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Sensitivity of Seismic Interferometry and Conventional Reflection Seismics at a Landfil to Processing and Survey Errors

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SUMMARY

Understanding how sensitive the seismic method is to errors that can occur during a seismic survey or during the processing of the seismic data is of high importance for any exploration geophysical project. Our aim is to image the subsurface of a landfill, which is typically a heterogeneous system due to the presence of numerous scatterers. Therefore, in our case precision is of very high importance. Because of this, we test and compare the sensitivity of seismic interferometry (SI) and conventional reflection seismics survey (CRSS) to errors produced due to time-lapse surveys, migration-velocity errors and muting. Using numerically modelled data, we show that SI provides better subsurface information than CRSS.

Introduction

Contaminants present in municipal solid waste landfills can form a threat to the environment and are therefore a burden for the society due to future leachate and gas emissions. Nowadays, there are attempts to treat the landfills so that the future emissions are minimized by using the landfills as bioreactors (Sponza and Agdag, 2004). This can be achieved, for example, by recirculation of leachate. However, in order to optimize this technique, a better understanding of the subsurface is essential (Powrie and Beaven, 1999). We aim to create a method that includes modelling and measurements related to different scientific methods (geophysics, bio-geochemistry, hydro-engineering) in order to predict the emission potential of a landfill (Bun et al., 2012). This will enable us to ensure that the treatment method is working and that the aftercare period is minimized.

Landfills are very heterogeneous systems and therefore challenging to image. Our goal is to be able to image the heterogeneity of a landfill that plays a key role in the recirculation of the leachate. Higher density areas can act as obstructions and may not allow the leachate to flow through the whole landfill, thus slowing down the treatment. Because the subsurface is so heterogeneous, we want to prevent errors, due to the processing and survey procedure, to appear in our result. In order to image the distribution of heterogeneities in the mechanical properties of the landfill, we choose to use the seismic reflection method. We compare the sensitivity of the imaging results to errors and uncertainties associated with conventional reflection seismic surveys (CRSS) and seismic interferometry (SI) by cross-correlation using active sources, in order to evaluate the efficacy of these two methods.

Basic idea and the approach

To test the sensitivity of SI and CRSS to specific situations, we model the seismic wavefield using a finite-difference code (Thorbecke and Draganov, 2011). The complex subsurface velocity model we use is shown in Figure 1. It represents a landfill 100 m wide and 25 m deep with specific areas that have different composition than the background and correspond to areas of metal, glass and plastic. Those areas act like scatterers and are a mixture of those materials with organic matter. Therefore, although the seismic velocities for metal and glass are 2960 m/s and 3111 m/s, respectively (Kaye and Laby, 1995), to realistic mimic the mixture we use much lower velocities, e.g., 1100 m/s and 1300 m/s, respectively. We keep the velocity of plastic at 440 m/s. We use S-wave velocities because they are linked to the stiffness of the material. Also, because S-wave velocity in soil is generally much less than the P-wave velocity, for comparable frequencies, S waves give a much shorter wavelength and hence, a much higher resolution. Regarding densities for metal, glass, plastic and the background soil, we have used realistic values. The sizes of the scatterers range from 0.5 m to 1.8 m in height and 0.35 m to 3.89 m in width; the scatterers are positioned randomly. We use a background velocity with a vertical gradient from 200 m/s at the surface to 220 m/s at 25 m depth.

We apply SI to the CRSS data by cross-correlating two common-receiver gathers and summing over the sources the correlated traces to retrieve the reflection response at one of the receivers as if there were a virtual source at the other receiver (Schuster, 2001; Wapenaar et al., 2002; Schuster et al., 2004). To retrieve correctly the reflection response, the active sources together with the Earth's free surface should enclose the receivers (Wapenaar and Fokkema, 2006). In CRSS, the active sources are only at the Earth's surface. Nevertheless, the reflection response can be retrieved from the CRSS data (e.g., van Wijk, 2006), but in the process, due to the so-called one-sided illumination, also non-physical arrivals will be retrieved (Snieder, Wapenaar and Lerner, 2006). Wapenaar (2006) showed that when sufficient energy is back-scattered from the subsurface, the one-sided illumination will be compensated and the non-physical arrivals disappear. In the landfill case, the high density areas (the scatterers) could help to compensate for the one-side illumination.

