Definitive Detection of the Slow Compressional Wave in Saturated Porous Synthetic Rock

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Summary
A new experimental technique allows for the definitive observation of the slow dilatational wave in saturated porous materials. The various observed wave modes P-fast, S, and P-slow are easily identified. This technique uses an acoustic beam that is close to a plane wave and the geometrical effects are minimized as well as edge effects. The recorded data do not need major corrections to be used in, for example, attenuation estimates. The slow dilatational wave is completely characterized by its velocity and attenuation.

Introduction
The measurements of Amplitude Variation with Offset assume that the reflectivity variation can be described as if occurring between perfectly elastic materials. AVO is most usually applied, however, to detect fluids in saturated porous rocks. The elastic theory may not necessarily properly describe the reflectivity in this case. Consequently we are studying this problem at a fundamental level in the laboratory. One important component of this study is the appropriate characterization of our materials. One of the properties of a saturated porous medium is the existence of a second P-wave.

Biot (1955) predicted the existence of a second compressional wave that can propagate in saturated porous materials. Then, several other approaches have been proposed that describe wave propagation in saturated porous materials such as de la Cruz et al. (1985). This wave is known as the slow wave. Since then, numerous attempts have been made in the laboratory to detect this highly attenuated wave. Plona (1980) first observed the slow dilatational wave in a porous synthetic rock. Since then other workers have claimed to have observed this wave both in synthetic (Johnson et al., 1994; Geerits and Kelder, 1997) and in natural sandstone (Kelder and Smeulders, 1997). Here a modified experiment that employs a large transducer to create a near plane-wave for transmission through porous plates is described. This method has been successfully employed in the calibration of reflectivity on elastic materials (Bouzidi and Schmitt 2000). The Slow wave is definitively observed here and can be well characterized.

Experimental technique

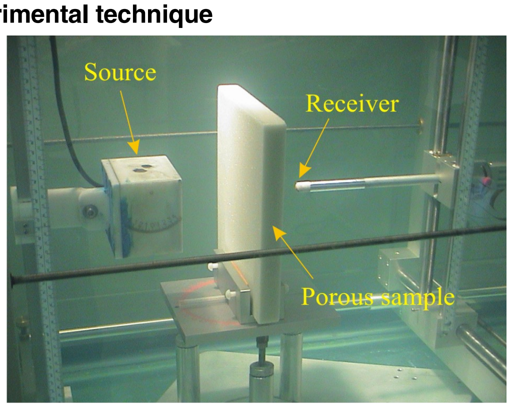


Figure 1: *Experimental set-up for transmission through porous plate. A large area transducer (10-cm x 7.5-cm) as a source and a near-point receiver are used here. The porous synthetic sample is used. The angle of incidence is varied by a rotation of the porous plate. All the set-up is immersed in water.*

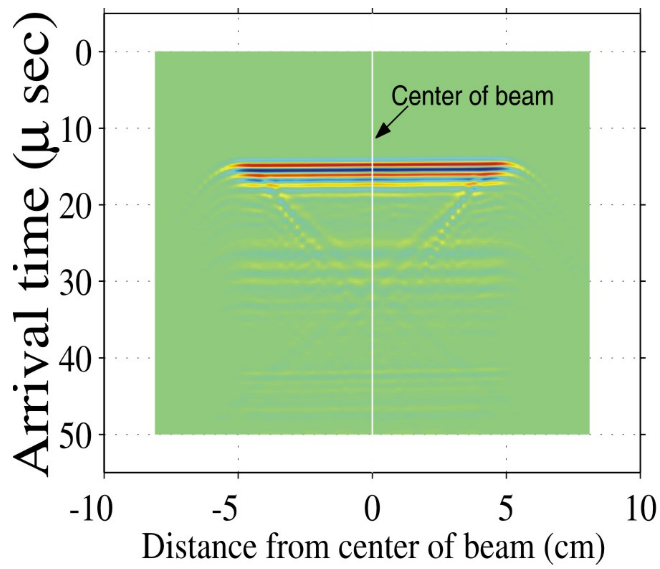


Figure 2a: *The ultrasonic acoustic wave field as measured at normal incidence 2-cm away from the source. The source is kept fixed while the near-point receiver scans horizontally. The beam is flat (arrival time) in a range of about 10-cm.*

