Orientation azimuth calibration of borehole geophones

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Geophone orientation calibration

Overhead View

H1

H2

Side View

Well

Cable

VSP Tool

Microseismic Hypocenter
Outline

• Objectives

• Methods and Survey Geometry

• Results and Modelling

• Conclusions

• Acknowledgements
Objectives

• Determine the optimal survey design for orientation calibration

• Characterise and quantify the effects of lateral raybending and seismic anisotropy on geophone orientation azimuth calibration
Geophone Orientation – Analytic Method

• The equation used to analytically calculate rotation azimuths was (DiSiena et al., 1984)

\[
\tan 2\theta = \frac{2H_1 \otimes H_2}{H_1 \otimes H_1 - H_2 \otimes H_2}.
\]

Vertical Well:

\[\phi_r = \phi_s + \theta\]

• \(\otimes\) is a zero lag cross-correlation
• \(H_1\) and \(H_2\) are the windowed data (100 ms)
• \(\theta\) is the source-receiver (H1 or X) orientation angle
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- $\otimes$ is a zero lag cross-correlation
- $H_1$ and $H_2$ are the windowed data (100 ms)
- $\theta$ is the source-receiver ($H_1$ or $X$) orientation angle
Example of a Simple Radial Plot

- **One Standard Deviation Envelope**
- **Mean & Standard Deviation**
  - Mean: 44.5°
  - STD: 2.59°
- **Data Point**
  - Offset = 1100 m
  - Angle = 49°
- **Mean Orientation Azimuth**
Lousana VSP

- 16 3-C receivers: spacing of ~15 m
- 2D Survey with four tool positions (64 total levels)
- 3D Survey (249 source locations)
- Vertical Well
Shot Gather (3D, X = 33 m, Y = -81 m)
Orientation vs. Offset

Receiver 1 (717 m)

Deviation from Mean (degrees) vs. Absolute Offset (m)

Near offset cutoff

Legend:
- 0°-180°
- 45°-225°
- 90°-270°
- 135°-315°
Orientation vs. Offset

Receiver 1 (717 m)

Receiver 5 (778 m)

Receiver 9 (838 m)

Receiver 13 (899 m)
Offset Sectoring

\[ \sim = \text{Receiver depth} \]

\[ \sim = 2 \times \text{Receiver depth} \]
Theoretical Signal Based on Offset

Geometrical spreading & incident angle:

\[ \frac{A_H}{A_0} = \frac{x}{x^2 + z^2} \]

- Assumes very high Q
- Ignores raybending
Radial Plot

- Mean: 300.5°
  - STD: 1.63°

- Mean: 258.0°
  - STD: 1.64°

- Mean: 102.5°
  - STD: 1.75°

- Mean: 124.0°
  - STD: 2.21°

- Mean: 135.9°
  - STD: 1.63°
Orientation vs. Azimuth (Offset > 500 m)
Dipping Beds (Lateral Raybending)
Dipping Beds (Lateral Raybending)

Assumed Angle

Measured Angle

X (m)

Y (m)

Z (m)

0

100

200

300

-300

-200

-100

0

100

200

300

400

500

600
Finite Difference Model (Using TIGER)

30 receivers
10-300 m
(10 m spacing)

Layer 1 $V_p=2000$ m/s
Layer 1 $V_S=1000$ m/s
Layer 2 $V_p=2900$ m/s
Layer 2 $V_S=1740$ m/s

30° Dip
Depth at well=175 m
90 shots (30 per line)
10 m spacing
Shot and Receiver Gathers
Orientation vs. Azimuth

Range: +/- 40°
Orientation vs. Azimuth

Range: +/- 40°
Anisotropy (HTI)

Plan View

Symmetry Axis (Slow Direction)
Source
Source-Receiver Azimuth

Possible Error in Orientation Azimuth
Receiver
Phase Angle $\theta$
Group Angle $\phi$

Adapted from Thomsen (1986)
Finite Difference Model

30 receivers
10-300 m
(10 m spacing)

Layer 1 \( V_p = 2000 \text{ m/s} \)
Layer 1 \( V_s = 1000 \text{ m/s} \)
Layer 2 \( V_p = 2900 \text{ m/s} \)
Layer 2 \( V_s = 1740 \text{ m/s} \)

Layer 1 \( \varepsilon = 0.1 \)
Layer 1 \( \delta = 0.025 \)
Layer 1 \( \gamma = 0.1 \)
Depth at well = 180 m

90 shots (30 per line)
10 m spacing
Shot and Receiver Gathers

- **Graph 1:**
  - X-Y axis: Time (s) vs. Receiver Number
  - Graph shows two components: H1 (X) Component and H2 (Y) Component

- **Graph 2:**
  - X-Y axis: Time (s) vs. Shot Horizontal Offset (m)
  - Graph shows two components: H1 (X) Component and H2 (Y) Component

**Legend:**
- **Blue Line:** H1 (X) Component
- **Red Line:** H2 (Y) Component
Orientation vs. Azimuth

Range: +/- 10°
Orientation vs. Azimuth

Range: +/- 10°
Signatures from Dip or HTI?
Conclusions: Objective 1

Determine optimal **survey design** for calibration

- Source locations nearer than 1/2 receiver depth increase scatter; optimal offset range between 1-2 times receiver depth.

- Scatter:
  - 2D (all/far offsets): $5.22^\circ/0.67^\circ$
  - 3D (all/far offsets): $2.41^\circ/1.74^\circ$
Conclusions: Objective 2

Characterise and quantify the effects of lateral raybending and seismic anisotropy on geophone orientation azimuth calibration.

- Lateral raybending: one-cycle sinusoid over azimuth (zero updip and downdip)

- Azimuthal anisotropy: two-cycle sinusoid over azimuth (zero in fast and slow directions)

- Deviation patterns from lateral raybending possible match in Lousana case study
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