Boundary element modelling of seismic waves in media with distributed cracks

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We describe the 2-D elastodynamic boundary element method (BEM) and apply it to solve scattering problems. The method is based on the integral representation of a scattered wavefield by placing a fictitious source distribution on the surface of the scattering objects (Fig 1). The fictitious sources can be determined by matching the appropriate boundary conditions at the bounding surfaces of the inclusions. This method, known as an indirect BEM, is the mathematical descriptions of Huygens’ principle, and it has the capability to calculate full wavefields including multiple scattering. The accuracy of the method is assured by comparing the BEM results with those calculated using other methods. We present some numerical examples of scattering of seismic waves by several different distributions of inclusions in order to demonstrate the versatility of the method.

Figure 1: Problem configuration: A scattering object $S$ bounded by the curve $L$ with outwards unit normal $n$.

Figure 2: Different geometries for randomly distributed cracks: (a) Gaussian, (b) exponential, (c) uniform; and (d) Gamma distributions.

We present examples for the scattering of SH-waves by distributed cracks. Four different random realisations of the cracks are modeled (Fig. 2). In each model, there are 30 cavities distributed in a 120mx120m area. Each crack has a half width of $a = 2.5m$, and is discretized into 8 elements. The surrounding solid has $v_p = 3500 \text{ m/s}$, $v_s = 2020 \text{ m/s}$, and density $\rho = 2.3 \text{ gcm}^{-3}$. A plane wave source is used that travels in the positive x-direction. 90 receivers are located parallel to the z-axis at $x = 120 \text{ m}$ starting from $z=150 \text{ m}$ with an increment of $\Delta z = -1.6 \text{ m}$. A Ricker wavelet with a dominant frequency of 100 Hz is used, so that $k_p a = 0.45$, and $k_s a = 0.78$ ($k_p$ and $k_s$ are P and S-wavenumbers), or $\lambda_p/2a = 7$ and $\lambda_s/2a = 4$ ($\lambda_p$ and $\lambda_s$ are P and S-wavelengths, respectively). Plane waves (SH, SV and P) travel along the positive x-direction, and 90 receivers are located along z-axis at $x = 120 \text{ m}$ starting from $z = 150 \text{ m}$ and with an increment of $\Delta z = -1.6 \text{ m}$.

The resulting synthetic seismograms are given in Fig. 3. The coda waves last longer for the SH-waves from models (c) and (d) and this can be explained by the fact that cracks are more clustered in the central part for models (a) and (b), whereas cracks are more scattered or more uniformly distributed for models (c) and (d). This is exactly what may be expected. A similar phenomenon can be seen for the corresponding P- and SV-wave wavefields (not shown here), but the wavefield is much more complicated than from the SH-wave
sources, which is due to the inter-conversion between P- and SV-waves. A slight time delay can be seen in the middle of the plots (middle receivers) and this is due to the fact that the middle receivers are located immediately behind the cracks so that more scattering interferences are expected. These examples show that different distributions of inclusions have a significant influence on the multiple scattering, and this may have an important implication in explaining coda waves in terms of randomly distributed crustal heterogeneities. Currently, the BEM is applied to model anisotropic effects of aligned distributed cracks.

This work was supported by the Natural Environment Research Council, and is published with the approval of the Director of the British Geological Survey (NERC).

Figure 4. Synthetic full wavefield from the plane SH-wave incidence. (a) to (d) correspond to crack distributions (a) to (d) in Figure 3. The numbers on the left side of the synthetic seismograms are the receiver numbers.