Shock-induced surface waves in porous reservoirs

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Summary The frequency-dependent characteristics of the surface waves that propagate along boreholes in fully saturated porous formations are studied in a broad band of frequencies (100 Hz-200 kHz). Numerical results are presented for the dispersion relation, pore pressure and displacements. Experimental data regarding speed and attenuation are reported. The experiments were performed using a shock tube technique in natural and synthetic porous materials.

INTRODUCTION

A detailed knowledge of the relation between the material properties and the propagation of surface waves in liquid-saturated porous media is important in order to obtain an accurate characterization of water and hydrocarbon reservoirs. The frequency-dependent phase velocities and damping coefficients can be inverted in order to obtain the porosity and the elastic properties of the surrounding formation. There are also theoretical and some experimental indications that the speed and attenuation of the surface waves are strongly influenced by the permeability[1][2]. Therefore, accurate acoustic measurements could be used to infer permeability information from the waveform recordings. However, the analysis are basically restricted to the fundamental surface wave usually called tube wave. Furthermore, laboratory data for surface waves along boreholes in porous formations are scarce[2].

In this work we study the frequency-dependent properties of the different surface modes that propagate in a cylindrical interface between a fluid and a fully saturated porous medium. Numerical calculations based on Biot's theory are presented for the dispersion relation, pore pressure and displacements of the different waves. Experimentally, we use shock waves to generate surface waves in a borehole in porous cylinders. Synthetic and natural samples with permeability values ranging from 360 mD to 10.8 mD were used to study the permeability effects in the broad band of frequencies (1-60 kHz) involved in the experiments. The experiments were performed in a shock tube setup[3]. The influence of the confinement due to the shock tube wall is also studied.

PERMEABILITY EFFECTS ON THE PSEUDO-STONELEY WAVE

Figs. 1 show the phase velocities and damping coefficients as a function of frequency for different permeability values for a natural rock sample of Berea sandstone. The results correspond to the pseudo-Stoneley wave. We generally assumed laterally infinite media, except for the case $k_0 = 360$ mD where also the shock tube wall is considered (confined reservoir).

The contribution of the slow wave in comparison with the other bulk modes has been calculated for the averaged radial displacement induced by the pseudo-Stoneley wave. The outcome of these calculations explains the strong permeability dependence for low frequencies, where the slow wave contribution is one order of magnitude larger than the fast compressional and shear waves in the porous reservoir.

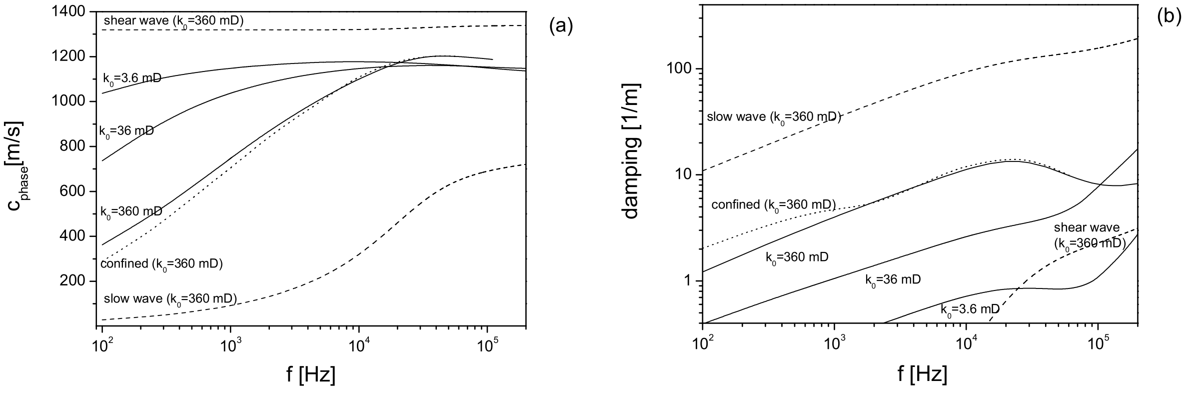

Figure 1: *Frequency-dependent phase velocities (a) and damping coefficients (b) for the pseudo-Stoneley wave for different permeability values. The solid lines correspond to the infinite reservoir configuration. The results for the confined reservoir for* $k_0 = 360$ *mD are shown in dotted line. The slow wave and shear wave velocities and damping are also dislayed for this case (*$k_0 = 360$ *mD).*

