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Dynamic response of a solid with multiple inclusions under anti-plane strain conditions by the BEM

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ABSTRACT

In this work, a 2D problem in elastodynamics that involves the finite elastic solid containing multiple cylindrical and elliptical inclusions and/or cavities of arbitrary size, number, material properties and geometrical configuration is solved. More specifically, anti-plane strain conditions are assumed to hold and all external loads have a time harmonic variation. The numerical method used for this purpose is the direct, displacement-based boundary element method (BEM) with sub-structuring capabilities. The BEM employs frequency-dependent fundamental solutions for a point load in the unbounded continuum, and requires discretization of all external and internal surfaces and interfaces only. The method is well suited for the computation of stress concentration factors, while solution at points inside the domain of interest can be expressed directly in terms of boundary data without recourse to domain discretization. Thus, an effective numerical scheme is developed, verified and subsequently used for extensive parametric studies. The numerical results obtained here show a marked dependence of the stress and displacement wave fields on the shape of the inclusions, their material properties, number and position, as well as their mutual interaction with the incoming horizontally polarized shear (SH) waves. The potential of the BEM to efficiently produce accurate results for the dynamic response of both finite and semi-infinite solids that are strengthened and/or weakened by multiple inclusions, as compared to other domain-type methods, makes it a valuable computational tool for solving certain categories of engineering problems. These range from fields as diverse as material science and non-destructive testing evaluation, to seismology and exploratory geophysics.

1. Introduction

Scattering, diffraction and dynamic stress concentration phenomena in solids containing inclusions and cavities is a topic of high interest to geophysicists, seismologists, mechanical engineers and material science specialists. This is so because these problems form the theoretical background behind geological profile mapping, earthquake-resistant analysis and design, mineral prospecting, size characterization in structural components, detection of defects in high-technology industrial products, etc. Although the dynamic analysis of elastic solids weakened by inclusions and/or cavities has drawn considerable attention in the past [1–3], there is still need for a critical view of existing results and for further development of new, efficient computational tools for solution of problems with higher levels of mechanical complication. The present work is a continuation of the authors' previous efforts in this direction [4], which focused on numerical simulation of dynamic stress and scattered displacement wave fields in finite-size solids containing multiple in-plane cylindrical inclusions. In order to complete these types of solutions, the aim here is to investigate the scattering and diffraction of elastic wave fields and the associated dynamic stress concentration phenomenon in finite elastic solids under anti-plane strain conditions. In both Ref. [4] and in here, the aim is to show that wave diffraction and the ensuing dynamic stress concentration phenomenon depend on a number of common factors, as will be discussed in what follows, but are furthermore dependant on the polarization of the propagating elastic waves, which is different. This way, we reconstruct the so called "2.5 D" problem comprising both plane strain (P- and SV-wave) and anti-plane (SH-wave) cases. The solids under

Abbreviations: BEM, boundary element method; FEM, finite element method; SCF, stress concentration factor; BVP, boundary-value problem; BIE, boundary integral equation; BE, boundary element; FE, finite element.

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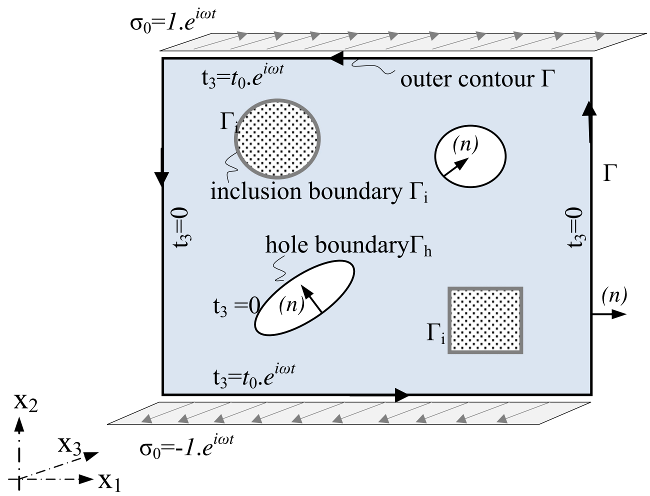

Fig. 1. Geometry of a plate containing both inclusions and cavities.

investigation may contain multiple inclusions of any shape (although we focus here on circular and elliptical shapes), size, number, elastic properties and geometrical configuration. Insofar as the interest is in SH waves only, the state-of-the-art discussion will focus on the case of anti-plane strain wave propagation.

