Development of Microseismic Tools for Post-Injection Monitoring of Containment Efficiency of CO_2 Geological Storage

Areas: Geological Storage, Civil, Carbon Sequestration
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Partner: Güralp Systems Ltd.

- This project was funded by Innovate UK and developed in partnership with Güralp Systems Ltd.
- The aim of this project was the integration of hardware and software tools for effective MS monitoring of safe geological storage of CO_2.
- Addressed the need to monitor using tools that can be deployed for long periods of time and without the need of a deep monitoring borehole near the injection well.
- Under these conditions, new signal processing techniques are required in order to enhance the signal and mitigate background noise.
- The result is a monitoring product combining high-gain, low-noise surface acquisition tools and processing software to monitor deep reservoirs using shallow monitoring arrays.
- The project examined the signature of a CO_2 plume surveyed by active seismic shots and the use of surface and noise sources for monitoring changes in the position of the CO_2 post-injection.
- The interpretation of the changes observed from active surveys were completed through the construction of forward numerical models that realistically reproduced the effect of changes in pore pressure, fracture development and CO_2 content on the transmission of acoustic waves.

Numerical modelling of wave transmission through CO_2 bearing reservoir

- Numerical models were prepared using Itasca's particle flow code in 2D (PFC2D).
- This stage included the preparation of particle assemblies and damping and quieting of the samples following the application of stresses reproducing the conditions of fluid injection at depth.
- PFC2D is a distinct element geo-mechanical modelling program using the bonded particle model (BPM) in which the rock material is modelled as an assembly of circular particles bonded together at their contacts (figure 1). Under the applied load, the bonds can break and a small crack can form. Fluid flow is simulated in PFC2D by assuming that each particle contact is a flow channel and that these channels connect up small "reservoirs" that store fluid at some pressure (figure 2).
- In this study, two sets of CO_2 with different pressures (10MPa and 15MPa) at the same temperature (310K) were injected into the reservoir.
- At the different stages, the sample is measured on transmission velocity and amplitude of the changes in pore pressure and crack density induced during the migration of a CO_2 plume.
- PFC uses an explicit calculation scheme to solve the equation of motion for velocity measurement. This enables dynamic simulations to be performed in which information propagates across the material at a speed that depends on the mass and stiffness of the particles. Figure 3a shows the measured velocities using for the different directions of wave propagation and measured motions of receiver particles for the sample at the initial state before the CO_2 injection.
- Figure 3b and 3c display the velocity variations for each stage compared to the initial state. The range of time-lapse velocity changes gives a good indication of the position of the CO_2 plume when the direction of the seismic source is perpendicular to the direction of measured particle motions. This result shows that velocity variations from S-waves could be used to better illustrate the effect of fluid injection.

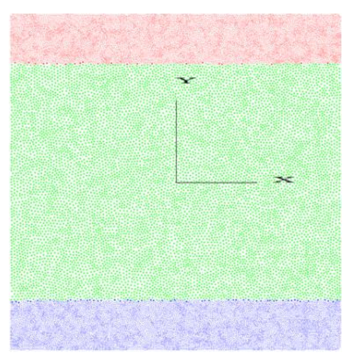

Figure 1: BPM reservoir model. The particles representing shale, sandstone and marl are coloured blue, green and red, respectively. The X and Y directions correspond to the minimum horizontal stress and vertical stress.

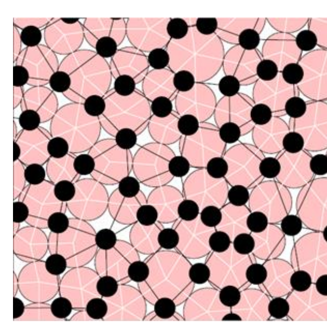

Figure 2: Reservoirs (black dots), flow paths (black lines) and bonds (white lines) in compacted bonded assembly of particles.

