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Sparse CO_2 seismic monitoring at the CaMI field research station

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Summary

Field experiments for a sparse seismic approach to CO_2 monitoring were performed at the Containment and Monitoring Institute (CaMI) field research station in Newell County, Alberta, operated by Carbon Management Canada (CMC). As carbon hubs develop and approach gigatonne storage levels in areas extending over multiple townships, or hundreds of square kilometers, frequent monitoring with costly conventional 4D surface seismic methods becomes impractical. A sparse monitoring approach using permanent sources and receivers can provide daily, highly repeatable monitoring of sparsely distributed reflection points over large areas in addition to passive seismic monitoring for induced seismicity. Continuous monitoring with sparse nodes can demonstrate conformance and reservoir containment by detecting CO_2 plume growth within the reservoir and provide early warning of loss of containment if time-lapse changes are observed above the injection interval. Tests at the CaMI site have demonstrated a permanent source location design that uses a steel pile screwed through 25 m of glacial till, allowing source signal transmission to bypass non-stationary filtering effects of the surface and the highly dispersive weathering layer. Source tests were recorded on borehole geophones, distributed acoustic sensing (DAS) fiber, and buried passive seismic monitoring arrays (SADAR®) record the highly repeatable source signal.

Method

Requirements for permanent, sparsely distributed seismic nodes include:

- Highly repeatable signals and receivers providing adequate depth penetration
- Automation of both shots and recordings with precise GPS-controlled timing
- Remote accessibility for control, diagnostics and re-programming
- Physical accessibility for maintenance, replacement, or decommissioning

Figure 1 shows the sparse monitoring concept in a section view schematic. Sparse nodes comprising permanent sources and receivers are spaced at optimal shot offsets (Hunter and Pullan, 1989) to record reflections in the form of common-midpoint traces between receivers, or far-offset vertical seismic profile (VSP) shot gathers near injection or observation wells. These sparse nodes simultaneously provide passive monitoring capability for induced seismicity. Acquisition is automated, with shots occurring at pre-set times, precisely controlled by a connection to the GPS network.

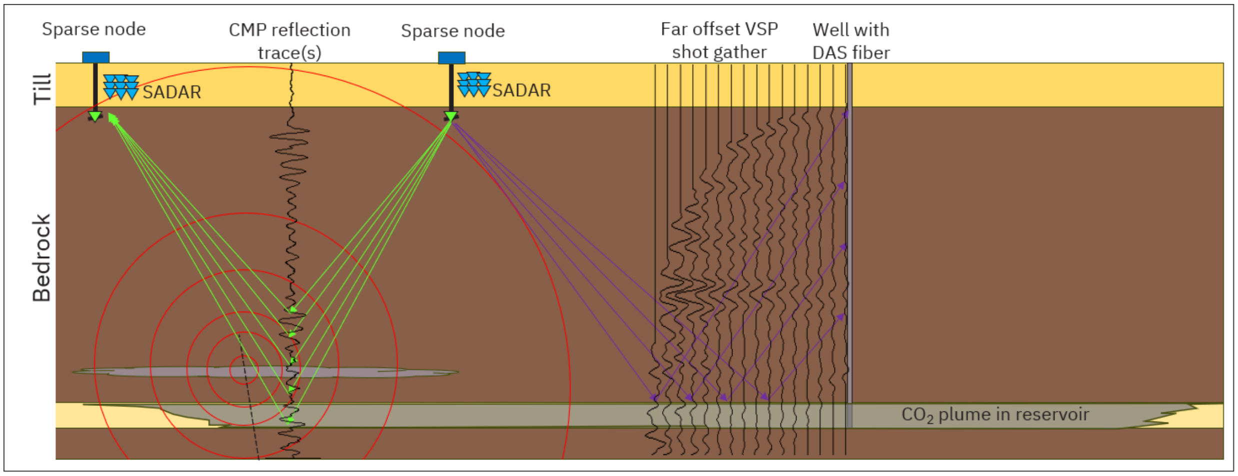

Figure 1. Section view schematic of the sparse node concept. Permanent, continuously-recording receivers provide passive seismic monitoring capability for induced seismicity (red wavefronts) and record regularly scheduled permanent source reflections (green raypaths). Borehole receivers record far-offset VSP shot records from nearby permanent source locations (purple raypaths).

