A theoretical investigation of a mechanical response of fluid-saturated porous materials based on a coupled discrete-continuum approach

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ABSTRACT

We propose a numerical model of liquid-saturated porous material (brittle or ductile), based on a coupled approach combining the particle-based numerical method and finite difference method. In the framework of the model a porous solid skeleton is described with the discrete element method, named the “Method of movable cellular automaton (MCA)” [1, 2]. An ensemble of discrete elements simulates processes of deformation of a porous solid and filtration of single-phase liquid in an interconnected network of "micropores" (pores, micro-channels and other discontinuities enclosed in the volume of a discrete element). We suggest, following the ideas of Biot [3], that stress-strain state of a discrete element is directly interconnected with a change of a volume of pores and pore pressure of a fluid in the "micropores". Mass transfer of a fluid between the "micropores" and "macropores" (the latter are considered as the areas between spatially separated and non-interacting discrete elements) is calculated on a finer grid superimposed on an ensemble of movable discrete elements. This approach allows description of a behavior of samples and systems with developed multi-scale porosity, like ceramics, coal seams, biological tissues etc.

A developed model was applied to study a mechanical response of brittle samples with water-saturated pore volume. It has been shown that the strength of liquid-saturated samples is determined not only by strength properties of "dry" (unfilled) material and a pore pressure, but largely by sample geometry, deformation rate and characteristics of porosity of a material. Analysis of simulation results allowed us to suggest a generalizing dependence of the uniaxial compressive strength of water-saturated permeable brittle material on the specific diameter of filtration channels, which is the ratio of the characteristic diameter of the filtration channels to the square root of the strain rate. Values of parameters of mentioned dependence are strongly connected with the character of the relation between pore volume and pressure of a liquid. Obtained results demonstrate the ability of the developed model to study of nonstationary processes of deformation and fracture of fluid-saturated materials under dynamic loading.

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