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The asymmetric elastic wavefields in a model comprising a liquid layer overlying an anisotropic solid seabed due to an arbitrary source within the solid

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ABSTRACT

The asymmetric three-dimensional radiation pattern and resultant elastodynamic response of stress waves in a model comprising a compressible water column overlying a transversely isotropic seabed in which a time-harmonic source acts is theoretically investigated. The use of potential functions, the Hankel transform, and a Fourier series expansion are adopted to deal with the equations of motion for both media. Closed-form integral expressions are developed for the potentials and the stress/displacement components. The expressions and introduced procedure are sufficiently flexible to incorporate various types of source loads. To evaluate the field quantities, the residue method and a robust integration scheme are utilized to handle the poles and branch points within the integrand. Any possible number of dispersive propagation modes are taken into account in the integral evaluation. The deduced velocity dispersion curves depict the characteristics of the various modes. They also indicate the existing singular points (poles) for a specific dimensionless frequency and the surface wave type associated with each pole. Numerical results are presented for the hydrodynamic pressure and displacement in the liquid layer and stress and displacement components in the solid seabed due to distributed and concentrated source excitations. The formulation and the numerical scheme are valid for calculating the wavefield anywhere within the model including both far- and near-field effects. The sensitivity of the results to different parameters is also analyzed. Both analytical and numerical comparisons with existing solutions for simpler cases are made to confirm the validity of the results. The results are especially useful in seismic hazard assessment of submarine earthquakes, landslides, and tsunamis. They can also be extended to deal with the fluid-solid-structure interaction problems.

1. Introduction

Modelling the radiation pattern and resultant elastic wave response of a liquid layer overlying a solid medium due to an external excitation within the solid is encountered in various fields. In particular, one can refer to undersea seismic exploration, earthquake-hazard assessment, structural engineering, marine dynamics, tsunami generation and offshore hydrocarbon production. Stoneley [1] performed pioneering work on the effect of the ocean on the seismic response of a contacting solid seabed. Other notable contributors in the early development of wave propagation in liquid-solid systems include Biot [2], Haskell [3], Tolstoy [4], Ewing et al. [5], and Bennett and Hermann [6]. Until now, numerous scientists have investigated wave motion and dispersion in such models. Roberts [7] considered the dynamic elastic response of an isotropic solid half-space in contact with a liquid half-space due to a three-dimensional point load acting in either the solid or in the fluid. Novikova et al. [8] studied analytically a water column overlying a layered, isotropic solid in connection with

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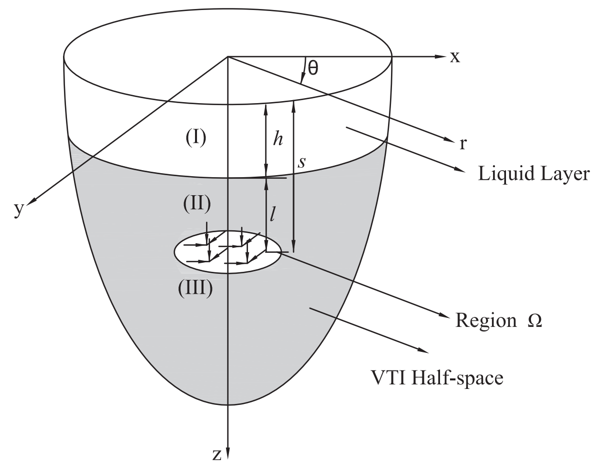

Fig. 1. Geometry of the system, showing the liquid and solid layers and the source configuration.

the tsunamis and the Rayleigh wave propagation process. Zhu et al. [9] and Rodriguez-Castellanos et al. [10,11] also utilized the integral transform method and boundary element techniques, respectively, to produce curves of pressure variation in the water in contact with an isotropic solid half-space. Mohapatra and Sahoo [12] studied the interaction of the surface waves with an elastic bed utilizing small amplitude water wave theory and the plate deflection assumption for the solid. Das et al. [13] investigated the flexural gravity wave motion over a poroelastic bed using Biot's consolidation theory and incorporating the effect of the ocean stratification.