At the CaMI site, conventional time-lapse repeatability at surface is negatively affected by differences in water saturation, temperature, and other non-stationary effects within a 25 m thick weathering layer primarily composed of glacial till (Kolkman-Quinn et al., 2023). For permanent source locations, a steel screw-pile provides coupling to sedimentary bedrock for low-energy impulsive and vibrational sources mounted on the pile at surface. The toe of the steel pile acts as a point source at depth, and reflection signals are recorded on a variety of permanently installed receivers, including geophones and fiber in boreholes and at surface, and volumetric phased SADAR® arrays (Seismic and Acoustic Detection and Ranging) buried 10 - 22 m below surface, originally installed for passive seismic monitoring (Macquet et al., 2022; Zhang et al., 2023).

Results

Figure 2 shows VSP shot gathers from a compressed-nitrogen driven hammer (thumper) source (Lawton et al., 2013) recorded on borehole geophones. Figure 2a shows the sharp, impulsive direct arrivals from the thumper when transmitted through the steel pile to its toe a depth of 24.7 m. Figure 2b shows the same source when fired on the ground surface, suffering significant attenuation and filtering in the weathering layer, and arriving 15 ms later due to the slower velocities in the glacial till. The screwpile successfully transmitted the source signal with high fidelity and acted as a point source coupled with sedimentary bedrock.

An automated trigger system was designed by CMC. The pulse-per-second (PPS) signal from the GPS network provides precisely timed triggers allowing for synchronized acquisition at independent source and receiver locations without the need for copper or fiber cable connections to control the acquisition. This enabled daily acquisition tests with an electrically-controlled impulsive source prototype developed by Hyfold Technology Corp.

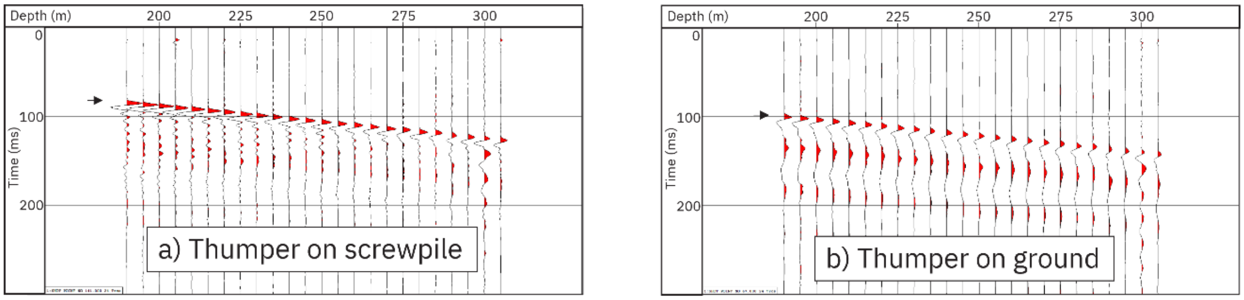

Figure 2. Borehole geophone shot gathers of a compressed-nitrogen driven hammer (thumper) tested on a steel screw pile location: a) thumper on screw pile, b) thumper on ground adjacent to screw pile. The black arrow indicates the direct arrivals, with a 15 ms difference in travel time due to signal transmission through 25 m of steel rather than unconsolidated glacial till.

Novel/Additive Information

Field experiments were performed with sparse monitoring design including electrically controlled, GPS-timed sources and receivers.

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References

J. A. Hunter, S. E Pullan (1989). The shallow seismic optimum offset shallow technique*. Symposium on the Application of Geophysics to Engineering and Environmental Problems Proceedings*, 143-174.

Kolkman-Quinn, B., Lawton, D. C., and Macquet, M. (2023). CO_2 leak detection threshold using vertical seismic profiles. *International Journal of Greenhouse Gas Control*, **123**, 103839.

Lawton, D. C., Gallant, E. V., Bertram, M. B., Hall, K. W., and Bertram, K. L. (2013). A new S-wave seismic source*. CREWES Research Report*, 25, **51**, 6.

Macquet, M., Lawton, D., Osadetz, K., Maidment, G., Bertram, M., Hall, K., Kolkman-Quinn, B., Monsegny Parra, J., Race, F., Savard, G., Wang, Y., 2022, Overview of Carbon Management Canada's pilot-scale CO_2 injection site for developing and testing monitoring technologies for carbon capture and storage, and methane detection: CSEG Recorder, **47**, 1.

Zhang, J., Hutchenson, K., Nyffenegger, P., Grant, E., Jennings, J., Tinker, M., Macquet, M., Lawton, D. (2023). Performance comparison of compact phased arrays and traditional seismic networks for microseismic monitoring at a CO_2 sequestration test site. *The Leading Edge*, **42** (5): 332–342.