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Isolation of plane shear wave using water saturated trench barrier

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ABSTRACT

The article presents a theoretical investigation of the propagation of normally and obliquely incident plane shear waves past a rectangular trench filled up with water saturated soil sandwiched between anisotropic elastic media. The motivation for this work is due to the effectiveness of the isolation of waves by the in-filled rectangular trench. Unlike the most of the previous researchers, this model considers the soil–structure interaction effects and directly determines the influence of barrier in the form of in-filled trench on the mode of wave propagation. It is of interest to determine the reflection and transmission coefficients, and the energy partition distribution of shear waves in the in-filled rectangular trench showing the influence of barrier on the propagation of waves. An extensive parametric study through numerical computation is carried out to investigate the influence of the material properties of the in-filled trench and the amplitude ratios on shear waves. The in-filled trench barrier directly declines the intensity of waves significantly in such a way that the waves do not create any hazards to the nearby structures, if exists at all.

1. Introduction

Propagation features of vibrations generated by several vibration sources depend on the type of the resource waves which can be assessed by measuring particle motions. Even manmade activities such as pile driving, traffic or train movement, may cause seismic waves propagating in the superficial soil layers, typically within a few tens of meters from the ground surface. The vibrations may be within an intolerable limit for adjacent structures and sensitive equipments in the form of wave barrier may be used to mitigate vibration energy. Generally, it is possible to prevent the adverse effects of these vibrations by providing a suitable wave barrier between the source and the structure to be protected. This system of vibration isolation is classified into two categories, *active isolation* and *passive isolation*. Installing the wave barriers near the vibration source to alleviate adverse effects of vibrations is known as *active isolation*. On the other hand, *passive isolation* barrier can be built up away from the source but around or close to the structure to be protected.

The ground-borne vibrations generated by machine foundation, train traffic or blasting may cause distress to adjacent structures and annoyance to people. For instance, most of the vibration energy generated due to train passage is carried by Rayleigh waves that propagate close to the ground surface and transmit the vibrations to the structure foundation. These vibrations lie in the frequency range of 4–50 Hz and may bring some buildings to resonance with their vertical vibration modes [1–3]. This type of vibration can be a major problem in densely populated metropolitan areas and for structures housing sensitive machinery. Therefore, in many countries new environmental regulations have been introduced placing some constraints on railway operations. As a consequence, the isolation of the traffic-induced vibrations has become an important issue. Stationary vibration sources such as machine foundations can be effectively isolated from its surrounding by active barrier. The passive isolation barrier is effective for wide variety of wave generating sources. Different types of wave barriers have been varying from very stiff concrete walls or piles to very flexible gas cushions [4,5]. Among them, both open trench and in-filled trench are the most common in practical application because they present effective and low cost isolation measures.

Beskos et al. [6] appear to be the first group of researchers to use BEM (in the frequency domain) for studying some vibration-isolation problems involving open trenches. Later, Beskos et al. [7] and in the Laplace domain (for transient wave source) to study a few vibration-screening problems using open and concrete trenches in a half-space. May and Bolt [8] performed a plane-strain FEM study on the vibration-screening effectiveness of open trenches to horizontally propagating P, SV and SH waves, in a two-layered soil.

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Under the literature on ground-borne vibrations, Woods [9] conducted a series of field tests to investigate the screening performance of several governing parameter of trenches both in active and passive isolation system. Woods [10] defined amplitude reduction ratio (ARR) and deduced that the minimum trench depth 0.65 times the Rayleigh wave length is required to achieve 0.75% deduction in ground displacement amplitude. Under assumption of a plane strain condition, Lysmer and Waas [11], Haupt [12] and Segol et al. [13] assessed the vibration screening isolation. Kattis et al. [14,15] developed an advanced-frequency domain code technique to study the screening efficiency of open, in- filled trenches and pile barriers. They reported that trenches are more proficient than pile barriers, except for vibrations with large wavelength, where deep trenches are impractical. Shrivastava and Kameswara Rao [16] examined the efficiency of open and filled trenches for screening Rayleigh waves due to impulse loads. Adam and Estroff [17] studied the effectiveness of open and in-filled trenches in reducing the six-storey building vibration.

The theory described by Biot [18] for wave propagation in an isotropic-fluid saturated porous solid is a complete one, through which investigators, namely Deresiewicz [19] and Bose [20] solved a numbers of problems. The problem of the propagation of water waves past a submarine trench has been studied by Lassiter [21], Lee and Ayer [22]. In those studies, the primary interest reflects in the reflection and transmission of waves propagating past bottom trenches, but little or no attention has been given to the dynamics of the trench itself.

Fuyuki and Matsumoto [23] found that the effect of the width of shallow open trenches could be significant, however in another related study, Woods [10] and Segol et al. [13] concluded that the width is not important. Prompted and motivated by this, the present investigation, in searching the fact, deals the reflection and transmission of shear waves propagating past water-saturated trench barrier of finite width and infinite depth. Consequently, the energy partition distribution has been exhibited to show the effectiveness of in-filled trench on the wave energy. An attempt has also been made to sort out the possibility of multiple reflections at a certain depth of the trench through numerical computation. Finally, the action of water-saturated trench barrier on the mode of propagation of plane shear wave is examined through numerical computation.