The CRSS data are modelled considering a spilt-spread geometry: five cables of 24 receivers each, 0.5 m receiver spacing and 2 m source spacing. The first cable is moved to the end of the line when the source position reaches the end of the first receiver cable (24th receiver position). We model 72 shots,

which are later processed, including muting the first arrivals and prestack depth migration. SI is applied to the processed CRSS shot gathers. This includes the following steps: resorting in common-receiver gathers, correlation of each one of the receiver gathers with other common-receiver gathers and with itself, summation over the source positions, energy normalization, deconvolution for the source wavelet and finally prestack depth migration.

Figure 1 The distribution of scatterers in our model of landfill. The gray-shaded ellipses represent areas with different material composition. The background velocity has a vertical gradient with *S*-wave velocity increasing with depth.

Issue 1: Source position non-repeatability in time-lapse seismics.

During time-lapse surveys a source non-repeatability poses a serious problem to imaging the changes in the subsurface. We investigate this by modelling a base CRSS survey. We process this dataset to image the landfill (see Figure 2a). We then apply SI to this dataset and image the subsurface using the retrieved SI data (see Figure 2b). After that we model a monitor survey with non-repeatability errors in the source positions (random errors up to 1 m around the original source positions). We keep the subsurface model the same. Figures 2c and 2d show the imaging results for the monitor survey for the CRSS and SI, respectively. We see that SI exhibits not only higher repeatability in the imaged scatterers than CRSS, but also less artifacts. AGC with a constant time-window length has been applied to all images for the visualization purposes. We have computed a value for the image repeatability using the normalized root-mean square (NRMS) amplitudes (Mehta et al., 2007): the repeatability is 89.5% for CRSS and 31.8% for SI.

Issue 2: Uncertainty in the migration velocity.

Another important source of error in obtaining clear images of the subsurface is the uncertainty in the migration velocity. When the velocity model is not known exactly, migration artifacts appear in the final image. We migrate the base CRSS and SI data using a velocity model with 5% error in it, see Figure 3(a,b). Comparing these images to the ones in Figure 2(a,b) we see that although both CRSS and SI are affected by the error, SI exhibits less artifacts.

Issue 3: Uncertainty in the muting procedure.

For successful imaging of the shallower scatterers, an important step is the muting of the direct arrivals. The muting process, manual or automatic, could result in errors - in muting through the scattered field from a shallow scatterer. To understand the sensitivity of the two methods to the muting errors, we apply automatic muting procedure to both the base CRSS and SI datasets. The obtained images are shown in Figure 4(a,b). Comparing the latter images with the corresponding ones in Figure 2(a,b), we see that SI shows more stability in imaging the shallower scatterers. NRMS values are 27.5% for SI and 70% for CRSS, showing that SI is less sensitive to errors produced by inaccurate muting.

Conclusions

We have processed the conventional reflection seismic survey (CRSS) data to image the strongly scattering subsurface of a landfill. We have also imaged the subsurface using data obtained from the application of seismic interferometry (SI) to the CRSS data. We have compared the sensitivity of the images from the two methods to errors due to source non-repeatability, errors in the migration velocities and in the muting of the direct arrivals (for imaging of the shallower scatterers). We find that for a highly heterogeneous subsurface, such as a landfill, SI does provide more precise images and better repeatability in the obtained images than CRSS.

Figure 2 The migrated results for the model in Figure 1 obtained using data from (a) conventional reflection seismic survey (CRSS), (b) seismic interferometry (SI), (c) CRSS with non-repeatability errors in the source positions and (d) SI with non-repeatability errors in the source positions.

Figure 3 The migrated results for the model in Figure 1 when the migration velocity has a 5% error: (a) CRSS and (b) SI.

Figure 4 The migrated results for the model in Figure 1 from (a) CRSS and (b) SI after automatic muting is applied to eliminate the direct arrivals.

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