How to get group/phase velocities in anisotropic rocks from traveltimes measured in the lab?

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Introduction

There is an ongoing discussion on whether ultrasonic lab measurements in anisotropic medium yield phase or group velocity (Delinger and Vernik, 1994; Dewhurst and Siggins, 2006). Obviously if the transducers size used to measure elastic wave velocity is small compared to the wave travel distance, then these transducers could be considered as point source/receiver and, therefore, the velocity measured in the test is the group velocity. On the other hand, if the transducers size is large, then, in accordance with Huygens' principle, the wave front generated by such transducer is a combination of a plane wave (assuming that transducers emit along the whole surface simultaneously) and point source wave front. Practically, this is not an issue if the measurements are done in an isotropic medium where point source would produce spherical wavefront and therefore the effective travel distance in the case of finite-sized transducers is simply minimum distance between source and receiver. In anisotropic medium the measurements depend on relative position of source and receiver as well as on their orientation with respect to medium, e.g., with respect to the symmetry axis if such exists. In the current study we test the above ideas experimentally.

Experimental setup

The main idea of the experiments was to measure wavefront emitted by a relatively large transducer into a homogeneous anisotropic medium. The shape of the wavefront can be inferred from the measurements of the surface movement of the sample (see Figure 1). Here we are interested in the instant when a point of the surface starts to move. This instant is referred to as arrival time, and measured with a laser Doppler interferometer (Vibrometer OFV- 5000 Modular Vibrometer Controller with Vibrometer Sensor Head OFV-503 (Politec Ltd.), see Lebedev et al., 2011). In the current study we used the following transducers: videoscan V102 from Olympus (1 MHz, 32 mm in outer diameter with 25 mm piezoceramic).

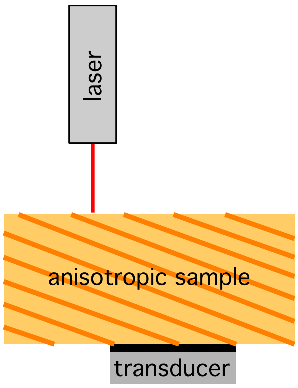


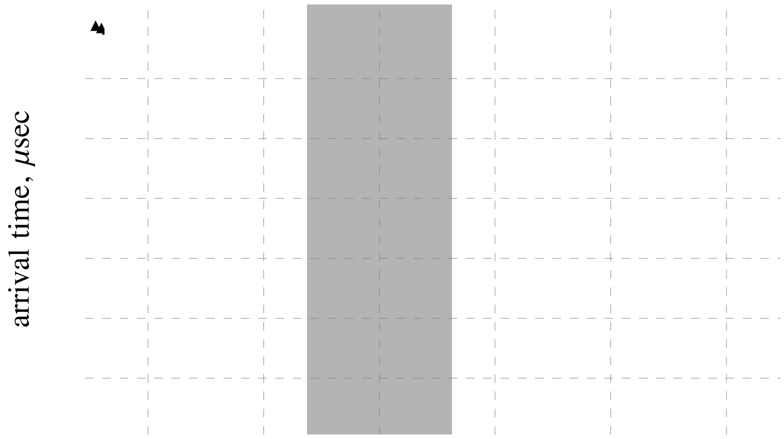
Figure 1: Sketch of experiment

Results

To model anisotropic medium we used samples made of Phenolic grade CE that is synthetic material made of layered woven fabric embedded in epoxy resin. In particular, we prepared five samples with different inclination of bedding plane (see Figure 1). Sample 1: (a) bedding plane inclination = 0^0 and width = 95.9 mm, and (b) bedding plane inclination = 90^0 and width = 102.9 mm. Sample 2: bedding plane inclination = 18^0 and width = 78.3 mm. Sample 3: bedding plane inclination = 35^0 and width = 79.0 mm. Sample 4: bedding plane inclination = 54^0 and width = 78.7 mm. Sample 5: bedding plane inclination = 73^0 and width = 78.9 mm.

Results of the experiments are summarized in Figure 2. Here we see very good agreement between laser and transducer measurements. Moreover for the 0^0 and 90^0 samples we repeated laser (black triangles in background) and transducer (green crosses in background) measurements (the source transducer has been removed and then glued again to the sample). One can observe very good repeatability.

Figure 2: Travel time through phenolic samples vs offset distance from transducer center. Grey shaded



area marks position of source piezoceramic. Points correspond to laser measurements, crosses correspond to travel times measured by 32 mm receiver transducer. Black solid lines correspond to analytical arrival times assuming 25 mm source and using Thomsen's model and Huygens' principle.

Conclusions

We have demonstrated experientially that wavefront of an elastic wave propagating through an anisotropic medium can be constructed using simple Huygens' principle. In particular, knowing the transducer emission pattern, one can reconstruct the wave front in an anisotropic medium. Practically, since in anisotropic medium transducer measurements depend on relative position of source and receiver as well as on their orientation with respect to medium, one should incorporate Huygens' principle into the ultrasonic lab data analysis workflow.

References

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