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Identification of some statistical parameters of a random heterogeneous medium using measurements of the surface wavefield

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Abstract. *This presentation discusses the identification of some statistical properties of an elastic random medium based on surface measurements. The influence of two fundamental factors in the diffusion regime, i.e. the ratio between the dominant wavelength and the correlation length of the heterogeneities, and the ratio between P and S wave speeds is studied. The influence of the correlation model is also assessed. The global diffusion time of the medium is then used as a key parameter to identify the correlation length of the random medium.*

Keywords: Identification, Random medium, Correlation length, Diffusion regime.

Exploration of the structure of the Earth using seismograms recorded at the surface is a classical problem in geophysics. Its applications range from academic understanding of the interior of the Earth to more industrially-oriented questions related to oil exploration or CO₂ and nuclear waste sequestration. The seismograms typically consist of a ballistic and coherent part corresponding to the first arrivals of P and S or Rayleigh waves, followed by a wave train made of multiply scattered waves called the Coda, with less definite features, [1]. While most inversion methods use this first-arrivals information, and try to identify for the values of the elastic properties in each point in space, we rather aim at using the information contained in the Coda, and wish only to obtain statistical information about the properties of the medium. The inverse problem we consider is therefore a priori much better posed than the classical one because it uses more information for less parameters. We assume that the behavior of the Coda can be understood through a model of diffusion of the elastic energy [1, 3].

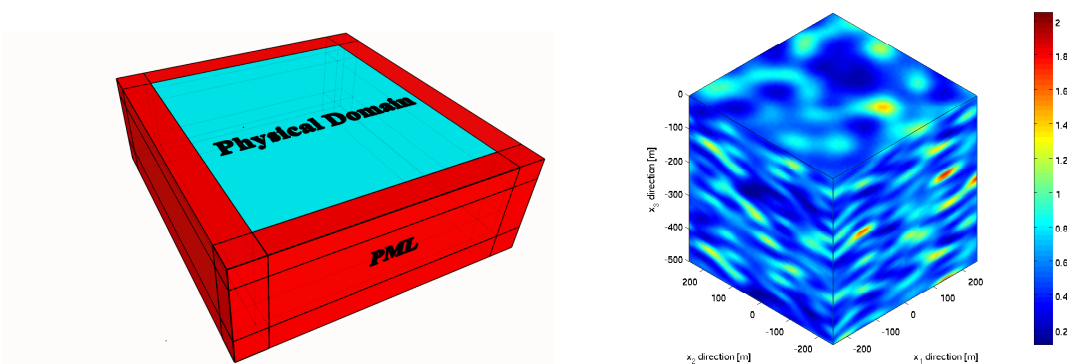


Figure 1: Propagation domain as a half-space with PMLs at boundaries (a), and one realization of a random elastic modulus.

We consider the propagation of elastic waves in a half-space (Fig. 1) with random isotropic mechanical properties. The constitutive random elastic tensor is then parametrized through its average value and variance, a correlation structure, and a correlation length [2]. Fig. 1 also depicts a realization of the first component of the random elastic matrix $C_{11} = \lambda + 2\mu$ where λ and μ are the Lamé coefficients. The tensor is assumed to be statistically homogeneous. Four types of correlation models, i.e. exponential, Gaussian, squared cardinal sine and Von Kármán are used

to describe the correlations of the Lamé coefficients. In the case of an isotropic medium with continuous random heterogeneities, the scattering parameters as well as some parameters of the diffusion regime depend on: 1) the amplitude of the fluctuations $[\sigma^2]$, 2) the ratio $a = \lambda/\ell_c$ between the dominant wavelength and the correlation length of the heterogeneities, and 3) the ratio $K = v_P/v_S$ between P and S wave speeds. For example, the total scattering cross-section for P to P mode conversion, normalized by ωa^3 where ω is the local angular frequency, in the case of an exponentially correlated isotropic random medium with mutually independent elastic parameters and a constant density, is:

$$\frac{\Sigma_{pp}(K, a, \sigma_\lambda^2, \sigma_\mu^2)}{\omega a^3} = \frac{2(K^2 - 2)^2}{K^4(1 + 4a^2)} \sigma_\lambda^2 + \left\{ \frac{2}{3a^4} + \frac{3(1 + 2a^2)^2}{2a^8} - \frac{(1 + 2a^2)^3}{2a^{10}} \ln(1 + 4a^2) + \frac{7(1 + 2a^2)^4}{2a^8(1 + 4a^2)} \right\} \frac{\sigma_\mu^2}{K^4} \quad (1)$$

In order to evaluate numerically the scattering parameters, especially the scattering and transport mean free paths and the elastic diffusivity of the underlying random medium, we use a high-performance parallel Spectral-Element-based code [2].

The general objective of this research is to perform identification based on a part of the seismic recordings that is seldom used and based on a stochastic model of the medium and a diffusion approximation. We assess here the influence of the basic random model parameters onto the diffusion regime parameters as a first step towards this goal. The next step is to evaluate the scattering parameters using statistical analysis of the Coda waves.

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