A_1A_2 \tan \varphi\right]} \]
Waveform Curvature: 1D trace

\[ k_{2D}(z, w) = \frac{w''}{(1 + w'^2)^{3/2}} \]

where  
- \( z \): vertical coordinate  
- \( w \): waveform amplitude

2nd-order derivative  \( \rightarrow \) resolution enhancement
Waveform Curvature: 2D section

Take inline section for example:

\[
k_{3D}^{\text{max}}(x, z, w) = \text{MAX}(k_{3D}^\phi(x, z, w), \phi=[0^\circ, 360^\circ]) \text{ (in blue)}
\]

\[
k_{3D}^{\text{min}}(x, z, w) = \text{MIN}(k_{3D}^\phi(x, z, w), \phi=[0^\circ, 360^\circ]) \text{ (in red)}
\]

where  
x: crossline coordinate  
z: vertical coordinate  
w: waveform amplitude
A comparison

Table: Geometric curvature vs. waveform curvature

<table>
<thead>
<tr>
<th></th>
<th>Geometric curvature</th>
<th>Waveform curvature</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Object</strong></td>
<td>Curvature analysis of seismic signals</td>
<td>Reflection waveform</td>
</tr>
<tr>
<td><strong>Information for analysis</strong></td>
<td>a. Structural depth/time</td>
<td>Reflection waveform</td>
</tr>
<tr>
<td></td>
<td>b. Reflection amplitude</td>
<td></td>
</tr>
<tr>
<td><strong>Computation direction</strong></td>
<td>Horizontal (the x-y plane)</td>
<td>Vertical (the x-z and/or y-z plane)</td>
</tr>
<tr>
<td><strong>Implications</strong></td>
<td>Structure analysis:</td>
<td>Waveform analysis:</td>
</tr>
<tr>
<td></td>
<td>a. Fault detection</td>
<td>a. Resolution enhancement</td>
</tr>
<tr>
<td></td>
<td>b. Fracture characterization</td>
<td>b. Dip estimation</td>
</tr>
<tr>
<td></td>
<td>c. Reflector morphology delineation</td>
<td>c. Reflector decomposition</td>
</tr>
</tbody>
</table>
Implication #1: Resolution enhancement

a. Curvature: 2\textsuperscript{nd}-order derivative $\rightarrow$ better resolution

b. Maximum curvature: Normal to the reflection $\rightarrow$ more reliable analysis
Implication #2: Dip estimation

Minimum curvature: Parallel to the reflection $\rightarrow$ reflector dip

More in my next presentation at 3:05 pm

Orientation of Minimum waveform curvature

Dip-guided horizon tracking
Implication #3: Reflector decomposition

Peaks

Troughs

S-crossings

Z-crossings
Application to horizon modeling

Seismic image → Peak decomposition → Thinning → Seed picking and sorting

Horizon model → Seeded horizon tracking
Limitations

• Sensitivity to high-frequency components
• Sensitivity to vertical window size
• Sensitivity to seismic noises
Limitation #1: Sensitivity to high-frequency components

Take Ricker wavelet for example

\[ w(t) = A \cdot (1 - 2\pi^2 f_M^2 t^2) e^{-\pi^2 f_M^2 t^2} \]

Waveform curvature:

\[ k(0, w) = 6 \cdot A \cdot \pi^2 f_M^2 \]

- Linear to amplitude \( A \)
- Quadratic to frequency \( f \)
Limitation #2:
Sensitivity to vertical window size

Window size no larger than half of the waveform period
Limitation #3: Sensitivity to seismic noise

For resolution enhancement: use original amplitude

For dip estimation: Apply smoothing first

For horizon decomposition: Apply smoothing first
Conclusions

• Curvature analysis is applied to seismic waveforms;
• Several implications:
  • Resolution enhancement along the direction normal to seismic reflectors
  • Dip estimation
  • Reflector decomposition to peaks, troughs, and z/s-crossings;
• Potentials for horizon interpretation and modelling
More information (e.g., recent research, publications, tools, and codes) is available by:

- Visit our SEG booth: #2109
- Visit our center: [http://www.ghassanalregib.com](http://www.ghassanalregib.com)
- Visit my webpage: [https://haibindi.wixsite.com/home](https://haibindi.wixsite.com/home)