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Shear wave in a pre-stressed poroelastic medium diffracted by a rigid strip

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ABSTRACT

The investigated work analytically addresses the diffraction of horizontally polarised shear wave by a rigid strip in a pre-stressed transversely isotropic poroelastic infinite medium. The far field solution for the diffracted displacement of shear wave has been established in closed form. The diffraction patterns for displacement in the said medium have been computed numerically and its dependence on wave number has been depicted graphically. Further, the study also delineates the pronounced influence of various affecting parameters viz. anisotropy parameter, porosity parameter, speed of the shear wave, and incident angle on the diffracted displacement of the propagating wave. The effects of horizontal as well as vertical compressive and tensile pre-stresses on diffracted displacement of propagating wave have been examined meticulously in a comparative manner. It can be remarkably quoted that porosity prevailing in the medium disfavors the diffracted displacement of the propagating wave. In addition, some special cases have been deduced from the determined expression of the diffracted displacement of shear wave at a large distance from the strip.

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1. Introduction

In yesteryears and till date, the diffraction of elastic waves from different obstacles present in the media has drawn considerable attention of many distinct researchers across the globe. In the existing literature based on the technique of separation of variables, attempts had been made to solve the problem of the diffraction and scattering of elastic waves by an obstacle in different elastic media. Moreover, a number of such problems in context to electromagnetic theory have been accomplished on large scale by employing the Wiener-Hopf technique. In view of their application in fracture mechanics, seismology, geophysics and so forth, the problems of diffraction of elastic waves by cracks or rigid strips have been aimed in particular. The presence of such type of obstacles produces surplus waves when they are excited by approaching elastic waves, leading to a phenomenon commonly known as diffraction or scattering. Drawing on this knowledge, amplification on one hand while de-amplification on the other, may be seen relative to the amplitude of input motion. It is, therefore, important to understand the theoretical aspects of such scattering and diffraction phenomena. In ultrasonic non-destructive evaluation (NDE) techniques, the interest is in the diffracted wave field as it carries a great deal of information on the

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characteristics of the obstacles. Owing to the simple nature of the interaction of shear waves with distinct obstacles, SH-waves among different elastic waves are usually taken into account in order to enhance the theoretical understanding of the wave diffraction mechanism by the considered obstacle. This, in turn, results in clear visualization of the movement of SH-waves making the mechanism of the SH-wave diffraction more understandable. As a matter of fact, analytical methods impart closed form solutions with better accuracy and relatively less numerical implementation while dealing with most of the practical problems which involve arbitrary-shaped obstacles. Besides this, analytical solutions are essential for exploring the physical nature of a particular problem, and offer the best benchmark to verify other approximate solutions when available for that very particular problem.

Increasing progress and advancement have been made in the domain of wave propagation featuring the scattering and diffraction theory pertaining to acoustic, electromagnetic and elastic waves. Numerous researchers have shown their keen interest to understand the phenomena of diffraction and scattering subjected to elastic waves in the recent past. Faulkner [1] discussed about the diffraction of an electromagnetic plane-wave by a metallic strip. He employed Weiner-Hopf technique to solve the problem of diffraction of aforesaid plane-wave. The diffraction of polarized harmonic shear waves by a sharp crack of finite length under anti-plane strain was studied by Loeber and Sih [2]. In this analysis, a couple of integral equations were obtained which were treated using integral transform technique. The different obstacles present in distinct elastic media have significant influences on the diffraction of elastic waves. The diffraction of an anti-plane shear wave by an edge crack in a semi-infinite elastic medium was elaborated by several researchers [3–5]. Later on, the problem of diffraction of normally incident longitudinal and antiplane shear waves by two parallel and coplanar Griffith cracks embedded in an infinite, isotropic and homogeneous elastic medium was investigated by Jain and Kanwal [6]. The diffraction of time harmonic horizontally polarized shear waves by material and geometric irregularities in an isotropic linearly elastic infinite plate was depicted by Abduljabbar et al. [7]. An emphasis on displaying the diffraction phenomenon of magnetoelastic shear waves by a rigid strip in an elastic perfect conductor was placed by Chattopadhyay and Maugin [8]. The two-dimensional problem of diffraction of shear waves by a rigid strip in a medium of monoclinic type was discussed by Chattopadhyay and Bandyopadhyay [9]. Moreover, the diffraction pattern of magnetoelastic shear waves in a self-reinforced medium by a rigid strip was traced out by Chattopadhyay et al. [10]. In addition, Datta and Shah [11] investigated the scattering of plane SH-waves by sub-surface circular cavities and thin slits in a semi-infinite elastic medium. The scattering of a time-harmonic antiplane shear wave by two parallel and coplanar Griffith cracks embedded in an infinite elastic medium was examined by Itou [12]. Thereafter, the scattering and diffraction of plane SV-waves by circular cylindrical canyons of various depths in an elastic half-space was studied by Lee and Cao [13].