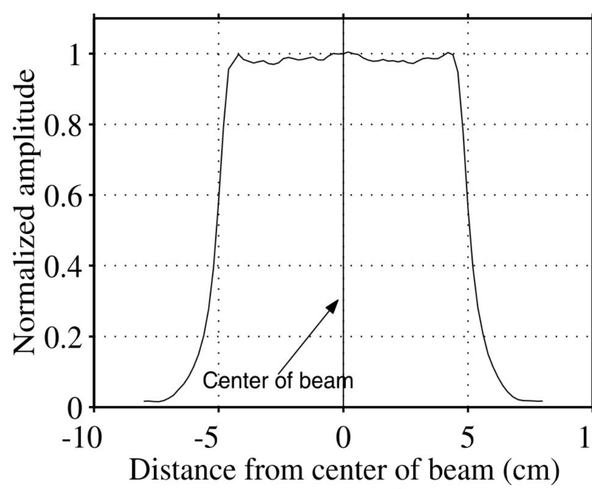


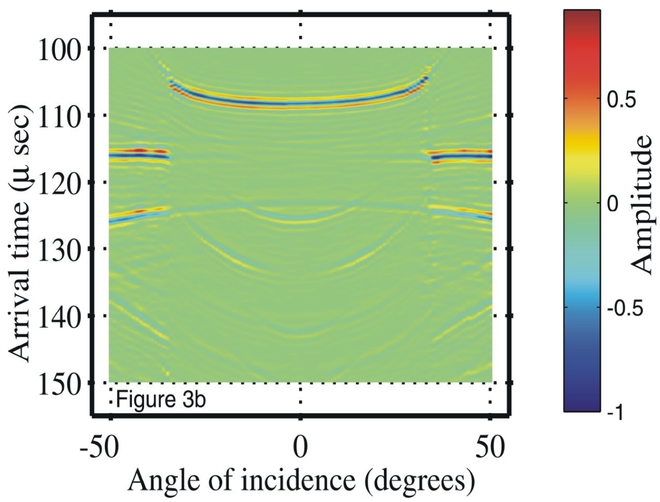
Figure 2b: *The amplitude envelope of the ultrasonic acoustic wave field as measured at normal incidence 2-cm away from the source. The amplitudes are nearly constant in a range of about 9-cm.*

A new method of probing porous materials has been developed using a large area (10-cm x 7.5-cm) ultrasonic transducer as an acoustic source. The laboratory experimental set-up is shown in figure 1. The source used here generates a flat acoustic beam with amplitudes near the center that stay stable for large distances (Fig. 2a-b). A near-point receiver is used for the detection of wave-field transmitted through a water-saturated synthetic porous sample. This sample is made out of sintered glass beads and has a porosity of 0.39.

Results

The wave field transmitted through the porous plate is recorded for a large range of incidence angles (-50° to 50°). Here the source and receiver are kept fixed and the angle of incidence is varied by the rotation of the porous plate. The raw data normalized trace by trace by individual RMS amplitude is shown in figure 3a. The various wave modes are easily identified in the image.

Figure 3a: *The transmitted wavefield as recorded by the near-point receiver. The various modes are identified. The slow wave appears at all angles and curves downwards as the arrival time increases with angle because of its velocity that is slower than that of water. The converted shear wave has almost no curvature as its velocity is near that of water. Note that the slow wave is as energetic as the shear wave.*



