An interferometric solution for raypath-consistent shear wave statics

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Introduction

- The S-wave statics problem:
  - The near surface “seen” by S-waves is different than the one seen by P-waves (e.g. water table depth).
  - S-wave statics solutions may be independent of P-wave statics.
  - Slow velocities magnify the effect of small changes in the propagation.
  - Non-Stationarity? Why? How to correct them?
PS Ray-Tracing

Reflector Depth 200m

Reflector Depth 550m

v_p
v_s
LVL

REFL. 1

REFL. 2

Depth (m)
Offset (m)

Velocity (m/s)

LVL Transm. Angle (deg)

0
5
10
15
20

0 200 400 600 800 1000 1200 1400 1600 1800 2000
0
200
400
600
Offset (m)
Depth (m)
Reflector Depth 550m

LVL Transm. Angle (deg)
Reflection times with the same transmission angle are recorded at different offsets.

✓
Geometry of the problem

Travel times for a dipping LVL:

\[ t_{calc} = \frac{h}{V_{LVL}} \frac{\cos(\theta)}{\cos(\phi_{LVL} - \theta)} \]

- \( h \): Vertical thickness
- \( V \): Shear wave velocity
- \( \phi \): Dip of the base of the LVL
- \( \theta \): Raypath angle
Deviation from vertical time (ms)
(h = 100 m, $V_{\text{LVL}} = 500$ m/s)
Traveltime Interferometry

Total static time $\Delta t = \tau'_{SOR} - \tau_{SOR}$

Receiver side static time $\Delta t_R = \tau'_{OR} - \tau_{OR}$
**Traveltime Interferometry**

- **Delayed path**
  \[ s'(t) = \delta(t - (\tau + \Delta t)) \]

- **Static-free path**
  \[ s(t) = \delta(t - \tau) \]

- **Static time**
  \[ = \delta(t + \Delta t) \]
Statics processing workflow

1. **Input data sorted by common rayparameter gather**
   - Input NMO corrected receiver gathers
   - Apply radial trace transform
   - Sort data by common rayparameter gathers
     - Xcorrelate pilot traces and raw data
     - Convolve xcorrelation functions with raw data
     - Sort data back to receiver gathers

2. **Use xcorrelations as matching filters**
   - Move static-corrected data back to the X-T domain

3. **Input “static-free” data**
   - Create pilot traces
   - Input “static-free” data:
     - PP interpreted horizons scaled to PS Times or,
     - PP stack sections scaled to PS times

4. **Output static free data**
   - Apply inverse radial trace transform
   - Output static free data
Finite-Difference Modeling

P-wave Velocity (m/s)

S-wave Velocity (m/s)
Raw X-component Shot Gather

- P-Wave Energy
- Receiver Statics
- PS-Wave Reflections
Receiver Gather
Receiver Gather (Zoom at offset 250m)

\[ \Delta t_{R1} = 22 \text{ ms} \]

\[ \neq \text{Stationary} \]

\[ \Delta t_{R1} = 9 \text{ ms} \]
Receiver Gather
Radial-Trace Gather

<table>
<thead>
<tr>
<th>TIME (ms)</th>
<th>0</th>
<th>200</th>
<th>400</th>
<th>600</th>
<th>800</th>
<th>1000</th>
<th>1200</th>
<th>1400</th>
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</thead>
<tbody>
<tr>
<td>RMSVEL</td>
<td>0</td>
<td>-946</td>
<td>-458</td>
<td>-2</td>
<td>453</td>
<td>940</td>
<td>150</td>
<td></td>
</tr>
<tr>
<td>RECV</td>
<td>1140</td>
<td>1140</td>
<td>1140</td>
<td>1140</td>
<td>1140</td>
<td>1140</td>
<td>1140</td>
<td>1140</td>
</tr>
</tbody>
</table>
RT Gather (zoom at 500 m/s radial trace)

$\Delta t_{R1} = 22 \text{ ms}$

$\approx$ Stationary

$\Delta t_{R1} = 20 \text{ ms}$
Finite-difference modeling
ACP Stack w/o statics
Common rayparameter gather (350 m/s)
De-structured rayparameter gather
Pilot rayparameter gather
Cross-correlation functions
ACP Stack w/o statics
ACP Stack w surface consistent statics
ACP Stack w ray-path consistent statics
\[ t_{calc} = \frac{h}{V \cos(\theta)} \]

- \( h \): Vertical thickness
- \( V \): LVL velocity
- \( \theta \): Transmission angle
\[ t_{\text{calc}} = \frac{h}{V_{\text{LVL}} \cos(\phi_{\text{LVL}} - \theta)} \]

- \( h \): Vertical thickness
- \( V \): LVL velocity
- \( \phi \): Dip of the base of the LVL
- \( \theta \): Transmission angle
Summary

• If velocity contrasts at the near surface are not large, S-wave statics may show ray-path dependency.

• Ray-path dependency implies a non-stationary behavior in time domain.

• Interferometric statics applied in the R-T domain showed to solved the problem.

• Straight ray-path assumptions for applying the radial transform may not be enough. Snell ray transform can be the next step.

• Inversion of the cross-correlations peaks time may be used for computing a velocity model for the near surface.
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