Physical testing of the effect of tilting on the reflection coefficient in an anisotropic material

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Summary

In this work we study the effect of tilting of a well characterized material with weakly orthorhombic symmetry. The method we use allows us to directly measure waveforms of the reflected wavefield from a liquid-solid interface. The envelope of the amplitude is then obtained and compared for the different azimuths. Our results show that azimuthal variations of the reflection coefficient are larger in a tilted medium. Such amplitude anomalies are particularly important at precritical angles, being more notable at the critical angle vicinity. Those results support former theoretical work.

Introduction

The effect of tilting in AVO is an important issue that has recently been addressed by several works (see i.e. Behara and Tsvankin, 2009). It can introduce important complexity to the seismic data and produce wrong estimations of the anisotropic paremeters. Moreover it is common to find tilted structures in the real Earth. Therefore, it is important to study the effects using physical modeling, as such studies permit not only to control the material properties, but also the acquisition methodology. That sort of studies are not very popular in anisotropic materials. A recent work by Alhussain *et al.,* (2008), accounted for the velocity anisotropy under controlled laboratory conditions, they were able to successfully test theory for vertically aligned fractures. They used plexiglass to represent the anisotropic solid, and by immersing it into water they reproduce a liquid-solid interface. The experimental setup also produces a liquid-solid interface, and has been previously tested using sintered porous samples (see i.e. Bouzidi and Schmitt, 2008) with very good results.

Methodology

The experimental setup used during this work is the same described in Bouzidi and Schmitt (2008). We have improved this setup to allow rotation of the sample over the z-axis and waveform recording in azimuthal directions. The main idea of the setup is to use a large and a small piezoelectric ultrasonic transducer as the source and the receiver, respectively, in order to simulate plane wave propagation. The source transducer is excited at a resonance frequency of 0.75 MHz with an electronic pulse, and the reflected or transmitted waveform is recorded via an oscilloscope. In order to have good resolution in the frequency domain, and avoid aliasing, we record 30,000 samples with a sampling interval of 0.002 μs. The experiments are carried out under water-loaded conditions, at room temperature and atmospheric pressure. A sample of the material to study is immersed into the water as well, in order to recreate a liquid-solid interface. Another advantage of this experimental setup is that welding between surfaces is assured without the need of any external pressure to the system. For the reflectivity tests, the source and the receiver transducers are mounted on a goniometer in order to control the incidence angle and to properly align the receiver transducer with the expected specular path of the reflection (see Figure 1). The top of the sample is aligned using a laser pointer to the source to receiver angle of 180 deg, and located on a platform that helps to suspend it into the water and simulate liquid-solid-liquid interfaces. We record waveforms for incidence angles between 12.75° and 50° with an increment rate of 0.25°.

We use two parallelepiped samples with 50 mm thick and 125 mm each side. Each sample has a different dipping angle: 0° and 45° (Figure 1). The samples were covered with a waterproof lacquer to avoid surrounding water to come inside.

The anisotropic material we use was previously studied by Mah (2005). It is a grade CE phenolic material which Mah (2005) estimated to have the following stiffness tensor:

$$c_{ij} = \begin{pmatrix} 15.9 & 7.0 & 6.8 & 0 & 0 & 0 \\ 7.0 & 15.5 & 6.9 & 0 & 0 & 0 \\ 6.8 & 6.9 & 11.1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 3.4 & 0 & 0 \\ 0 & 0 & 0 & 0 & 3.0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 3.8 \end{pmatrix}$$

where the units are in GPa. As we can see $c_{11} \sim c_{22}$, $c_{13} \sim c_{23}$, and $c_{44} \sim c_{55}$. In order to make the tensor hexagonal symmetry, $c_{66} = (c_{11} - c_{12})/2 = 4.4$ GPa, which is slightly higher that the value obtained. The results obtained by Mah (2005) suggest the tensor is weakly orthorrombic. Comparison of the azimuthal P-wave velocity assuming a VTI medium and the real orthorrombic symmetry of the material are shown in Figure 2.

Results

We recorded waveforms for different azimuthal angles for the two blocks. The reflectivity curves were obtained from the envelope of the amplitude of the first arrival, which correspond to the liquid-solid interface. As we can observe from Figure 3, azimuthal variations for the 0° dipping sample are minimal. It is important to mention here that the maximum amplitude occurs at the critical angle, and that the fastest the velocity the smallest the critical angle as stated by the Snell's Law. Therefore we can conclude that azimuthal variations are due to the fact that the material is weakly orthorhombic. It is also possible to observe that the measurements agree with what we expected from the azimuthal velocity shown in Figure 2, and that the fastest direction corresponds to azimuth 0° (green curve Figure 3a). In difference, the reflectivity curves for the tilted media with the dipping angle of 45° show strong dependence on the azimuth. One can clearly observe that the larger variation is at the azimuth 90° and -90°. Minor variations are observed at azimuths 45° and -45°, and the reflectivity at 0° azimuth conserve the same trend is as for the no-dipping sample, but with lower amplitudes.