2. Formulation of the problem

Let us consider a rectangular trench of width l and of infinite depth (deep trench), filled up with water saturated soil, sandwiched between two anisotropic elastic layers. The surface in contact is located at $x=0$ and $x=l$, and the z-axis is directed vertically downward (z-direction). Let us assume that a ray of SH-wave is incident at the plane $x=0$ from the anisotropic elastic layer along AO, at an angle e with the normal (Fig. 1). The ray will give rise to reflection and transmission of SH-waves along OC and OD, respectively. The ray OD will in turn give rise to reflection and transmission of SH-waves along DE and DF, respectively. Moreover, further investigation will be carried out for the possibility of additional multiple reflections, if any.

Neglecting the viscosity of water, the equations of motion in the absence of body forces are (cf. Biot [18])

$$\begin{aligned}
\frac{\partial T_{xx}}{\partial x}+\frac{\partial T_{xy}}{\partial y}+\frac{\partial T_{xz}}{\partial z}&=\frac{\partial^2}{\partial t^2}(\rho_{11}u_x+\rho_{12}U_x)\\
\frac{\partial T_{yx}}{\partial x}+\frac{\partial T_{yy}}{\partial y}+\frac{\partial T_{yz}}{\partial z}&=\frac{\partial^2}{\partial t^2}(\rho_{11}u_y+\rho_{12}U_y)\\
\frac{\partial T_{zx}}{\partial x}+\frac{\partial T_{zy}}{\partial y}+\frac{\partial T_{zz}}{\partial z}&=\frac{\partial^2}{\partial t^2}(\rho_{11}u_z+\rho_{12}U_z)
\end{aligned}\qquad(1)$$

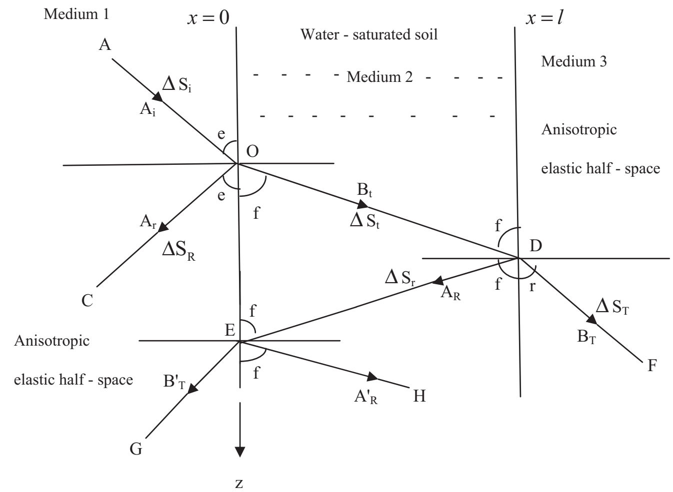

Fig. 1. System of incident, reflected and transmitted shear waves in a water saturated rectangular trench.

$$\frac{\partial T}{\partial x}=\frac{\partial^2}{\partial t^2}(\rho_{12}u_x+\rho_{22}U_x)$$

$$\frac{\partial T}{\partial y}=\frac{\partial^2}{\partial t^2}(\rho_{12}u_y+\rho_{22}U_y)$$

where (u_x, v_y, w_z) and (U_x, V_y, W_z) are the components of the displacement vector of solid and fluid part of the porous aggregate respectively and the mass coefficients density parameters ρ_{11}, ρ_{22}, ρ_{12} are for the solid, liquid, and their inertia coupling.

Assuming that there exists no relative motion between liquid and solid in the porous structure, the mass coefficients parameters ρ_{11}, ρ_{12} and ρ_{22} are connected to the total mass density of the solid–liquid aggregate ρ and mass densities ρ_s and ρ_w for solid and water, respectively, as given by Biot [24]

$$\begin{aligned}
&\rho_{11}+\rho_{12}=(1-\chi)\rho_s\\
&\rho_{12}+\rho_{22}=\chi\rho_w
\end{aligned}\qquad(2)$$

in which χ is the porosity of the porous layer. Thus, the mass density of the aggregate is

$$\rho_{11}+2\rho_{12}+\rho_{22}=\rho_s-\chi(\rho_s-\rho_w)=\rho$$

These coefficients, moreover, obey the inequalities,

$$\begin{aligned}
&\rho_{11}>0,\ \rho_{22}>0,\ \rho_{12}<0,\\
&\rho_{11}\rho_{22}-\rho_{12}^2>0
\end{aligned}\qquad(3)$$

The stress–strain relations for the water-saturated trench layer are

$$\begin{aligned}
T_{xx}&=Ae+2Ne_{xx}+Q\varepsilon, & T_{xy}&=Ne_{xy}\\
T_{yy}&=Ae+2Ne_{yy}+Q\varepsilon, & T_{yz}&=Ge_{yz}\\
T_{zz}&=Ae+2Ne_{zz}+Q\varepsilon, & T_{zx}&=Ge_{zx}
\end{aligned}\qquad(4)$$

$$T=Qe+R\varepsilon$$

where

$$e=\operatorname{div}u,\quad \varepsilon=\operatorname{div}U$$

$$e_{xx}=\frac{\partial u_x}{\partial x},\quad e_{xy}=\frac{\partial v_y}{\partial x}+\frac{\partial u_x}{\partial y};\quad e_{xz}=\frac{\partial w_z}{\partial x}+\frac{\partial u_x}{\partial z};\qquad(4a)$$

Further, Q is a measure of coupling between volume change of solid and of liquid, and R is a measure of pressure on fluid (water).