Seismic monitoring with continuous seismic sources

Tyler Spackman and Don Lawton
Motivations

• Active source monitoring (4D seismic) has many applications related to fluid injection & extraction:
  • Waterfloods
  • Steam chamber monitoring
  • Caprock integrity
  • CO₂ sequestration

• Two major issues with conventional 4D acquisition:
  1. Survey repeatability
  2. Time intervals between surveys

• Continuous seismic sources address both of these issues
Background

• Sources operate by rotating an eccentric mass around an axle which is fixed to the ground

• Source signature easily modelled by sinusoidal function

• Component of particle displacement can be boosted or cancelled by reversing rotation direction, then taking the sum or difference of the resulting data
**Analogy:** washing machine

- Clothes inside machine form eccentric mass
- Causes vibration of entire machine
• GPUSA orbital vibrators for continuous monitoring
• Installed in fixed location (surface, wells) and used in conjunction with permanent geophone array or DAS

Linear vibrators installed at surface

Borehole continuous source for crosswell monitoring

Survey repeatability
• Surface sources anchored below near surface layers to reduce attenuation

• Install several screw piles around survey area for multiple source points

• Impact of screw pile on source location/signature?

Images courtesy GPUSA
“Conventional” 4D seismic program:
- 1+ years between surveys
- Survey geometry that attempts to recreate baseline

Continuous source 4D seismic program:
- Create daily/weekly/monthly stacks
- Permanent source & receiver geometry

Chadwick et al., 2010
Freifeld et al., 2016

Time interval between survey
Field work

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Objective: determine ideal location for continuous seismic source for acquiring VSP in observation well #1
• Test a range of offsets to find the optimum balance between:
  1. Maximizing spatial coverage of injected CO₂ plume
  2. Maximizing angle content to capture potential AVO/AVA effects
• Observation well #2: DAS fibre, geophones at ~190m
Field work

• Mateeva et al. (2012): recorded amplitude in straight DAS fibre varies as $\cos^2(\theta)$, where $\theta$ is the angle between the incident ray and the fibre.

• From raytracing with source at 110m offset, incidence angles at the fibre:

<table>
<thead>
<tr>
<th>Angle (degrees)</th>
<th>$\cos^2(\theta)$ scalar</th>
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</thead>
<tbody>
<tr>
<td>Minimum</td>
<td>11.5</td>
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<tr>
<td>Maximum</td>
<td>24.5</td>
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<table>
<thead>
<tr>
<th>Angle (degrees)</th>
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<tbody>
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<td>Minimum</td>
<td>8.1</td>
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<tr>
<td>Maximum</td>
<td>13.8</td>
</tr>
</tbody>
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Obs. well #1

Obs. well #2
Non-zero offset synthetics modeled using injector well logs

Two endmembers: 100% water saturation, 100% CO₂ saturation

Attempt to identify if there is potential for AVO anomalies
Field work

100% water saturation (pre-injection case)

100% CO₂ saturation (post-injection case)

Synthetic gather response
Future work

• Begin acquisition using continuous sources in late 2017/early 2018

• Develop processing routine that requires minimal user inputs

• How to handle large quantities of data?
Conclusions

- Continuous seismic sources offer significant improvement over conventional 4D seismic programs in survey repeatability, time interval between surveys.
- Continuous source data can be easily modelled using a sinusoidal source function, thus can boost or suppress a selected component of the data by reversing the rotation direction.
- Offset of 110 metres between observation well #1 and continuous source provides optimal combination of:
  1. Spatial coverage of predicted high-saturation area around injector
  2. Angle content in recorded data
  3. Minimal reduction in amplitudes recorded in straight fibre
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Questions?