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Boundary element method for 2D solids with fluid-filled pores

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ABSTRACT

In this paper, a boundary element method is developed for solving the problems of 2D solids with fluid-filled pores. The solid is assumed as linear elastic, which contains many fluid-filled pores of various shapes, and the fluid filling the pores is assumed to be linear compressible. Two different approaches, named superposition method and multi-subdomain method have been presented. The first one is based on the principle of superposition, in which all the pressures in the fluid-filled pores will be determined first, and then all the other boundary unknowns can be computed. In the other approach, the subdomains of the fluid in pores are solved to obtain the relation of the interface displacements with the interface pressure first, and then all the boundary unknowns, including the fluid pressure in each pore, can be solved simultaneously. Two simple examples of the 2D solids containing one circular fluid-filled pore are applied to verify the accuracy and to show the efficiency of the presented methods. And then, the effective elastic modulus and effective Poisson's ratio are simulated based on several models of the 2D solids containing 100 randomly distributed circular or elliptical fluid-filled pores. The numerical results computed by the two schemes have nearly the same accuracy, whereas the multi-subdomain method has higher computational efficiency than the superposition method. Some differences between the results obtained by the BEM and those given by Kachanov's method in the literature have been observed, which will be further investigated in the future work.

1. Introduction

There are a variety of porous media in the nature, such as rocks, soil, polymer foams, metal foams, concrete foams, sponges and biological tissues, some of which are fully saturated, some are partially saturated and some are dry ones. In most porous media, the fluid in pores can flow from one pore to the others. The fluid in different pores is isolated in some cases of the porous media, which can be modelled as solid with numerous fluid-filled pores. The mechanical properties of such porous media will be affected to a certain extent by the shapes, sizes and microstructures of the pores. The investigation on the effective elastic properties of such porous media has attracted considerable interests in the research of solid mechanics.

O'Connell and Budiansky [1,2] investigated the effective elastic properties of materials with fluid-filled pores in the special case of pores' geometry—narrow, crack-like cavities, whereas the applicability of their results is limited by the implicit assumption that all cavities have the same aspect ratios. The polarization phenomenon of fluid pressure induced by the applied load was addressed by Zimmerman [3], assuming that the porous space is interconnected together. Kachanov [4] considered an arbitrary orientational distribution of narrow crack-like cavities and examined the fluid pressure polarization as well as the impact of fluid on stress interactions on cracks. Shafiro and Kachanov [5,6] presented a general 3D analysis that covers fluid-filled pores of arbitrary ellipsoidal shapes, in particular, mixtures of cavities of diverse shapes, including pores and cracks. Besides, Giraud and Huynh [7] applied the Eshelby tensor to determine the effective poroelastic properties of anisotropic rocks-like composites.

Although much research has been done on the effective elastic properties of fluid-saturated porous media, most of them are based on the analytical methods, in which some specific assumptions or limitations usually had to be adopted. Only few research works have been reported to examine the effective elastic properties of materials with fluid-filled pores by numerical methods, especially by the boundary element method. Since the boundary element method only needs the boundary discretization, it has obvious advantages over other numerical methods for various elastic problems containing numerous cracks or inclusions [8–13]. The main purpose of this paper is to develop the boundary element method for the problems of 2D solid with fluid-filled pores, and to simulate the equivalent mechanic behaviors of such materials.

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