Solution of scattering and diffraction of SH-waves by different type of heterogeneities began after the 1950s. An exact solution based on the wave-function expansion method for plane SH-wave propagation in an infinite elastic domain containing a circular cavity has been available in the literature for quite some time, see Ref. [1]. A similar solution was subsequently obtained for diffraction of SH waves by a cylindrical cavity in the elastic half-plane, see Refs. [5–7]. The same problem was solved by the indirect BEM [8] based on the 2D Green's function for a viscoelastic half-plane. Next, the weighted residual method was developed in Ref. [9] for stress computations along the perimeter of circular or elliptic cavities subjected to SH waves moving through the infinite elastic plane. A hybrid computational technique based on the wave function expansion method combined with the method of images was developed in Ref. [10] for evaluating the dynamic stress concentration factor (SCF) near a circular cavity within a layer subjected to an SH wave. Also, anti-plane strain dynamic analysis involving up to three elliptic cavities was studied by the Fourier transform in conjunction with the integral equation method in Ref. [11]. Furthermore, Smerzini et al. [12] presented results for an embedded circular cavity subjected to SH wave propagation from a seismic source along a line parallel to the axis of the cavity. Tsaur and Chang [13] obtained a novel solution, based on the region-matching technique combined with the method of images, for the multiple scattering of SH waves by a horizontally-truncated circular cavity. An analytical method is proposed in Ref. [14] to perform dynamic analyses for multiple circular cavities in the half-plane, while the indirect-type BEM was used by Ohtsu [15] in studying the seismic response of canyons, tunnels and trenches in a half-plane under SH waves.

Following a different line of approach, the weighted residual method was applied by Manoogian [16] to the problem of scattering and diffraction of SH waves by tunnels of arbitrary shape (e.g., circular, elliptic and square) located in half-plane. Also, the semi-circular cavity in the half-plane under SH-wave excitation was studied using the wave function expansion method augmented by a new decoupling technique in Ref. [17]. Randomly distributed infinite circular and elliptic cylinders in the full plane subjected to SH-waves were investigated by the *T*-matrix approach in Ref. [18], while Avila-Carrera et al. [19] considered scattering of SH waves by a finite array of regularly distributed cylindrical cavities and inclusions. By using the indirect BEM, Benites et al. [20] investigated SH wave scattering by a system of multiple cavities in an infinite plane and in a half-plane. Finally, Dravinski and Yu [21] obtained BEM solutions for the surface response of a half-plane with multiple buried inclusions of arbitrary shape and location to SH wave. Results that were recovered for a system two, three and nine inclusions convincingly demonstrated that the free surface response is strongly influenced by the dynamic interaction between inclusions with different stiffness.

In sum, the following conclusions can be drawn from the above state-of-the-art: (a) Most of the results focus on the cavities of circular or elliptic shape, with few results available for other shapes; (b) again, most of the results are for single inclusion (or a cavity), and few papers consider multiple inclusions in arbitrary arrangement; (c) the majority of results are for cavities or inclusions in the infinite or semi-infinite plane. To the authors' best knowledge, few results are available for finite-size elastic solids with multiple inclusions of arbitrary shape, number, size and material properties; (d) almost all papers evaluate stress concentration factors and the scattered elastic wave field, while only in few instances the role played by the inclusions in modifying the signals that develop

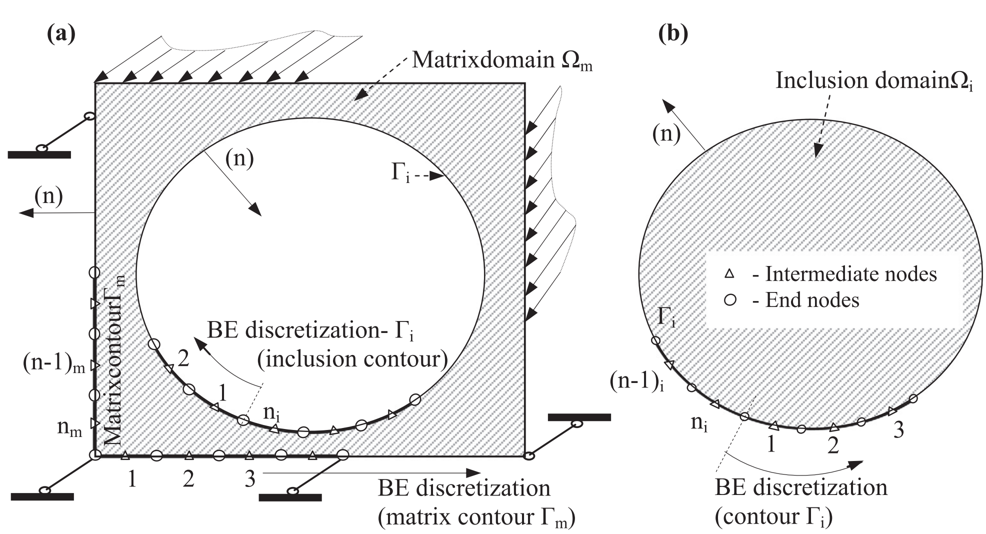

Fig. 2. Anti-plane strain BEM model for a single inclusion: (a) matrix domain; (b) inclusion.