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Attenuation and dispersion of SH-waves in a loosely bonded sandwiched fluid saturated porous layer

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A B S T R A C T

The present paper deals with SH-wave propagation in an upper heterogeneous fiber-reinforced layer overlying a loosely bonded heterogeneous porous layer and an initially stressed viscoelastic half-space. Dispersion relations are derived when the ratio of heterogeneity parameter associated with rigidity to that of density of the sandwiched layer is equal to zero, one and greater than one. The real and imaginary part of the dispersion equation correspond to the dispersion and attenuation curves respectively. The effect of presence and absence of heterogeneity, loose bonding, internal friction, width ratio and initial stress on the dispersion curve as well as attenuation curve is studied extensively. The effect of heterogeneity associated to the sandwiched fluid saturated porous layer on the propagation of SH-wave is among the major highlights of the study.

1. Introduction

Materials containing pores in it are designated as porous materials. These pores are generally filled with fluid. The skeletal portion of the material is usually known as the frame. Biot's theory predicts a shear wave propagating in the frame with an inertial contribution from the pore fluid. The theories of consolidation and propagation of elastic-wave in fluid-saturated porous media were also discussed by Biot [1]. Numerous work has been carried out considering the concept of porous media in the arena of engineering and applied sciences such as filtration, soil rock mechanics, construction engineering, acoustics, biophysics, hydrogeology and material science. Wang and Zhang [2] interpreted the dispersion curves and attenuation curves for the propagation of Love-waves in a porous half-space. The propagation of the Love wave in an inhomogeneous fluid saturated porous layered half-space were elucidated by Ke et al. [3]. Pal and Ghorai [4] reported the problem of propagation of Love waves in a dry sandy layer lying under initial stress overlying an anisotropic porous half-space under gravity. Recently, Son and Kang [5] manifested the propagation of shear wave in a poroelastic layer sandwiched between two elastic media of finite width. Some remarkable work in this field also include Alshomrani et al. [6], Kumar et al. [7] and Verma and Jiwari [8].

The fiber-reinforced materials are composed of the fiber, the matrix and the interface between the constituent materials. Synthetic reinforced concrete materials are utilized for different type of constructions. Natural reinforcement of layers takes place under the action of large amount of initial stress. Initial stress may evolve due to overburdened layer, atmospheric pressure, weight dropping and largeness, slow process of creep, variation in temperature, gravitational field, etc., which have striking impact on the propagation of waves. Therefore, the investigation on the behavior of seismic waves while propagating through such media seems to be obligatory. Moreover, the study has numerous significant applications in mining, architecture, civil engineering, geophysical prospecting and soil mechanics. Theory developed in Spencer [9] circumvents the constitutive equations for a fiber-reinforced linearly anisotropic medium with respect to preferred direction. Singh and Singh [10] examined that the phase velocities of quasi P- and SV- waves depends on the angle between direction of propagation and the direction of reinforcement. Recently, Chattopadhyay and Singh [11] attempted to investigate the effect of reinforcement on the propagation of crack due to magnetoelastic shear waves in a self-reinforced medium. Moreover, the theory persuading the abstraction of initial stress was worked out by many authors including Biot [12], Chattopadhyay and Singh [13], Singh et al. [14].

The dynamic earth processes responsible for earthquake mostly takes place in the viscous asthenosphere (the transition zone between the crust and mantle). Under the action of a long time wide range of temperature and pressure, the constituents of earth behave viscously. Materials relevant for diverse structural and engineering province may involuntarily evince viscoelastic behavior. An investigation on the torsional wave propagation in a viscoelastic layer lying over heterogeneous half- space was made by Kumari and Sharma [15]. Wave propagation in a transversely isotropic heterogeneous material complying the generalized power law model was studied by Wang et al.

