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Crack imaging in randomly heterogeneous media

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ABSTRACT

In reservoir characterization or non destructive testing it is necessary to get a better understanding of the effect of fractures on the wave field and to be able to image cracks, respectively. Here, the crack is within a randomly heterogeneous media. The Kirchhoff migration is applied followed by computing the envelope which emphasizes the crack. Additionally, using coherence analysis increases resolution.

INTRODUCTION

A reservoir is characterized rather by an ensemble of cracks or fractures than by one single crack. Hence, the extend of the extensive fractured region is of interest and their effect on seismograms which have to be analyzed. At the beginning of our work we concentrate on imaging one crack surrounded by a randomly heterogeneous media. We use the well known Kirchhoff migration and compute afterwards the envelope which improves the image, i.e. it is easier to localize the crack. During the Kirchhoff migration we supplementarily do coherence computations which help us to interpret or verify the result. As we focus on a single crack the work is attractive for non destructive testing where damaged material, e.g. concrete, often has prominent cracks but not necessarily a cluster of it.

GENERATING THE MODEL

Before we start producing some synthetic data we have to generate somehow a randomly heterogeneous medium. In the following we describe the parameters of the slightly modified program MEDIUM2D (Burr (1996)) which produces the model needed.

The synthetic model is bounded by a thin layer of air. The width and height of the model is 0.1 m. The ellipses which represent gravel of different sizes make up 50 % of

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the overall area. The gravel has a P-velocity of 4.03 km/s, a density of 2.59 g/cm^3 and a standard P/S-ratio of $\sqrt{3}$. The background material, i.e. the cement, has a P-velocity of 3.95 km/s, a density of 2.17 g/cm^3 and also a P/S-ratio of $\sqrt{3}$. The little white spots in Figure 1 indicate air inclusions. Their content amounts to 4 %. The area of the crack is about 8 mm^2.

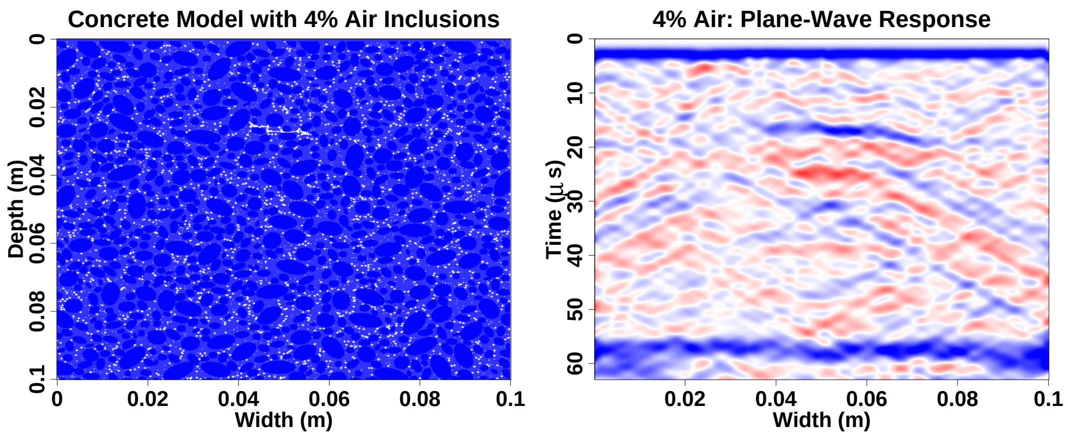

Figure 1: *On the* **left** *side is a heterogeneous concrete model with a defect, i.e. the crack. The ellipses represent gravel within cement. The* **right** *side shows the plane-wave response calculated with the Finite Difference program* ULTIMOD *using a rotated staggered grid.*

GENERATING AND IMAGING SYNTHETIC DATA

The Finite Difference program ULTIMOD (Karrenbach (1995)) is used to compute the propagation of a plane/wave through the model. In order to handle high contrasts the computations in ULTIMOD are performed on a rotated staggered grid. For more details concerning this modification please refer to Saenger and Shapiro (1998) (this issue). A Ricker1 wavelet (first derivative of the Gaussian distribution curve) is propagated. Its fundamental frequency is 300 kHz, whereas the maximum frequency is 500 kHz. The plane-wave response is depicted on the right in Figure 1. Different observations can be made:

- the seismogram looks wavy, frayed and changes smoothly
- the amplitude of the back-echo is about as strong as the reflection of the crack
- lots of diagonal reflections possessing slopes of opposite sign occur.

