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On the use of a pulsed-laser source in laboratory seismic experiments

Replication of large-scale seismic exploration at laboratory scale with controllable sources is a promising approach that could not only be applied to study small-scale physical properties of the medium, but also contribute to significant progress in wave-propagation understanding and complex media imaging at exploration scale via upscaling methods. We seek to characterize the properties of a laser-generated seismic source for new geophysical experiments at laboratory scale. This consists in generating seismic waves by pulsed-laser impacts and measuring the displacement wavefield by laser vibrometry. Parallel 2D/3D simulations using Discontinuous Galerkin discretization method and analytic predictions have been done to match the experimental data.

**Research context & objectives**

The idea of Full Waveform Inversion (FWI) is to perform a quantitative reconstruction of the theoretical signals and patterns of a sample of interest using data obtained by sensor arrays, and to use this information to infer the medium parameters. FWI is a powerful tool for inverting full waveforms, but it is computationally expensive and sensitive to noise. In this study, we have used a pulsed-laser source as a controllable and reproducible source of seismic waves to study the properties of the medium using full waveforms.

**Pulsed-laser source : General**

Lab set-up for pulsed-laser source characterization

Two different experimental tools were mounted to investigate in Cartesian coordinates or in cylinder coordinates: 1) Q-switched laser generator; 2) convergent lens; 3) Aluminum pulsed samples of various thickness (10, 50, 100 mm), Vp = 6500 m/s, Vs = 2200 m/s. 4) Single point Laser Doppler Vibrometer (LDV). 5) Core sample; 6) Piezoelectric source.

**Theoretical and analytical signals**

A) Temporal laser-generated source under thermoelastic regime with displacement computed by solving the wave equation and the thermoelastic equations. B) Laser-generated source under ablation regime which is modeled as a point-source. C) Zoom on the measured ablation-regime pulse.

**Seismogram and radiation patterns**

Seismograms measured along linear receivers on the 50 mm thick aluminum block with different sources, accompanied by simulated/modded radiation patterns. a) Radiation pattern of a point source (laser ablation); b) Radiation pattern of a piezoelectric source (φ = 110μm); c) Radiation pattern of a typical thermoelastic source (φ = 1.6 mm) under laser impact.

**Epicentral records under the ablation regime**

<table>
<thead>
<tr>
<th>Simulation (SD)</th>
<th>Experiment (30 mm thick)</th>
</tr>
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<tbody>
<tr>
<td>P1 = 7200 m/s</td>
<td>P1 = 7200 m/s</td>
</tr>
<tr>
<td>J2 = 4.1</td>
<td>J2 = 4.1</td>
</tr>
<tr>
<td>J3 = 1.5</td>
<td>J3 = 1.5</td>
</tr>
<tr>
<td>J4 = 1.2</td>
<td>J4 = 1.2</td>
</tr>
</tbody>
</table>

**Conclusion**

The laser-generated seismic source opens new perspectives on various applications such as precise Non-Destructive Test on metals under high temperatures, non-destructive exploration of small and intermediate scale samples of random shapes in the laboratory, etc. We are especially interested in its potential for geophysical applications in rock mechanics, rocks or digital rock imaging for geological reservoir explorations. The laser-generated source appears to be well controllable, flexible and reproducible under some precautions. The combination of the pulsed laser source and the LDV is particularly adapted to generate broadband seismic full waveforms in heterogeneous natural rocks. The practical nature of the laser source makes it convenient to model and explore into numerical schemes. We aim at performing FWI with these data and further more, doing amplitude/frequency related analyses for anisotropy, attenuation and porosity estimation.