Conclusions

We have used the actual methodology to successfully test the effect of tilting on the reflection coefficient. It is evident that the combination azimuth dipping plays an important roll on variations of the reflection coefficient. We confirm that such variations can be used to identify principal directions of propagation. Physical modeling can help to understand this phenomenon, particularly to test the effectiveness of using velocity anisotropy to identify symmetry axis for different tilting.

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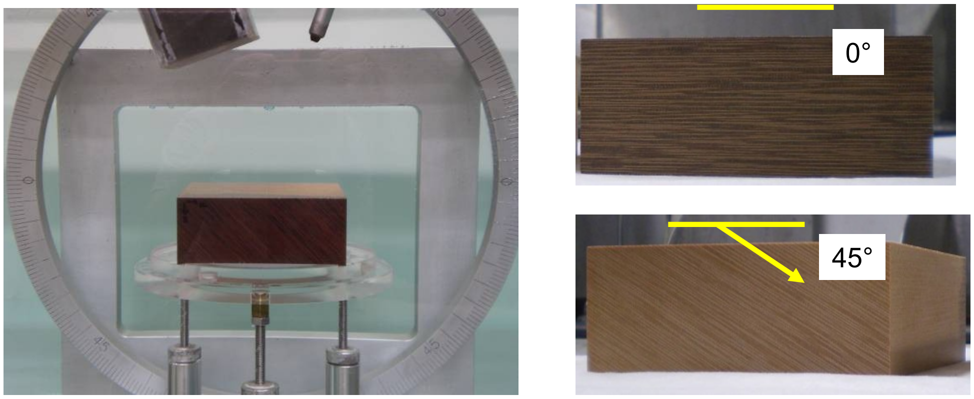

Figure 1: a) Experimental setup. b) Sample with a dipping angle of 0° and c) 45°.

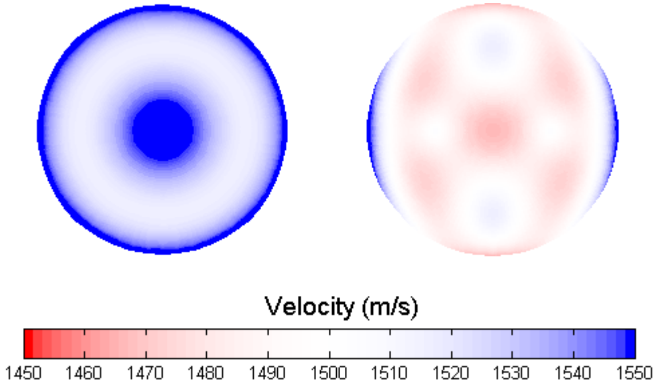

Figure 2: Azimuthal P-wave velocity a) assuming a VTI medium, b) using the estimated stiffness tensor after Mah (2005).

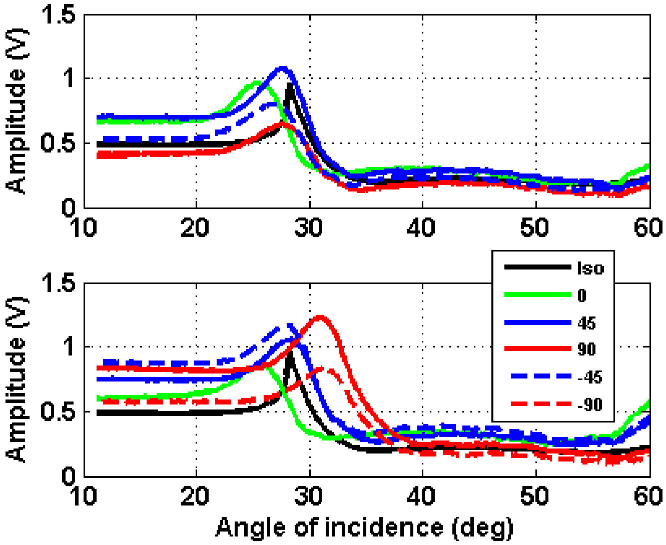

Figure 3: Reflection coefficient versus angle of incidence for dipping angles of a) 0° and b) 45°. The measurements were done for different azimuths: 0° (green), 45° (blue), 90° (red), -45° (dashed blue), -90° (dashed red). The black line is the theoretical reflection coefficient for an isotropic material.