As we do not have a layered medium or a different medium where it makes sense to use a velocity function for migration, we have to use an effective velocity. This velocity cannot just be an average P- or S-velocity but also has to take the lengthened ray path due to multiple scattering into account. We pick along the receiver line a few traveltimes of the back-echo in order to calculate the effective velocity of the medium. In Figure 1 it can be seen clearly that the reflection of the bottom of the model varies along the modelwidth because the plane-wave is scattered. Thereafter, this velocity is the migration velocity. Notice the wavefront healing that occurs after the plane-wave passes the crack which is noticeable by the fact that the back-echo is a continuous reflection.

Figure 2 shows the Kirchhoff migration of the plane-wave response on the left. It is quite surprising that the crack is imaged with such a good quality although the unmigrated data do look very complicated. No further processing steps are applied before the migration. We tried to improve the image by suppressing the slanted events in the (τ,p)-domain. This effort did not yield better results.

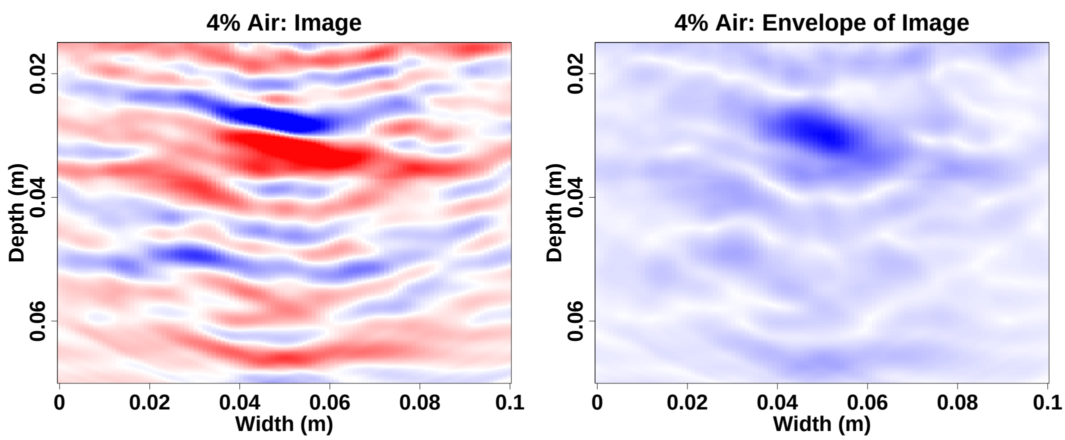

Figure 2: *The migration of the plane-wave response is on the* **left**. *On the* **right** *is the envelope of the migrated section.*

Another processing step was much more successful. We computed after the migration the envelope or instantaneous amplitude, respectively. Now, the image becomes much more distinct as one can see and compare in Figure 2. Areas of high amplitude which do not correspond to the crack fade out after the envelope has been calculated. Only the reflection of the crack is left over. Unfortunately, these benefits have to be paid by decreasing resolution.

Using coherence analysis during the migration process we tried to improve the expressiveness of the image. The semblance (Neidell and Taner (1971)) is calculated along the diffraction parabola while simultaneously summing along it for the migration. The output is shown on the left in Figure 3. The semblance values are in the