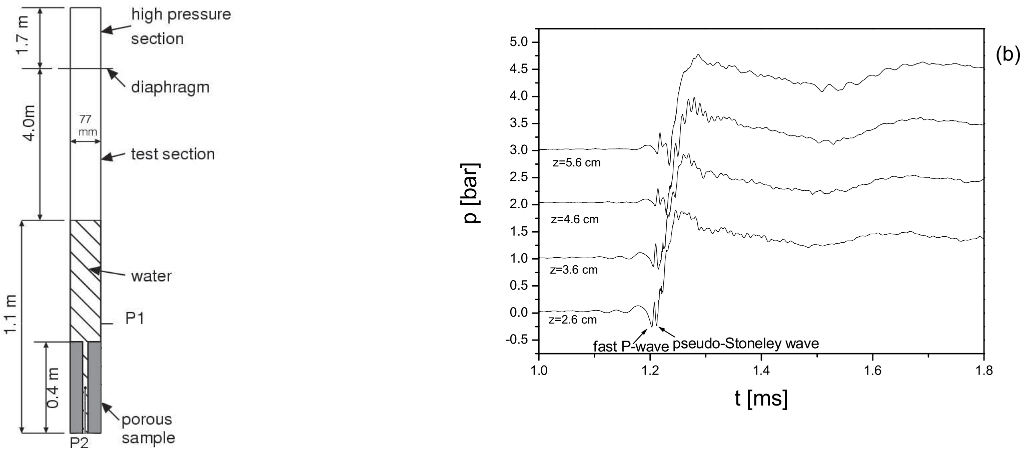

Figure 2: *Vertical shock tube setup (a) and typical pressure recordings at different depths (b).*

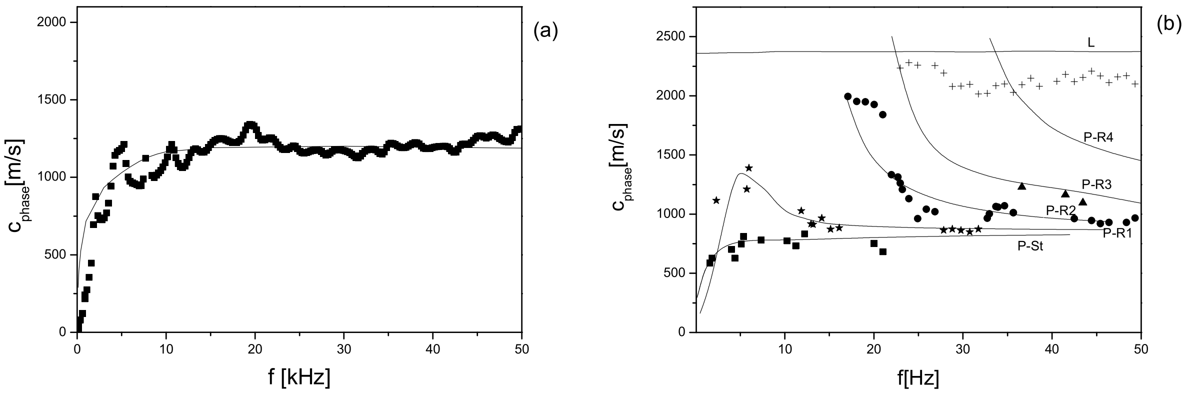

Figure 3: *Comparison between experiments and theory(solid lines) for the phase velocities of the surface waves in a Berea sandstone sample ($k_0 = 360$ mD) (a) and a synthetic sample (b) ($k_0 = 10.8$ D).*

EXPERIMENTAL RESULTS

The experiments were performed in water-saturated porous cylinders with a concentric borehole placed in the test section of a shock tube (Fig 2-a).

A miniature pressure transducer is mounted in a mobile probe that can be displaced along the axial direction of the borehole axis. In this way pressure measurements are performed at different positions along the borehole. Fig. 2-b shows a representative series of signals for a Berea sandstone material. The measurements are processed using a FFT-Prony method to obtain the frequency-dependent phase velocities and damping. The results for the phase velocityies for two different samples are shown in Figs. 3. A good resolution of the pseudo-Stoneley wave is observed in both the time and frequency domain for the Berea sandstone sample (Fig. 3-a). In the synthetic sample, multiple surface waves (pseudo-Stoneley wave and pseudo-Rayleigh waves) as well as the compressional wave in the porous material are excited (Fig. 3-b). Mode transition are observed between the different surface modes.

References

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