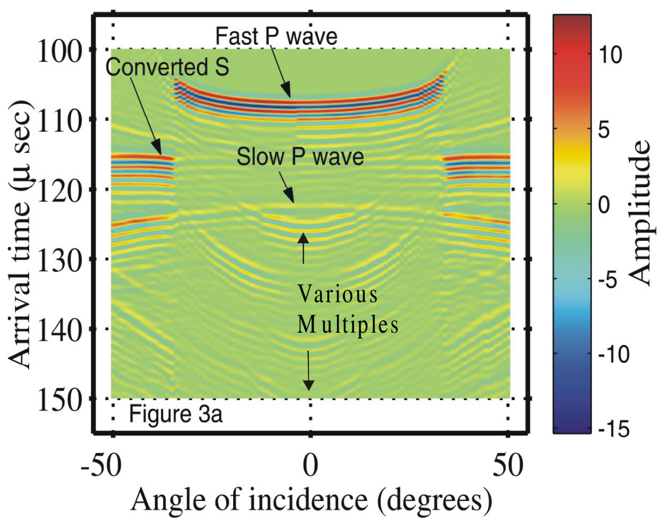


Figure 3b: *The transmitted wavefield with a Minimum Entropy deconvolution applied. The waveform is greatly contracted and events have better continuity.*

The same data is shown Figure 3b with Minimum Entropy Deconvolution applied. This process has greatly increased the resolution and enhanced the continuity of all events. The fast P-wave (~2500 m/s) disappears after the critical angle at about 32°. At this angle the converted shear wave becomes more energetic. In contrast the slow P-wave (~1000 m/s) appears at all angles of incidence. There is no critical angle for this wave (Velocity less than that of water). The travel distance for all wave modes in the sample increases with angle of incidence. Therefore compared to the velocity of water waves with higher velocities arrive earlier and waves with lower velocities arrive later. Thus faster wave arrivals curve upwards whereas slower wave arrivals curve downwards. The converted S wave has almost no curvature as its velocity is near that of water (~1480 m/s). The only wave that curves downwards is the slow compressional wave. Its velocity is lower than that of water. The advantage of using such a set-up is that for the slow wave nearly all ray paths fall within the aperture of the source where the amplitude is constant for a large range of angle of incidence. This makes this wave easily detectible and its velocity and attenuation can be deduced without major corrections to the observed wave-field.

Conclusions

A new laboratory technique was developed for a definitive observation of the slow compressional wave in porous rock. This method allows a better characterization of this wave as its velocity and attenuation can be easily deduced without major corrections to the data. The geometrical spreading of the developed source is negligible. All ray paths of the slow P-wave reaching the near-point receiver originate nearly with the same amount of energy for a large range of incidence angles.

The characterization of the saturated porous sample here contributes greatly in the modeling of the observed experimental Amplitude Variation with Angle on various saturated porous samples presently under investigation.

References

Biot, M. A., 1956a, Theory of propagation of elastic waves in fluid saturated porous solids: I. Low frequency range: J. of Acoust. Soc. Am., **28**, 168-178.

Biot, M. A., 1956b, Theory of propagation of elastic waves in fluid saturated porous solids: I. Higher frequency range: J. of Acoust. Soc. Am., **28**, 179-191.

Bouzidi, Y., and Schmitt, D. R., 2000, Laboratory calibration of amplitude variation with angle using an acoustic goniometer: 70th Ann. Internat. Mtg: Soc. of Expl. Geophys., 210-213.

de la Cruz, V., Spanos, T. J. T., 1985, Seismic wave propagation in a porous medium. Geophysics, **50**, 1556-1567.

Geerits, T. W, and Kelder O., 1997, Acoustic wave propagation through porous media: Theory and experiments: J. of Acoust. Soc. Am., **102**, 2495-2510.

Johnson, D. L., and Plona, T. J., 1994, Probing porous media with first and second sound. II. Acoustic properties of water-saturated porous media: J. Appl. Phys., **76**, 115-125

Kelder, O., and Smeulders, D. M. J., 1997, Observation of the Biot slow wave in water-saturated Nivelsteiner sandstone: Geophysics, **62**, 1794-1796.

Plona, T. J., 1980, Observation of a second bulk compressional wave in a porous medium at ultrasonic frequencies: Appl. Phys. Lett., **36**, 259-261.