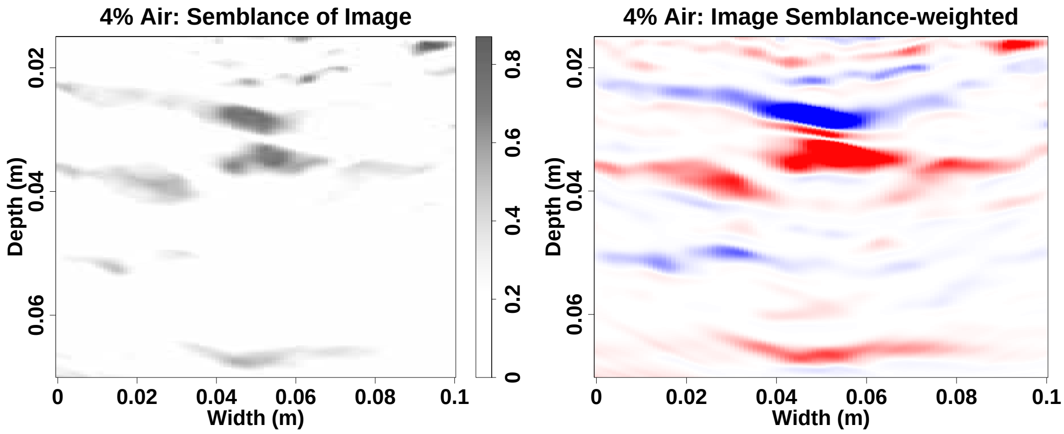

Figure 3: *On the* **left** *the semblance is depicted which is calculated during the Kirchhoff migration. The* **right** *figure is the result of the migrated seismogram multiplied by the semblance section.*

interval of one and zero. One means maximal coherency, whereas zero is associated with minimal coherency. The reflection of the crack is displayed by high semblance values. On the right side in Figure 3 the output of the multiplication of the migrated section with the semblance is displayed. Comparing this weighted image with the original one of Figure 2 makes the improvement obvious. The reflection of the crack is more pronounced. Nevertheless, the width of the reflection suggests the crack to be nearly twice as big as it is actually in the model.

Obviously, this is not the case for the semblance of the image on the left in Figure 3. To have a closer look at it, Figure 4 depicts a zoom of the crack in the concrete model and the corresponding part of the semblance data. Figure 4 demonstrates nicely that the crack is associated with the top boundary of the first region of high coherence values. The regions of high amplitudes or high coherence values being on top of each other appear due to the input wavelet which has a positive and a negative peak. The extension of the upper coherence region matches the crack perfectly. Thus, the semblance plot yields excellent results concerning detection and resolution.

CONCLUSION

We gained good results in imaging a crack in a randomly heterogeneous medium. It has been shown that the semblance, computed simultaneously, and the envelope, computed after Kirchhoff migration, complement one another, very well. The envelope pronounces the existence of a crack and the semblance provides good resolution in the corresponding area.

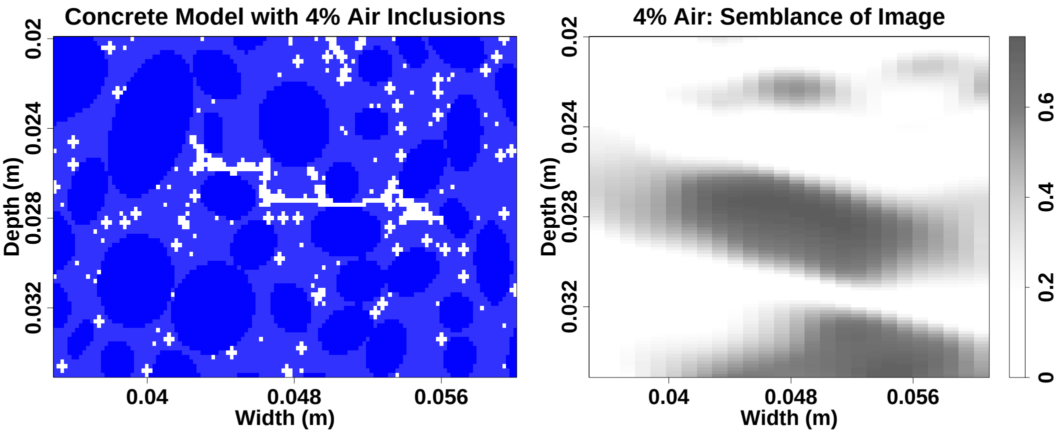

Figure 4: *The* **left** *figure shows a zoom of the concrete and the* **right** *figure is the corresponding zoom of the semblance.*

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