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The vibration of a half-space due to a buried mode I crack opening

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HIGHLIGHTS

- The 3D dynamic problem for an elastic cracked half-space is investigated.
- The boundary integral equations method with the Helmholtz potentials is used.
- The result is presented in frequency domain.
- The time-dependences of the displacements on the half-space surface are found.
- The variation of frequency parameters can be used to identify of the crack growth.

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ABSTRACT

The solution of a dynamic problem for calculation of a displacement field on a half-space surface caused by an internal mode I crack opening is presented. The problem is reduced to the system of boundary integral equations (BIEs). The equations of motion are solved with the use of Helmholtz potentials and applying Fourier integral transform. The effects of the crack size, the crack depth and the distance from the crack epicenter to the observation point on the parameters of elastic waves are investigated. It is established that the increasing of the defect size leads to narrowing bandwidth of elastic waves and to lowering of center frequency. The analysis given here can be used for identification of the crack growth during technical diagnostic of an industry objects and structural elements by AE method.

1. Introduction

One of the most interesting techniques used for the non-destructive evaluation of materials is the acoustic emission technique (AE) [1]. Compared to other non-destructive testing methods, AE can monitor the changes in materials behavior over a long time and without moving one of its components i.e. sensors. This makes the technique quite unique along with the ability to detect the crack propagation occurring not only on the surface but also deep inside a material. Almost all materials produce acoustic emissions when they are stressed beyond their normal design ranges to final failure.

Mathematical modeling of the defect creation process enables to set the relationships between the characteristics of the defects and the parameters of elastic waves. These relationships can be used to the development of AE methods for diagnostic the materials and structural elements. AE signals analysis makes possible reliably interpret the degree of the structures damage.

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The elastodynamic ray theory has been successfully applied to an investigation of acoustic emissions produced by elementary processes of deformation and fracture at a crack edge by Achenbach and Harris [2]. Authors have analyzed the wave front motions generated by an arbitrary distribution of climbing edge dislocations emanating from the tip of the semi-infinite crack in an unbounded linearly elastic body. The problem was solved by the Laplace transform and the Wiener–Hopf technique. The displacements on the front of the longitudinal wave are expressed in terms of emission coefficients. The coefficients have been plotted versus the angle of observation, for various values of the crack propagation speed. As a specific example, the first signals generated by brittle mode I propagation of an elliptical crack are calculated.

The method for determination of the displacement at any point in the infinite body has been presented by Jacobs et al. [3]. The proposed solution procedure is illustrated for the case of a semi-infinite crack tip that due to the dynamic mode I stress instantaneously reaches a constant velocity, propagates for a short time and instantaneously stops. For the solution of the problem, the Cagniard–de Hoop method was used. The displacement at any point in the infinite body is determined using the dynamic stress and the influence functions, which present the vertical and horizontal displacement at any point in an elastic half-space. The result shows the change in displacement due to variations in crack velocity and the effect of the duration of crack propagation. An advantage of the presented analysis is that the source for the acoustic emission signature is the actual crack propagation event and not a simple point source model.

The motion of an infinite elastic plane medium and of a half-plane produced by the sudden occurrence of the crack has been investigated by Alterman et al. [4] using the finite difference technique and the integral equation method. The crack is caused by shearing stresses and it is assumed to occupy a straight line of constant length. In order to get an analytic solution for short times near the middle of the crack it was took that the length of the crack tends to infinity. The authors notice that the crack in the half-plane behaves differently from the crack in the plane, mainly due to the strong effect of the surface waves on the free surface of the half-space and to the diffraction effect of the crack.

Andreykiv et al. [5] have proposed a calculation model for determination of acoustic emission caused by formation and subcritical growth of the internal crack in local areas near its contour. Using the Hankel and Laplace transforms, the problem was reduced to the Fredholm integral equation of the second kind. The dependences between amplitudes of AE signal and the area of subcritical crack growth are established.

Scruby et al. [6] have calculated acoustic emission waveforms for the epicenter location of the elastically isotropic half-space due to the operation of the microcrack, the shear dislocation and the pure dilatation sources. The effects of the source orientation, the source depth and the source rise-time (half-width of Gaussian pulse) on the normal surface displacements were investigated. The waveform spectra of the epicenter surface displacements generated by a horizontal microcrack at various source depths and as a function of source rise-time are shown graphically. The width of the spectrum is very sensitive to the source rise-time.

Wadley et al. [7] have used a multipolar approximation to predict the epicenter waveforms for two models (self-similar and side-opening crack models) of cracking and thermoelastic generation by a laser pulse. The mode I crack grows from the surface of metal plates. The effect of the behavior of the crack during its growth on the detected acoustic emission signal is investigated.

Sinclair [8] and Shibata [9] have researched the elastic wave at the epicenter of the internal source radiation.

When the cracks are located in an engineering structure, the AE waveform is also greatly influenced by interaction with the structure's boundaries. Thus Harris and Pott [10] have investigated the surface motion excited by the acoustic emission produced by fracture processes at the edge of a two-dimensional, semi-infinite, tensile crack. The crack is assumed to have its plane sufficiently close to the vertical that it can grow toward the surface. The problem is investigated on the basis of elastodynamic ray theory. The study of the near-field surface motion has shown that the surface motion caused by the incident compression emission dominates that caused by the incident shear emission except in a localized region directly above the crack-tip. In the far field the Rayleigh wave is the dominant disturbance. A measurement of acoustic emission should, in principle, give information about the crack's size, its orientation, and the fracture processes near the crack tip.

The scattering of time-harmonic plane longitudinal, shear, and Rayleigh waves by a crack (a straight crack and a Y-shaped crack) in two dimensions embedded in a semi-infinite homogeneous isotropic elastic half-space has been studied in [11]. A hybrid numerical technique combining a multipolar representation of the scattered field in the half-space with the finite element method has been used to obtain the far field displacements as well as the stress intensity factors for the crack tips. Vertical displacements on the free surface of the half-space are presented.

A detailed investigation of dynamic stresses and displacements in mode I near a circular crack in a half-space containing transversely isotropic material has been presented in [12]. The crack surfaces are affected by time-harmonic axisymmetric tractions parallel to the axis of material symmetry. The equations of motion are solved with the use of a simple potential function and applying Hankel integral transforms. The stresses and displacements are determined with the aid of the relations with the potential functions and the theorem of inverse of Hankel integral transforms. The boundary value problem is degenerated to a full-space containing a disc shaped crack in it if the depth of the crack approaches infinity. By knowing the vertical traction, the form of singularity of the contact traction at the crack tip has been shown. From the numerical results, it is observed that both the stress and the displacement are influenced by the degree of anisotropy.

There are many applications for the problems of both stationary and growing mode I cracks (see Borodachev [13], Zhong et al. [14], Zhou and Wu [15], Jin and Zhong [16], Karapetian [17], Komvopoulos [18], Kim et al. [19]). In these investigations, the displacements at the crack tip, at the center or on the surfaces of the crack, at the epicenter of the crack have been found.