Applying One-way Reciprocity Theorems in Time-lapse Seismic Imaging

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A seismic difference section, obtained by subtracting the reference section from a monitor section in a time-lapse seismic experiment, should ideally reveal the changes that occured in the subsurface in the elapsed time between the different measurements. However, even when the acquisition conditions of the seismic measurements were fully repeatable, the amplitudes in the difference section would be deteriorated as a result of traveltime shifts due to velocity changes in the reservoir. Hence, a seismic difference section is not a good measure for quantifying time-lapse changes in the subsurface.

In 1996, Fokkema and van den Berg formulated a mathematical relation between the seismic reference and monitor sections in a time-lapse seismic experiment, based on acoustic reciprocity. Dillen elaborated on this and, in particular, he analyzed the interaction integral between the wave fields of the seismic reference and monitor states at an arbitrary reference level (e.g. below a reservoir). He showed that the aforementioned amplitude deteriorations are for the greater part reduced in this interaction integral (Dillen, 2000, Ph.D. thesis, Delft University of Technology).

Recently we derived reciprocity theorems for the one-way wave equations in lossless as well as dissipative media. These theorems formulate relations between down- and upgoing wave fields in two different acoustic states. When applied to the situation of time-lapse seismic, a similar interaction integral is obtained as the one analyzed by Dillen. This interaction integral now allows an interpretation in terms of downgoing and upgoing wave fields. It appears to formulate the difference between two virtual seismic experiments at the acquisition surface. In each of these virtual experiments the downgoing wave field propagates through the reference state whereas the upgoing wave field propagates through the monitor state. On the other hand, the reflection in one of the virtual experiments occurs in the reference state and in the other in the monitor state. Hence, the traveltimes in these virtual experiments are the same; the only difference between these experiments is the reflection amplitude. Hence, the interaction integral represents a new difference section, in which the amplitudes are not deteriorated by time shifts. Of course the accuracy of the result depends on the accuracy with which the wave fields can be obtained at the reference level.