Anisotropy of the solid seabed, in which the wavespeed is directionally dependent, is a common assumption made in many oceanic crustal models. Normally, the specialized form of transverse isotropy in which the axis of symmetry is vertical (a VTI medium) is assumed. It may be the result of sediment layering, existence of horizontally aligned microcracks or preferred mineral orientation. The elastodynamics of a transversely isotropic solid material has been studied by numerous authors. Stoneley [14] described the role of anisotropy in the propagation of elastic waves in a transversely isotropic solid body. Further accounts are given, for example, by Payton [15], and Rajapakse and Wang [16]. Eskandari-Ghadi [17] introduced a special potential function method to solve the equations of motion for a transversely isotropic solid. This method was utilized by Khojasteh et al. [18] to analyze the asymmetric Green's functions for a dynamic load (source excitation) acting within a transversely isotropic body. They applied the Residue Theorem and an adaptive integration scheme for numerical evaluation of the infinite integrals. They also computed the dynamic Green's functions for layered half- and full-spaces, comprising dissimilar transversely isotropic materials [19,20]. Pan et al. [21] also developed a complete set of exact closed-form solutions to present elastic displacements and strains due to general polygonal dislocations in a transversely isotropic half-space.

Following on from the early work of Abubakar and Hudson [22], Sharma et al. [23] tackled the dispersion of surface waves in a half-space composed of a water column overlying a layered solid media. In a subsequent paper [24], Sharma presented the wave dispersion characteristics in an ocean crust model incorporating the effect of cracks. In both papers, only the dispersive characteristics of the models are investigated, which implicitly assumes plane waves (or the far-field situation) and ignores the source term. All these studies show a significant change in wave propagation characteristics due to the presence of the liquid layer.

The main objective of this research is to find stresses and displacements induced in a coupled ocean-anisotropic seabed model due to a harmonic excitation within the seabed and to analyze the characteristics of the associated elastic waves. The solid bed is transversely isotropic and the source can be of arbitrary shape, including both finite sized and point sources. To deal with the equations of motion, the method of potential functions along with an integral (Hankel) transform and Fourier series expansion in azimuth, introduced by Khojasteh et al. [18], are extended and utilized. By appropriately expressing the source term and applying the boundary conditions, closed-form solutions for the stress and displacement components are derived in the frequency-wavenumber domain. To find the response in the actual physical (frequency-space) domain, the resulting integrals are evaluated utilizing a specific integration scheme. According to the oscillatory nature of the integrands and the existence of singularities, special attention should be paid to poles, branch points, and how to choose the path of integration.

As a considerable improvement compared to other similar works, the method employed here allows for wavefield computation at any point in the media, i.e., far from the source or near to it. Furthermore, the method takes into account the reverberations and higher modes in the liquid layer. The time-harmonic excitation can act as either a force or a displacement over a finite area. The wavefield functions associated with each case are derived by suitably adjusting the source expression on the right side of the governing equations. The source can be at an arbitrary depth within the solid bed, either shallow or deep.

By involving the liquid layer and an asymmetric source excitation, this research provides the means to deal with a wide range of problems arising in marine seismology and offshore earthquake engineering. The formulated expressions and results of this study will be useful in applications that interpret seismic amplitudes from processes such as submarine earthquakes, landslides, tsunamis, explosions, and volcanic tremors. In particular, the effect of source excitation acting within the seabed is an area of active research for tsunami-hazard assessment (see for example [25]).

Furthermore, the derived Green's functions can be conveniently used to solve the interaction of structures located in the described model. They can be also applied in underwater seismic seabed characterization when modeling accelerograms. The elastic wavefield expressions developed in this paper are also relevant in investigations of earthquake physics. Determination of the earthquake source characteristics is of considerable importance in seismology. In this regard, Green's functions and associated field quantities are commonly employed in inversion methods used for this purpose (see, for example [26–28]). The basic formulation given in this paper can also be conveniently used for a model of a liquid layer overlying a two layered solid seabed made up of different materials.