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Two-dimensional seepage in porous media with heterogeneities

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Abstract

This paper deals with two-dimensional flow in heterogeneous media. New explicit analytical solutions are obtained for flow refraction on a growth fault, a growth anticline, and for a gravity–capillarity driven flow in an unsaturated medium with parabolic inclusion. Flow kinematic characteristics are studied. © 2000 Elsevier Science B.V. All rights reserved.

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1. Introduction

Stratigraphic macroheterogeneities of permeability and porosity distributions are typical for geological formations and appear as growth faults, anticlines, diapirs, lenses, cavities, among others (Chapman, 1981, 1983). Microheterogeneities are less regular in shape and are by convention represented as random “patches” or pixels (“voxels”) with assigned step-wise constant physical characteristics (Barton and Beier, 1995; Torquato et al., 1999). Analytical solutions for flows through heterogeneous formations are rare because the refraction conditions along interfaces are difficult to satisfy in a rigorous way (Kacimov and Obnosov, 1997). Modeling of aquifer lenses dates back to the seminal ideas of Maxwell who showed that a uniform incident flow refracted by an ellipsoidal inclusion remains uniform within the inclusion with a three-dimensional (3D) distortion of streamlines in the ambient near-interface zone. Parquet-type heterogeneities composed of the so-called elementary cells repeating regularly in space are widely used in modeling subsurface flows (Renard and de Marsily, 1997). However, again, fine near-interface flow peculiarities are usually neglected. Obnosov (1996, 1999) developed a new approach to study refraction problems. The method enables one to determine 2D velocity fields in parquets, formations with single and multiple lenses at arbitrary conductivities of constituting porous components. Below we employ these solutions to analyze three cases. First, we study saturated flow near a “perfect” fault AB (Fig. 1) such that far from the fault, path lines are straight in intermittent layers while near AB they meander. Second, we consider saturated flow refracted by a parabolic inclusion (Fig. 4) with arbitrary orientation of the imposed gradient. Third, we develop the approach of Philip (1998) and study an unsaturated descendant flow near a parabolic lens (Fig. 6).

2. Saturated flows

We consider a fault (Fig. 1a) composed of layers with constant thickness h and conductivities k_1 and k_2. The left-hand part of the massif of layers is shifted with respect to the right-hand part by a distance h along the fault line AB. We assume for definiteness

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