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On the exploitation of seismic resonances for cavity detection

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We study the interaction of a seismic wave-field with a spherical acoustic gas- or fluid-filled cavity. The intention of this study is to clarify whether seismic resonances can be expected, a characteristic feature, which may help detecting cavities in the subsurface. This is important for many applications, as in particular the detection of underground nuclear explosions which are to be prohibited by the Comprehensive-Test-Ban-Treaty (CTBT).

On-Site Inspections (OSI) should assure possible violation of the CTBT to be convicted after detection of a suspicious event from a nuclear explosion by the international monitoring system (IMS). One primary structural target for the field team during an OSI is the detection of cavities created by underground nuclear explosions. The application of seismic resonances of the cavity for its detection has been proposed in the CTBT by mentioning "resonance seismometry" as possible technique during OSIs.

In order to calculate the full seismic wave-field from an incident plane wave that interacts with the cavity, we considered an analytic formulation of the problem. The wave-field interaction consists of elastic scattering and the wave-field interaction between the acoustic and elastic media. Acoustic resonant modes, caused by internal reflections in the acoustic cavity, show up as spectral peaks in the frequency domain. The resonant peaks are in close correlation to the eigenfrequencies of the undamped system described by the particular acoustic medium bounded in a sphere with stiff walls. The filling of the cavity could thus be determined by the observation of spectral peaks from acoustic resonances. By energy transmission from the internal oscillations back into the elastic domain and intrisic attenuation, the oscillations experience damping, resulting in a frequency shift and a limitation of the resonance amplitudes. In case of a gas-filled cavity the impedance contrast is high resulting in very narrow, high-amplitude resonances. In synthetic seismograms calculated in the surrounding elastic domain, the acoustic resonances of gas-filled cavities show up as persisting oscillations. However, due to the weak acoustic-elastic coupling in this case the amplitudes of the oscillations are very low. Due to a lower impedance contrast, a fluid-filled cavity has a stronger acoustic-elastic coupling, which results in wide spectral peaks of lower amplitudes. In the synthetic seismograms derived in the surrounding medium of fluid-filled cavities, acoustic resonances show up as strong but fast decaying reverberations. Based on the analytical modeling methods for exploitation of these resonance features are developed and discussed.