Time-lapse Crosswell Seismic Tomography for Monitoring CO$_2$ Sequestration

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Contents

1. Borehole arrangement
2. Method of seismic tomography
3. Time-lapse tomography
4. Numerical experiments
5. Conclusions
Well positions at the top of the target aquifer

Formation Dip: 15°

Crosswell Seismic Tomography Section
Source – Receiver Geometry

- **OB-3**
- **OB-2**

**Front View**
- **IW-1**
- **Source:** 900 – 1284 m @4m interval
- **Receiver:** 900 – 1228 m @4m interval

**Side View**
- **OB-3**
- **OB-2**

**Plane View**
- **Tomography Section**

**Depth (m):**
- 900
- 1000
- 1100
- 1200

**Source – Receiver Geometry**

**CO2 Injection Point**

**CO2-2 Pit**

**CO2-3 Pit**

International Workshop on CO2 Geological Storage, Japan ’06

February 20-21, 2006, Tokyo
Data Acquisition System

Energy Source: Oyo’s OWS
Receiver: 24-channel hydrophone cable
Data acquisition: Oyo’s DAS-1 (24bit A/D)
**Oyo’s OWS Downhole Source**

<table>
<thead>
<tr>
<th>Specification</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diameter</td>
<td>108mm</td>
</tr>
<tr>
<td>Length</td>
<td>3,420mm</td>
</tr>
<tr>
<td>Weight</td>
<td>150kg</td>
</tr>
<tr>
<td>Pressure</td>
<td>30MPa (3,000m)</td>
</tr>
<tr>
<td>Temperature</td>
<td>150°C</td>
</tr>
<tr>
<td>Wire line</td>
<td>7 conductor armored cable</td>
</tr>
<tr>
<td>Cable head</td>
<td>Gearheart type 1-1/2”</td>
</tr>
<tr>
<td>Energy</td>
<td>max. 3,000J/shot</td>
</tr>
<tr>
<td>Shot interval</td>
<td>20 – 60 sec</td>
</tr>
<tr>
<td>Electric power</td>
<td>700W(AC100V)</td>
</tr>
<tr>
<td>Trigger sensor</td>
<td>Geophone</td>
</tr>
</tbody>
</table>

![Diagram of OWS Downhole Source](image)

**Diagram**

- Triggering Geophone
- Electric Motor
- Spring
- Catcher
- Hammer
- Multi-layered Disks
- OWS
Observation Pattern: Source-Receiver Combinations

OB-3:
receiver: 900 – 1228 m @4m interval

OB-2:
source: 900 – 1284 m @4m interval
Flow Chart of Tomography

- BPT for BLS tomography
- BLS tomogram for MS tomography

Wavefront Data Processing

BLS Traveltime Curves

Traveltime (msec)

Receiver Depth (m)

First Arrival Time
Time-lapse Crosswell Seismic Tomography

baseline survey  
| BLS | before injection | Feb 2003 |
| Jul 2003 | injection started |

monitoring surveys  
| MS1 | 3,200 t-CO₂ | Jan 2004 |
| MS2 | 6,200 t-CO₂ | Jul 2004 |

Cumulative CO₂ injected

Injection started

Elapsed time (day)

Injection rate (t/day)
Reconstructed Velocity Tomograms

Depth (m) | OB-3 | OB-2 | Depth (m) | OB-3 | OB-2 | Depth (m) | OB-3 | OB-2
--- | --- | --- | --- | --- | --- | --- | --- | ---
900 | IW-1 | IW-1 | 1200 | IW-1 | IW-1 | IW-1 | IW-1 | IW-1
1100 | | | 1100 | | | | |
1200 | | | 1200 | | | | |

Velocity (km/sec) | 3.3 | 3.1 | 2.9 | 2.7 | 2.5

BLS | MS1 | MS2
before injection | 3,200 t-CO₂ | 6,200 t-CO₂
Velocity Difference Tomogram (BLS / MS1)

Velocity difference = \( \frac{V_{MS1} - V_{BLS}}{V_{BLS}} \)

max. velocity reduction = 3.0%

3,200 t - CO₂
Velocity Difference Tomogram (BLS / MS2)

Velocity difference = \frac{(V_{MS2} - V_{BLS})}{V_{BLS}}

max. velocity reduction = 3.5%

6,200 t -CO₂

top of the aquifer

velocity difference %
Velocity Reduction

Velocity difference:

MS1: 3,200 t-CO$_2$

max. velocity reduction = 3.0%

MS2: 6,200 t-CO$_2$

max. velocity reduction = 3.5%
Traveltime Shift

(a) source = 1,000 m

(b) source = 1,060 m

6,200 t-CO₂

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Contradictions

Velocity decrease in the cap rock?

No breakthrough?

Small velocity reduction?

Time-lapse Acoustic Logging

Velocity difference tomogram
The velocity anomaly extending into the cap rock did not produce any traveltime delays for rays passing through the area. This apparent velocity anomaly must be an artifact or ghost.
Numerical Experiments

Model velocity reduction = 20%
Max. velocity reduction = 5.5%
The distribution of CO$_2$ injected into the aquifer can be imaged as an area of velocity reduction.

The velocity reduction was found to be 3.5% for MS2 (6,200 t-CO$_2$ injected), though the value obtained from acoustic logging was more than 20%. Judging from the result of numerical experiment, actual velocity reduction could be much larger than the 3.5% observed in MS2 velocity difference tomogram.

Although some anomalous velocity reduction zones were observed, the numerical experiments revealed that those anomalies must be artifacts or ghosts.

The velocity determination in a thin, low-velocity layer is one of the basic problems of traveltime tomography. However, some sophisticated inversion schemes (e.g. adequate constraints) can solve the problem.
Acknowledgments

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