Titre du projet: Une forêt se comporte-t-elle comme un métamatériau pour les ondes sismiques ?

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Résumé du projet (in French)

Une forêt d'arbres constitue pour les ondes sismiques un ensemble de résonateurs verticaux quasi ponctuels et arrangés de façon aléatoire ou quasi-périodique. La réalisation d'une expérience de terrain au printemps 2016 avec un réseau dense de mille géophones au sein d'une forêt de pins dans le Vercors aura pour but la mise en évidence de fréquences interdites pour la propagation de l'onde de Rayleigh. Ceci constituerait alors une démonstration spectaculaire de l'existence de systèmes de résonateurs couplés à l'échelle géophysique avec des applications certaines dans le domaine de la protection para-sismique. En effet, en transposant ces résultats à l'échelle plus grande d'une ville où le rôle des arbres serait joué par des buildings, pourrait-on concevoir dans le futur le design d'une ville qui se comporterait comme une cape d'invisibilité pour les ondes sismiques?

Research Project (in English)

The objective of the project is the deployment of a very dense array of three-component geophones at the interface between an open field and a forest. Different sites were investigated during the spring 2016, and the choice was made to perform the experiment near the Mimizan airfield in the Landes forest, in a pine-tree forest with an average density of 80 trees per 400 m^2.

The array will be made up of 31 × 31 = 961 sensors in a regular grid with 4-m inter-element spacing, thus covering an area of 120 m × 120 m (Fig. 1). The spacing has been chosen to match as closely as possible the half-wavelength spatial sampling requirement of the seismic field, both in the forest and in the open field. With the expectation of surface-wave velocities between 150 m/s and 300 m/s in the frequency range [5 Hz to 50 Hz], the choice of 4-m as the inter-element spacing appears to be the optimal compromise. Note that a similar dense array deployment (involving more than 1,100 sensors over a 500 m × 500 m area) was performed in June 2014 around the San Jacinto Fault (South California) in a collaborative study between ISTerre and the University of South California (Los Angeles, USA).

Ambient noise recording. In the first step, long intervals of continuous ambient noise will be recorded by the seismic array. A preliminary experiment performed in May 2014 with two seismometers, as one inside and one outside a small-sized forest at the University campus in Grenoble, revealed two potential bandgaps (around 40 Hz and 100 Hz) from 1 h of seismic ambient noise recording [Colombi et al, 2016]. These encouraging results justify by themselves the present project, with our ambition being to now measure the complete spatio-temporal signature of a forest, as was performed at the laboratory scale with rods attached to a plate [Rupin et al, 2014]. As ambient seismic noise is dominated by surface waves, this ambient noise might be a good candidate for working with the waves that are trapped close to the subsurface. In the case of omnidirectional noise sources, the dispersion curve can be obtained from a kx-ky frequency–wavenumber transformation along the two directions of the seismic array. However, this isotropic noise distribution is in practice difficult to obtain at frequencies above 5 Hz, because of the predominance of human-generated seismic noise sources (e.g., cars, industry). This means that long-term recordings might be necessary to reach this condition, and especially day and night recordings. For the extraction of dispersion curves from ambient noise data, the global seismic array will be divided into two sub-arrays, as the open-field array and the forest array. We expect to observe seismic bandgaps inside the forest, using the dispersion curve in the open field as a reference. As well as the bandgaps, the dispersion curve should reveal any typical abnormal behavior due to hybridization close to the resonant frequencies of the trees. If the aims are achieved, the dispersion curve inside the forest should reveal the metamaterial nature of the forest.

Finally, note that the wind might be another source of excitation for the trees, with potential flexural excitation transmitted to the ground. Wave excitation from the ground to the trees or from the trees to the ground might lead to different results, as different types of resonance can be implied in these two cases: longitudinal resonance, if vertical displacement associated with Rayleigh waves excites the trees; flexural resonance, which can lead to horizontal ground motion if the wind is the dominant excitation source.

