Time-lapse seismic full waveform inversion for monitoring near-surface velocity changes during microbubble injection

*Rie Kamei[1], UGeun Jang[2], David Lumley[1], Takuji Mouri[3], Masashi Nakatsukasa[3], Mamoru Takanashi[3], Ayato Kato[3]

1. University of Western Australia, 2. Seoul National University, 3. JOGMEC

Seismic monitoring provides valuable information regarding the time-varying changes in subsurface physical properties caused by natural or man-made processes. However, the resulting changes in the subsurface properties are often small both in terms of magnitude and spatial extent, leading to minimal time-lapse differences in seismic amplitudes and travel time. In order to better extract information from the time-lapse data, exploiting the full seismic waveform information in the data can be critical. We explore methods of seismic full waveform inversion that estimate an optimal model of time-varying elastic parameters at the wavelength scale. The full waveform inversion methods fit the observed time-lapse seismic waveforms with modelled waveforms based on numerical solutions of the wave equation. Using waveform information beyond first arrivals enables full waveform inversion to achieve much higher resolution (wavelength scale) compared to conventional traveltime tomography (Fresnel zone scale).

We apply acoustic full waveform inversion to time-lapse cross-well monitoring surveys, and estimate the velocity changes that occur during the injection of microbubble water into shallow unconsolidated Quaternary sediments in the Kanto basin of Japan at a depth of 25 m below the surface. Microbubble water is comprised of water infused with air bubbles of a diameter less than 0.1mm, and may be useful to improve resistance to ground liquefaction during major earthquakes. Monitoring the space-time distribution of microbubble injection is therefore important to understand the full potential of the technique.

The time-lapse data set consists of 17 monitoring surveys conducted over 74 hours which exhibit excellent repeatability, allowing us to analyze small time-lapse changes in the subsurface. We observe transient behaviors in the seismic waveforms during microbubble injection manifested as traveltime shifts and changes in amplitude and frequency content. Time-lapse full waveform inversion detects changes in P-wave velocity of less than 1 percent during microbubble injection, initially as velocity increases, and then subsequently as velocity decreases. The velocity changes are mainly imaged within a thin (1 m) layer between the injection well and the receiver well, inferring that microbubble water flow is constrained by the fluvial sediment depositional environment. The resulting velocity models fit the observed waveforms very well, supporting the validity of the estimated velocity changes. In order to further improve the estimation of velocity changes, we investigate the limitations of acoustic waveform inversion, and by applying and comparing elastic waveform inversion to the time-lapse data set.

Keywords: Full waveform inversion, Seismic monitoring, Fluid injection