Acquisition of microseismic data using near-surface geophone arrays

- Güralp Systems Ltd. developed a three-component downhole sensor adapted to permanent monitoring.
- It has a response of 120 s to 100 Hz, and a sensitivity of 2*1200 V/m/s for this evaluation.
- The stainless steel casing is designed to allow a simple and rapid installation (Figure 4).
- For rapid temporary deployment (often required for this type of application) the narrow diameter and short length allow for a simple fast surface burial in a way that minimizes soil disturbance.
- For permanent deployments a clamping mechanism was designed to allow for the unit to be clamped internally into a cased borehole.
- The sensors output sensitivity can be adjusted within a range (typically 2*1000 V/m/s up to 2*8000 V/m/s) which allows the system resolution to be set for this particular application.
- The sensor was evaluated on installation, data quality and comparison against other existing sensors.
- The data was digitized by a CMG-DM24 Digitizer unit, which can be provided as separate unit or integrated with the sensor.
- The tests showed that the CMG-Flute sensor achieves its objectives of allowing complete insertion in a rapid deployment to achieve better coupling, recording quieter background signals and sensor response, noise levels and sensitivity are suitable for micro seismic recordings.

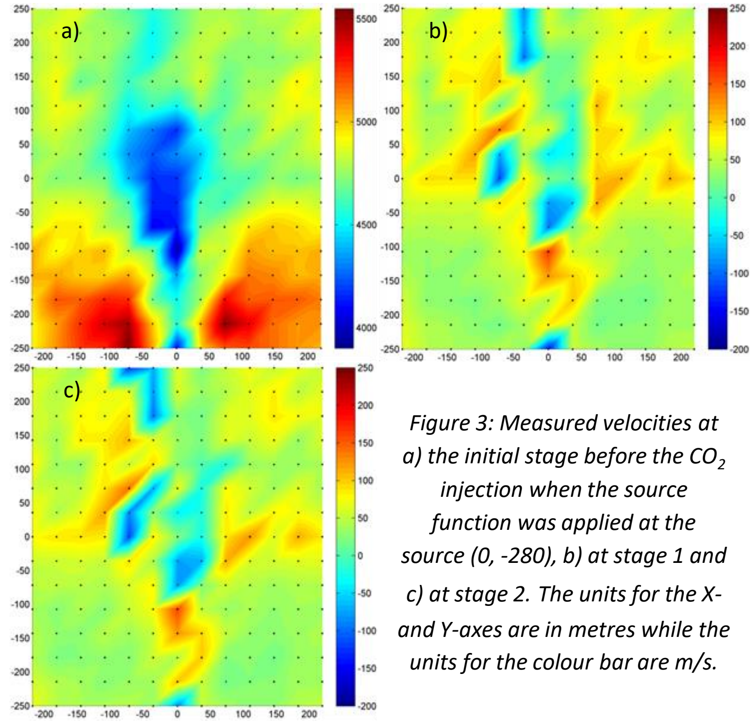

Figure 3: Measured velocities at a) the initial stage before the CO_2 injection when the source function was applied at the source (0, -280), b) at stage 1 and c) at stage 2. The units for the X- and Y-axes are in metres while the units for the colour bar are m/s.

Figure 4: The Flute casing

Software tools for the enhancement of low-amplitude seismic signals and processing of deep injection-induced microseismicity using near-surface acquisition arrays

- During this project, a method for locating microseismic events without phase picking was developed and tested.
- Cross-correlation based travel-time picking for passive seismic imaging was also developed and tested.
- Honouring the coupling between the event location and the velocity model, passive imaging can provide a more realistic image of the rock velocity structure, its time-lapse variation and more accurately locate events.
- In this test, due to the lack of vertical constraint, the recovered depth of each source may be at a relatively large distance from its true position. Therefore, in order to have the passive imaging technique work for surface monitoring survey, extra constraints such as the borehole monitoring geophones should be included.

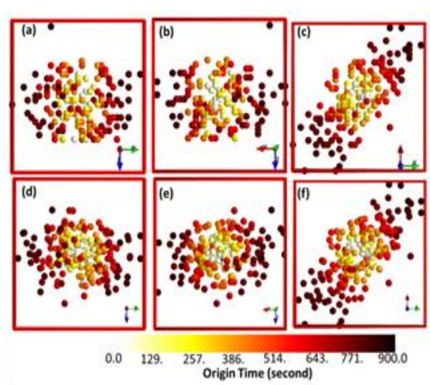

Figure 5: Locations of 176 events (a,b,c) compared with the modelled 200 events (d,e,f). Figure (a,d), (b,e), and (c,f) are viewing towards north, east, and downwards, respectively. In general, the automated location method recovers 88% of the true events.

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