High resolution spatial and temporal laboratory seismic datasets by Laser Doppler Vibrometry
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Research context & objectives

We propose to perform sub-meter scale seismic measurements with innovative experimental tools in a laboratory environment which reproduces large-scale field explorations in well-conditioned and controlled environment. The purpose is to develop high resolution seismic methods on various natural samples, that can be transferred later to large-scale field conditions. Seismic waves are produced in our experiments by a P-wave piezoelectric transducer stuck to the sample surface. Nanometer mechanical displacements induced by the transducer are measured by LDV around the sample. The data acquisition chain is tested in an aluminum cuboid of 280 mm side length. High-resolution (ds ≈ 1 µm, dt ≈ 10 ns) multidimensional mappings of surface displacements on various faces of the cuboid are performed; Furthermore, multidimensional datasets are obtained on both cuboid and cylinder samples by full-field 3D Scanning Vibrometers thanks to the collaboration with Polytec GmbH. Parallel 2D/3D numerical simulations using [IPDG][3] discretization method are done to match the experimental data.

LDV and geophysical applications

Multidimensional measurements

On an aluminum block

Displacement mapping

Normal components of displacements are measured on face 2 (source face), face 3 (upper face) and face 6 (opposite face). Snapshots and seismograms (along multidimensional points) at/until 19.3 s, 34.4 µs, 48.9 µs and 64.3 µs are displayed.

Displacement mapping on an aluminum core

Radial components of displacements are measured. Snapshots and seismograms (around the mid-section) at/until 11.3 µs, 34.4 µs, 48.9 µs and 64.3 µs are shown.

Corresponding simulations

Seismogram from the flat-surface dataset

Seismograms extracted from raw data. The out-of-plane components \( U_z \) are relatively strong on all the 3 receiver faces because the source醒目 points to the direction. The relative energy of the in-plane components \( U_{xy} \) and \( U_{yz} \) depends with the symmetry of wave propagation in homogeneous media. The full-field 3D scanning vibrometer measures evidently the out-of-plane components as well as the in-plane components.

On an Alu cylinder surface (Wavefield snapshots)

Snapshots of the displacements calculated by integrating the velocity measurements (raw data without filtering the ambient noise) at 19.78 µs, 22.72 µs, 36.42 µs and 48.90 µs. The first two are highlighted by P waves fronts and the last two by S waves. We can clearly see the different polarizations respectively for P and S waves.

Application on carbonate core

Experimental setup and wavefield snapshots

Seisimogram and X-ray tomography

Conclusion:

The excellent agreement between experiments and simulations demonstrates that the full wavefield is nicely recorded by the single point LDV, reciprocally validating our numerical scheme and models. A first qualitative analysis on the multidimensional data confirmed the data quality and the capability of the full-field 3D scanning vibrometer. We can then perform fast time-lapse tomography in order to get a first insight of the elastic wave velocity models for the carbonate core. Further analyses on simulated and experimental multidimensional data will enable us to look quantitatively into the polarizations and quantify the Amplitude vs Angle (AVA)[2] influence on the surface measurements. Seismic attributes such as amplitudes and frequencies contain also rich information on other rock physics properties such as anisotropy, proelasticity etc.[3]. The full-field data can eventually be used to test Full Waveform Inversion schemes which would in turn yield more reliable and accurate inversion results.

References

[3] Bastien Dupuy, Stéphane Garambois, Amir Asnaashari, Hadi M. Balhareth, Martin Landrø, Alexey Stovas, and C. Shiu. Multidimensional datasets are obtained on both cuboid and cylinder samples by full-field 3D Scanning Vibrometers thanks to the collaboration with Polytec GmbH. Parallel 2D/3D numerical simulations using [IPDG][3] discretization method are done to match the experimental data.

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