PERGAMON

International Journal of Solids and Structures 39 (2002) 6159–6190

INTERNATIONAL JOURNAL OF SOLIDS and STRUCTURES

www.elsevier.com/locate/ijsolstr

Electro-chemo-mechanical couplings in swelling clays derived from a micro/macro-homogenization procedure

Christian Moyne [a], Márcio A. Murad [b,*]

[a] *LEMTA CNRS–INPL–UHP (UMR 7563), 2, avenue de la Forêt de Haye, 54504 Vandœuvre lès Nancy Cedex, France*

[b] *Laboratório Nacional de Computação Científica LNCC/MCT, Av Getúlio Vargas 333, 25651-070 Petrópolis, RJ, Brazil*

Received 3 October 2001; received in revised form 24 July 2002

Abstract

A macroscopic model for highly compacted expansive clays composed of a charged solid phase saturated by a binary monovalent aqueous electrolyte solution is derived based on a rigorous scale-up of the microstructural behavior. The homogenization technique is applied to propagate information available in the pore-scale model to the macroscale. Macroscopic electrokinetic phenomena such as electro-osmotic flow driven by streaming potential gradients, electrophoretic motion of mobile charges and osmotically induced swelling are derived by homogenizing the microscopic electro-hydrodynamics coupled with the Nernst–Planck and Poisson–Boltzmann equations governing the flow of the electrolyte solution, ion movement and electric potential distribution. A notable consequence of the upscaling procedure proposed herein are the micromechanical representations for the electrokinetic coefficients and swelling pressure. The two-scale model is discretized by the finite element method and applied to numerically simulate contaminant migration and electrokinetic attenuation through a compacted clay liner underneath a sanitary landfill.

Keywords: Swelling clay; Homogenization; Streaming potential; Soil liner; Poisson–Boltzmann; Electro-osmosis; Chemico-osmosis; Electrophoresis; Double-layer theory; Modified Terzaghi's principle; Disjoining (swelling) pressure

1. Introduction

Electrochemical interaction between colloidal particles and an aqueous solution is a central subject in colloid science. This phenomenon is typical of expansive media including clays, shales, polymers gels, corneal endothelium and connective biological tissues. Clay minerals are extensively used in a wide range of applications. They are a key component in the formulation of ceramic products and drilling fluids. They are widely distributed in the earth's crust and play a crucial role in many aspects of nutrition on earth. Swelling of smectitic clay soils also have undesired consequences when they heave upward upon hydration (or shrink upon desication) causing damage to the foundations of buildings. Shales have been responsible for many wellbore instability problems. Due to their low hydraulic conductivity, plasticity, swelling and adsorptive

* Corresponding author. Tel.: +55-2-4233-6149; fax: +55-2-4233-6165.
E-mail addresses: christian.moyne@ensem.inpl-nancy.fr (C. Moyne), murad@lncc.br (M.A. Murad).

PII: S0020-7683(02)00461-4