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ScienceDirect

Procedia Engineering 144 (2016) 461 – 467

Procedia Engineering

www.elsevier.com/locate/procedia

12th International Conference on Vibration Problems, ICOVP 2015

Propagation of Love waves in composite layered structures loaded with viscous liquid

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Abstract

This article describes the theory of Love wave propagation in a layered elastic structure loaded on its surface by a viscous (Newtonian) liquid. The layered elastic structure consists of a composite layer lying over an inhomogeneous half space. The method of separation of variables has been used to obtain the frequency equation with suitable boundary conditions. An analytical expression for the complex dispersion equation of Love waves has been established. The influence of the viscosity of liquid, inhomogeneity on the dispersion curves of phase velocity of the Love wave amplitude is analysed graphically.

Peer-review under responsibility of the organizing committee of ICOVP 2015

Keywords: Love waves; viscous liquid; composite layer; inhomogeneity; dispersion relation

1. Introduction

Waves propagating through elastic medium carry lot of information with them which are useful in several fields like geophysics, seismology, earthquake engineering, environmental sciences, matter sciences etc. About 100 years ago, it was Love who first put forward surface waves in a layer over a half-space for homogeneous isotropic medium, in 1911 and that is well-known Love wave. The details of the propagation of surface waves are summarised in the books of literature such as Achenbach [1], Ewing *et al.* [2], etc. The study of Love waves is important to seismologist for its possible application in prediction of earth structure. In recent years, Love-wave-based devices have been developed for use as viscosity sensors, biosensors and chemical sensors.

Surface acoustic wave (SAW) devices are one kind of those sensors. Compared with traditional measurement methods, SAW (surface acoustic wave) device is especially suitable for harsh environment [3]. Love wave device is one of the typical SAW devices; it only has shear-horizontal displacement, so the attenuation of vibration is small. Relative to Lamb wave device, Love wave device has higher mechanical strength [4]. Usually, a thin film is coated on the surface of the Love wave device in order to prevent the erosion of IDT(inter digital transducer) when loaded with liquid. So Love wave device is very suitable for using as liquid sensor [5,6]. A detailed experimental study of a Love wave sensor for biochemical sensing in liquids was given by Kovacs *et al.* [7]. They showed that, for small viscosity, the interaction of an acoustic Love wave with a viscous liquid can be described by a Newtonian liquid model.

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Peer-review under responsibility of the organizing committee of ICOVP 2015
doi:10.1016/j.proeng.2016.05.156

Recently, fiber-reinforced composite materials have attracted attention as new structural materials. The characteristic property of a self-reinforced material is that its components act together as a single anisotropic unit as long as they remain in elastic condition (i.e. the two components are bound together so that there is no relative displacement between them). The idea of introducing a continuous reinforcement at every point of an elastic solid was given by Belfield *et al.* [8].Chattopadhyay and Choudhary [9, 10] studied the propagation of shear waves in self-reinforced medium. Chaudhary *et al.* [11] have discussed the transmission of shear waves through a self-reinforced layer between two inhomogeneous elastic half-spaces.

Because of inhomogeneous layered nature of Earth, it can be regarded as composed of different inhomogeneous layer with certain variation in rigidity and density. Many authors like Chattopadhyay *et al.* [12], Vardoulakis [13], etc. have studied the effect of various inhomogeneities on various waves.

In this present article, the medium has been considered as a composite layer under viscous liquid and overlying an inhomogeneous half space. The possibility of propagation of Love wave in such medium has been studied. The effects of inhomogeneity parameter and viscosity have been shown by the means of graphs.

2. Mathematical formulation of the problem

2.1. Physical model

A composite layer of finite thickness H overlying an inhomogeneous semi-infinite medium, which is coated by a viscous liquid on the upper surface, has been considered to propagate the Love waves. For the inhomogeneous medium, the linear variations have been considered in both rigidity and density with different inhomogeneity parameters. Cartesian co-ordinate system has been considered, where x_1 is positive along the direction of wave propagation and x_3 is positive pointing downwards (Fig.1). The wave is assumed to propagate along x_1-axis.

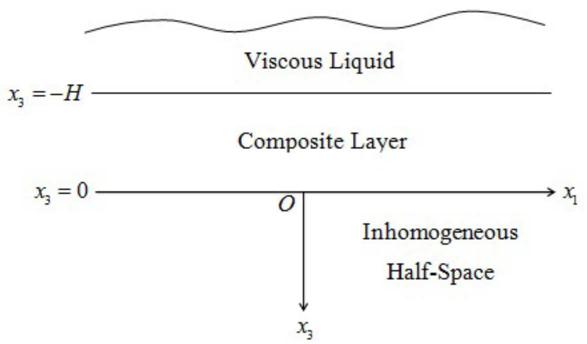

Fig. 1. Geometry of the problem.

For the propagation of Love waves, along x_1 axis, $u = w = 0$ and $v = v(x_1, x_3, t)$. Velocity field in the viscous liquid has been calculated by Navier-Stokes equation and the displacements in the composite layer and the in homogeneous half space is calculated following the basic stress-strain relations. The dynamical equations of motion are solved by the boundary condition at the interfaces $x_3 = -H$ and $x_3 = -0$.

2.2. Governing differential equations

2.2.1. Viscous liquid region ($x_3 < -H$)

The velocity field v_1(of the SH acoustic wave) in a viscous liquid ($x_3 < -H$) is governed by the NavierStokes equation:

$$\frac{\partial v_1}{\partial t} - \frac{\eta}{\rho_1}\left(\frac{\partial^2}{\partial x_1^2} + \frac{\partial^2}{\partial x_3^2}\right)v_1 = 0 \tag{1}$$

where η is the viscosity and ρ_1 is density of a liquid.