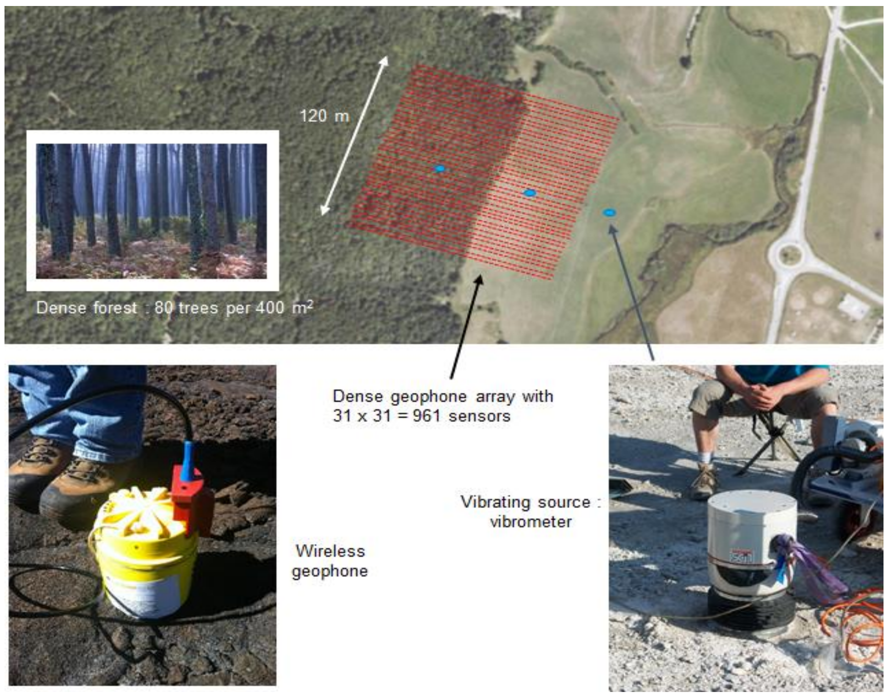

Figure 1: Top: Configuration of the META-FOREST experiment. The geophysics deployment will be located next to Villard-de-Lans on the Vercors plateau (50 mins from Grenoble). The goal is to install 961 three-component geophones on a 120 m × 120 m grid with 4-m inter-element spacing. The seismic array (red) is placed across the interface of an open field and a dense pine-tree forest (80 trees per 400 m^2). Bottom left: Continuous ambient noise recording will be carried out over 12 days with wireless seismic sensors from FairFieldNodal. Bottom right: As well as ambient noise, active source signals will be recorded using a vibrometer source positioned at different locations (top: blue ellipses) in the open field (inside and outside the array) and inside the forest.

Active shots. In a second step, a vibrometer source (property of ISTerre) will be used as an active source to complement the ambient-noise recordings. The vibrometer is fully programmable and works efficiently between 10 Hz and 500 Hz. With the restriction to frequencies between 10 Hz and 100 Hz, we will generate 1-min-long frequency-modulated sweeps, to obtain a sufficient signal-to-noise ratio for all of the seismic sensors. These active shots will be synchronized with GPS and will be stacked over a large number of repetitive acquisitions. The use of active shots will represent a spatio-temporal wavefield as it penetrates into the forest. We expect to observe strong damping of the incident field when it is filtered in the frequency bandgaps revealed by the dispersion curves. At the same time, we should also obtain sub-wavelength and supra-wavelength modes as in locally resonant metamaterials. The use of an active source will also provide measurements of the dispersion curves in the frequency band of the excitation, which will be compared to those obtained from the ambient-noise measurements.

Expected results (in English)

If successful, the outcome of this project is not limited to the no-matter-how-beautiful idea that a physics phenomenon as complex as metamaterial physics and that is classically observed with great effort at the very small scale can find a spectacular demonstration at the human scale with an object as natural and as common as a forest of trees.

We also believe that this project will lead to strong geophysical applications, including, for example:

1. Forbidden frequency bands, or 'bandgaps', can be exploitable for cancellation of ambient seismic noise at locations where ground vibrations are an issue, like for highly sensitive scientific measurements (e.g., local vibration of a large astronomic lens).

2. Similarly, bandgaps can be used to protect sensitive structures, like power plants, from potentially destructive surface waves from earthquakes. The design of a forest that would 'hide' buildings, or any kind of human structure, from damage caused by seismic events through such a natural 'cloak of invisibility' would be a societal revolution in the field of seismic hazards protection.

3. A forest will be the first large scale medium where metamaterial physics will have been demonstrated. However, we can envision future studies on an even larger scale; e.g., some modern cities can be seen as a collection of tall buildings that can definitely behave as resonators for low-frequency seismic waves (between 1 and 5 Hz). Following our experimental demonstration with a forest at the geophysics scale, the next question will be: "Does a city behave as a metamaterial for seismic waves? "

Research Objectives of the Master thesis (in English)

This master thesis would be about studying the influence of trees on seismic wave for two uses:

1- First, oil & gas companies want to understand how the seismic waves are deformed by trees. In fact, it is really hard for them to measure properly micro-seisms caused by oil exploration (for example in Canada where most of the surface is covered by forest). As the importance of these microseisms becomes bigger and bigger, oil & gas companies would like to have a proper model of seismic wave propagation along a forest to really see the impact and the true amplitude of these waves. To obtain this model, ISTerre will perform an original experiment in October 2016 with more than one thousand geophones at the border between a forest and a field.

2- The second part of the thesis would be to go further and see if forest can be used as a meta-material to guide seismic wave and protect an area. The use of meta materials are more and more used in the domain of seismic due to the great applications that can emerge from it. Furthermore, for this part of the project, a second experiment will be performed on a man-build area with pre-allocated "trees" (concrete cylinder). This second experiment will be done in partnership with the company Menard (Vinci) which works on civil engineering and seismic problems.

The role of the student would first be an experimental part with a lot of measurements either in the laboratory or in the field. Then the student will work on numerical simulations to correctly explain and understand the measured data. To help him with the theoretical part the student will be in contact with Sébastien Guenneau (Fresnel Institute, Marseille) and Richard Craster (Imperial College, London) who are used to work on meta-materials for seismic waves with a theoretical approach.

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