A porous medium consists of a solid skeleton and a pore space that may be typically filled with air, liquid or both. The porous media whose solid skeleton is elastic is called poroelastic. The solid skeleton consists of solid matrix and empty connected pore space. The connected pore space enables the filtration of the pore fluid through the porous medium. An analytical solution for the diffraction of plane P-waves by circular cylindrical canyons in a fluid-saturated porous half-space was presented by Li and Zhao [14]. Using the wave function expansion method, an analytical solution for the scattering and diffraction of incident plane SV-waves by a shallow circular-arc canyon in a saturated poroelastic half-space was provided by Liang et al. [15]. An indirect boundary integration equation method was applied by Liang and Liu [16] to study the diffraction of plane P-waves by a two-dimensional canyon of arbitrary shape in poroelastic half-space. Liang and Liu [17] also investigated in detail the nature of diffraction of plane P-waves around a canyon in poroelastic half-space. The method of separation of variables was adopted by Tsaur [18] to derive an exact series solution for the scattering and diffraction problems of a vertical edge crack connected to the surface of a half-space for an antiplane incident shear wave. Recently, an analytical solution via a stress free wave function for two-dimensional diffraction of P- and SV-waves around a semi-circular canyon in an elastic half-space was provided by Lee and Liu [19].

It is well established fact that the Earth is initially stressed medium. The term initial stress (pre-stress) refers to the stress existing in a body not subjected to the action of external forces. The pre-stress has a significant influence on the elastic wave propagation in porous solids. If the pre-stress on the poroelastic solid is within the limit of shear elasticity then it leads to compaction in the medium. As a result of this, sometimes the speed of elastic wave increases. On the other hand, if the pre-stress exceeds the shear elasticity then it may disturb the material orientation. Due to this, the anisotropy may be induced by means of aligned cracks, microcracks and differently oriented pore space [20]. Many researchers have made noticeable attempt to study the influence of initial stress in elastic media. Sciarra et al. [21] discussed the stability analysis of the binary mixture (solid-fluid mixture) model to describe the deformation of the solid under the influence of pre-stress. Quiligotti et al. [22] proposed a constitutive theory of a porous elastic solid filled with inviscid compressible fluid to examine the propagation of steady-state plane harmonic waves in poroelastic half-space. Further, Placidi et al. [23] used variation formulation approach to study the influence of initial stress on wave propagation associated with solid-fluid mixture. Ogden et al. [24] had shown the impact of pre-stress on the vibration and stability of elastic plates. Later on, Vinh and Giang [25] obtained the velocity formulae for Rayleigh wave in pre-strained elastic materials subject to an isotropic internal constraint. The combined effects of initial stress and finite deformation on the speed of Rayleigh waves in incompressible elastic solid were delineated by Shams and Ogden [26]. Gower et al. [27] discussed the initial stress symmetry and its applications in elasticity. Recently, the effect of initial stress on Love wave propagation at the boundary between a layer and a half-space was manifested by Shams [28]. Nam et al. [29] studied the impact of initial stress on the propagation of surface waves in a layered half-space. Up to now, none of the authors have discussed the diffraction of horizontally polarised shear wave by a rigid strip in an initially stressed transversely isotropic poroelastic medium.

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