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Nomenclature

Symbols and their Meaning

(u_1, u_2, u_3): Displacement components in uppermost heterogeneous fiber-reinforced layer,
(v_1, v_2, v_3): Displacement components in sandwiched heterogeneous fluid saturated porous layer
(w_1, w_2, w_3): Displacement components in lowermost viscoelastic semi-infinite medium
Ω_1, Ω_2: Bonding parameters associated to the common interface of the layer and upper half-space; and the layer and lower half-space
$H_2, H_1 - H_2$: Thickness of the fluid saturated porous layer; and heterogeneous fiber-reinforced layer
τ_{ij}^{*}: Stress components of the heterogeneous fiber-reinforced layer
$e_{ij}^{*}(=\partial_j u_i + \partial_i u_j)/2$: Infinitesimal strain components of the heterogeneous fiber-reinforced layer
α, β: Specific components of stress for the concrete part of composite material
δ_{ij}: Kronecker delta
ρ_1: Density of the heterogeneous fiber-reinforced medium
$\vec{a} = (a_1, a_2, a_3)$: Preferred directions of reinforcement
μ_T, μ_L: Shear modulus in transverse and longitudinal shear in the preferred direction.
μ_T', μ_L', ρ_1': Values of μ_T, μ_L, ρ_1 at $z = -H_1$
λ: Lame's constant of elasticity
ν_1: Heterogeneity parameter associated with uppermost layer
ν_2: Heterogeneity parameter associated with rigidity of sandwiched layer
ν_3: Heterogeneity parameter associated with density of sandwiched layer
k, c: Wave number and common wave velocity
Components of total stress acting on the solid extract of the porous material
e_{ij}^{**}: Strain components of the solid frame
p_2: Pressure on the fluid layer
ϵ_2: Increment of fluid content per unit volume
N, A, C, F, M, E, Q, G: Material constants associated with the porous medium
$N^{**}, M^{**}, \rho_e^{**}$: Material constants of transversely isotropic fluid saturated porous layer at the $z = -H_2$.
v_i, V_i: Displacement components of the bulk material and saturated fluid respectively
ϕ: Porosity of the medium
ρ_s, ρ_f : Mass densities of the skeleton and fluid of the porous medium
$\rho_2(=(1-\phi)\rho_s + \phi\rho_f)$: Total mass density of the porous material
m_{ll}, η_{ll}: Coefficients introduced by Biot
ω: Angular frequency
η_2: Viscosity of the fluid
$\alpha_l(\omega), K_l(\omega)$: Dynamic tortuosity and permeability respectively
τ_{ij}^{***}: Components of stresses associated to the viscoelastic half-space
ρ_3: Density of the viscoelastic half-space
P_3: Initial stress acting on the viscoelastic half-space
μ_3: Rigidity of the viscoelastic half-space
μ_3': Viscosity of the viscoelastic half-space
β_3: Internal friction parameter
Moreover, $i=1,2,3$ corresponding to x,y,z

[16]. Wang and Zhao [17] explored the study of propagation of Love wave in double layered piezoelectric/elastic composite plate with loosely bonded interface. Sahu et al. [18] studied the SH-wave propagation in a heterogeneous viscoelastic layer overlying a self-weighted half-space.

In most of the problems of earth sciences concerning layered media, it is usually supposed that the contact of two layers is welded. However, the interface of the layers may get weaken in the presence of liquid saturated porous layer and hence causing the two layers to be loosely bonded. Beside this, heterogeneity is a trivial characteristic of earth's layered structure. It refers to the variation in the elastic properties of layers of the media throughout its volume. Heterogeneity may be considered as laterally or vertically varying functions (linear, quadratic, exponential, etc.). Hence, the elastic wave propagation in heterogeneous medium may be taken into account while dealing with geophysical and engineering problems. The problems concerning loose bonding were dealt by authors including Murty [19], Nandal and Saini [20], Khurana and Vashisth [21].

This paper investigates SH-wave propagation in a heterogeneous porous layer sandwiched and loosely bonded with an upper heterogeneous fiber reinforced layer and a lower viscoelastic half-space under initial stress. The heterogeneity in the uppermost layer is assumed to vary exponentially with depth whereas the heterogeneity in the sandwiched layer is linearly varying function of depth. Dispersion relations have been derived for the cases when the ratio of heterogeneity parameter associated with rigidity to that of density of the sandwiched layer is equal to zero, one and greater than one. The obtained dispersion relations are found to be in complex form due to dissipation of the system. The effect of different affecting parameters viz. heterogeneities, loose bonding, width ratio, internal friction and initially stress on the dispersion curve as well as attenuation curve has been studied and shown by means of graphical illustration.

2. Formulation of the problem

We consider the propagation of SH-waves in a heterogeneous fluid saturated porous layer, sandwiched between a heterogeneous fiber-reinforced layer and an initially stressed visco-elastic half-space. The sandwiched layer is assumed to be imperfectly (loosely) bonded to the uppermost layer and lowermost half-space. The geometry of the considered problem has been elucidated in Fig. 1. Rectangular Cartesian coordinate system has been taken into consideration with origin O at the interface of the sandwiched layer and the half-space. x-axis is considered in the direction of wave propagation (horizontal) and z- axis is positive pointing vertically downward. Heterogeneity in the uppermost layer is considered vertically in exponential form whereas heterogeneity in the sandwiched layer is considered vertically in the linear form. We denote the partial derivative with respect to a variable x, y, z by ∂_x, ∂_y, ∂_z respectively. The first and second time derivative are represented as ∂_t and ∂_{tt} respectively. Moreover, d_x and d_{xx} stands for $\frac{d}{dx}$

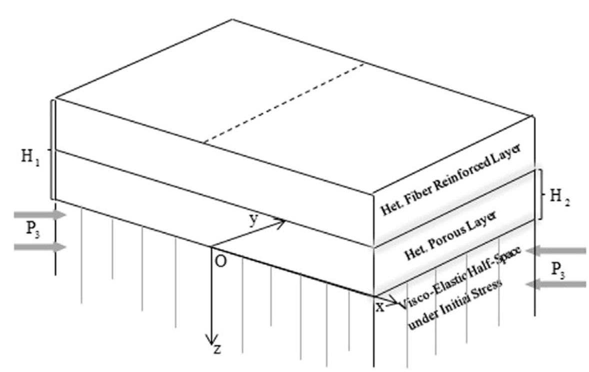

Fig. 1. Sketch of the problem.