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Surface-wave Analyses in Unconsolidated Granular Models with Increasing Degrees of Complexity

L. Bodet* (Sorbonne Universités, UPMC Univ Paris 06), P. Bergamo (Politecnico di Torino), A. Dhemaied (École des Ponts ParisTech), R. Martin (Géosciences Environnement Toulouse), R. Mourgues (Université du Maine), S. Pasquet (Sorbonne Universités, UPMC), F. Rejiba (Sorbonne Universités, UPMC), L.V. Socco (Politecnico di Torino) & V. Tournat (Université du Maine)

SUMMARY

Using micrometric glass beads, we build small scale physical models with increasing degrees of complexity in order to address theoretical and methodological issues of seismic methods (velocity gradients, lateral variations, pore overpressure, etc.). We simulate seismic records at the surface of the laboratory models thanks to a mechanical source and a laser-Doppler vibrometer. From recorded seismograms, we are able to invert surface-wave dispersion for one or two-dimensional velocity structures. These experiments are for instance used as benchmarks for processing and inversion techniques, enable the validation of numerical methods, or make it possible to study issues related to pore fluids.

Introduction

Theoretical and experimental developments in acoustics have always been helpful to geophysicists investigating the propagation of mechanical waves through the Earth, whatever the scale of interest. Acoustics, non-destructive evaluation, exploration seismic and seismology obviously share common issues that can be addressed simultaneously thanks to the development of innovative measurement devices and laboratory physical experiments (Blum *et al.*, 2011). Laser-based ultrasonic techniques have been providing appropriate tools for studying seismic-wave propagation in near-surface geophysics (Bodet *et al.*, 2005, 2009; Bretaudeau *et al.*, 2011; Bergamo *et al.*, 2014), exploration seismic (Campman *et al.*, 2004; DeCacqueray *et al.*, 2011) or seismology (van Wijk and Levshin, 2004). Regarding seismic methods, small-scale physical modelling and laser experiments are most of the time performed using homogeneous and consolidated materials. Metal and thermoplastics are for instance frequently used because they can be easily manufactured into various shapes and provide a wide range of mechanical parameters (Bretaudeau *et al.*, 2011). There is however an obvious need to study the propagation of seismic waves in more complex and realistic media (Krawczyk *et al.*, 2013), more particularly when problematic of unconsolidated and/or porous materials have to be considered.

Acoustic probing of granular media

Bodet *et al.* (2010) addressed the ability of laser-based experiments for the characterisation of dry granular materials. An experimental set-up (Fig. 1a) has been developed and a methodology validated on multi-layered glass beads models. A mechanical source and a laser-Doppler vibrometer were used to record small-scale seismic lines at the surface of the granular medium (Fig. 1b). Surface-wave (P-SV) dispersion and Pressure-wave (P) travel times were analysed to successfully retrieve one-dimensional P- and Shear-wave (S) velocity profiles with depth in the medium.

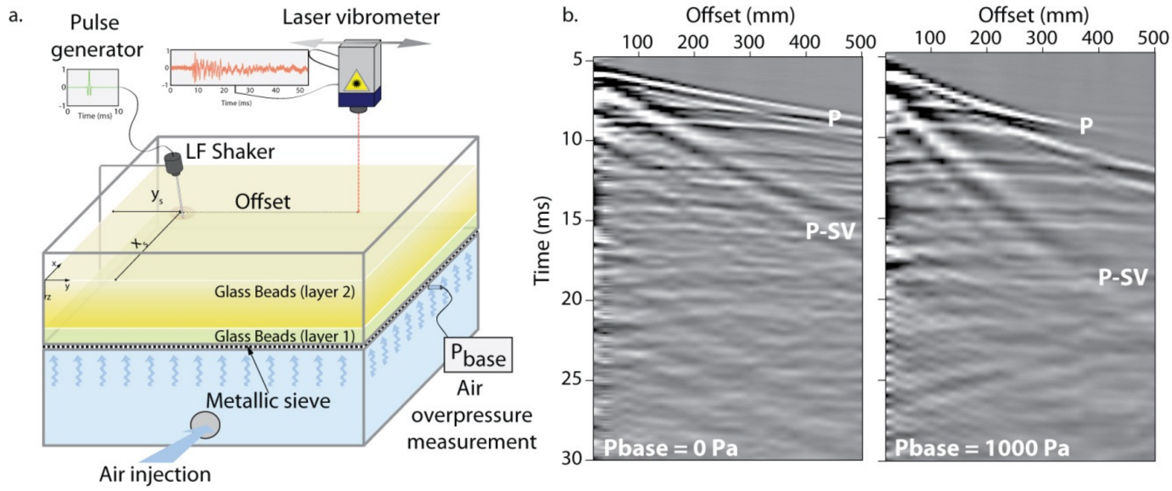

Figure 1 *Experiments involving pore overpressure. (a) An air reservoir is used to generate a pore pressure gradient in the model. (b) The recorded seismograms illustrate the decrease of P- and P-SV waves apparent velocities consequently related to a decrease of effective pressure.*

Building models with increasing degrees of complexity

In the context of near-surface geophysical prospecting, Bergamo *et al.* (2014) took advantages of this experimental set-up to simulate a seismic surface-wave survey over a laterally varying granular medium. The authors were able to construct a physical model with two layers presenting distinct in-depth velocity gradients, separated by a dipping interface. They used this physical model to address the efficiency of an innovative surface-wave processing technique developed to retrieve 2D structures from a limited number of receivers, using a spatial windowing based on a set of Gaussian windows with different shapes (Bergamo *et al.*, 2012). Similar experiments were performed by Bodet *et al.* (2012) in order to monitor granular media with varying pore pressures (Fig. 1), in the context of geological analogue and seismic modelling studies. The reproducibility of the experimental models preparation was first addressed thanks to three unconsolidated glass beads models with in-depth property gradients. A compressed air reservoir was then used at the base of a model to generate a pore pressure gradient in the medium (Fig. 1a). Despite the noise generated by the air injection, recorded seismograms presented coherent and exploitable wavefields. Preliminary results clearly showed the influence of decreasing differential pressure on the medium wave propagation velocities (Fig. 1b).

Conclusions

Laboratory experiments using laser-based ultrasonic techniques can be used to simulate seismic surveys on highly controlled small-scale physical models of the subsurface. The use of granular materials is suggested here to build multi-layered physical models characterised by lateral variations, strong property contrasts and velocity and pore overpressure gradients. Surface-wave processing technique can be successfully applied on these physical models and make it possible to address methodological aspects related to processing and inversion techniques in seismic prospecting. The use of such experiments appears to be of great interest to address a wide range of theoretical and practical issues (e.g. heterogeneous media, complex structures, various pore fluids, etc.) with the physical modelling of wave propagation. We expect this work to validate recent numerical developments conducted in the context of wave propagation in poro-elastic media, and to be applied to hydrogeological prospecting issues.

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