INTERACTION OF ULTRASONIC WAVES WITH CONTINUOUS INHOMOGENEITY OF POROUS MATERIALS

M. Cieszko, W. Kriese
Institute of Environmental Mechanics and Applied Computer Science,
Kazimierz Wielki University, Bydgoszcz, Poland

1. Introduction

The problem of ultrasonic wave interaction with continuous inhomogeneity of material is of great importance for theory and applications. On the one hand such materials are commonly present in living systems, nature, building engineering and industry. The macroscopic inhomogeneity is often a result of their formation, production or processes taking place during their life (e.g. osteoporosis), exploatation (e.g. sedimentation of pollutions on filters) or interactions with environment (e.g. degradation of concrete surface). On the other hand the ultrasonic research of such materials, due to their non-invasive character, are more commonly applied in diagnostics and determination of pore structure parameters and material constants.

The aim of this paper is to apply the new method of description of ultrasonic wave interactions with macroscopic inhomogeneity of material to the analysis of wave reflection and transmission through a layer of porous material with inhomogeneous pore space structure (Fig. 1).

2. Formulation of the problem

We consider a one dimensional problem of wave interaction with material inhomogeneity caused by a layer of pores. It concerns interaction of waves in the air incident on a porous surface layer of an undeformable material with continuously changeable pore structure parameters (Fig. 1a), and waves in an elastic solid with a layer of pores in that medium (Fig. 1b). We assume that the local acoustical properties of the material are characterized by the impedance Z and the wave number k. These parameters, in general, are dependent on the spatial coordinate x and the wave frequency ω.

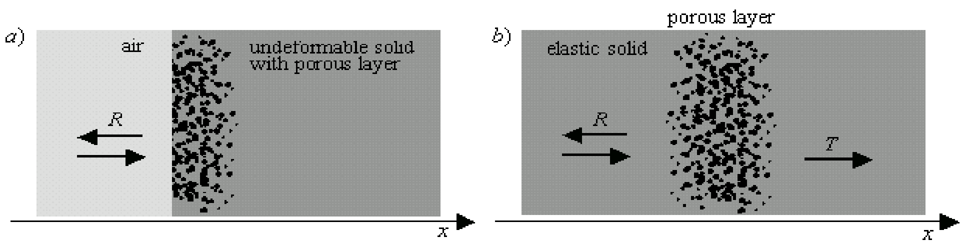

Fig. 1. The analyzed exemplary problems

Due to interaction with material inhomogeneity each wave propagating in such material generates the coupled backward wave. Therefore, the acoustical field in inhomogeneous material is defined by amplitudes T and R of the forward and backward waves, respectively.

In that case wave interaction with continuous inhomogeneity can be considered as multiple reflections and transition of the wave through the boundaries of infinitesimal layers. Such approach allows to derive the following system of equations for amplitudes T and R , [3]

$$\frac{dR}{dx} + ikR = \frac{dI}{dx}(2T + R) \quad , \qquad \frac{dT}{dx} - ikT = \frac{dI}{dx}(2R + T) \quad ,$$

where $I = \ln(Z_o / Z)/2$ and Z_o is constant.

Solution of these equations needs the parameters k and Z to be known functions of the spatial coordinate and wave frequency. In the paper such relations are obtained in two stages. First, both parameters are determined for homogenous materials and next their dependence on the spatial coordinate is postulated.

3. Acoustical characteristics of air-filled rigid porous material

To obtain the acoustical characteristics for air-filled rigid porous material, the one dimensional system of equations has been analyzed, [4]

$$\frac{\partial v}{\partial t} + a^2 \frac{\partial q}{\partial x} + \mu \frac{f_v^2}{K} v = 0 \, , \qquad \frac{\partial q}{\partial t} + \frac{1}{\delta^2} \frac{\partial v}{\partial x} = 0 \, ,$$

where $q = (\rho - \rho_o)/\rho_o$, and f_v , δ , K are parameters of volume porosity, tortuosity and permeability, respectively. Quantity a stands for the wave velocity in bulk fluid, and μ for a kinematical viscosity.

The derived equations for the wave number and impedance of the air-filled rigid porous material take the form

$$k = \frac{\omega\delta}{a} P \, , \qquad Z = \rho_0 a \frac{f_v}{\delta} P \, ,$$

where $P = 1/\sqrt{2}\left(\sqrt{1+\sqrt{1+\left(\mu f_v^2/K\omega\right)^2}} + i\sqrt{\sqrt{1+\left(\mu\, f_v^2/K\omega\right)^2} - 1}\right)$.

Analysis of influence of parameters characterizing inhomogeneity of pore space structure on characteristics of reflected and transmitted waves was performed in the paper for different dependence of pore structure parameters on the spatial coordinate.

The similar analysis was performed for wave propagating in elastic solid with inhomogeneous layer of pores.

4. References

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