INTERNATIONAL JOURNAL FOR NUMERICAL AND ANALYTICAL METHODS IN GEOMECHANICS
Int. J. Numer. Anal. Meth. Geomech., **23,** 673–696 (1999)

THERMOMECHANICAL MODEL OF HYDRATION SWELLING IN SMECTITIC CLAYS: I TWO-SCALE MIXTURE-THEORY APPROACH

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SUMMARY

A thermomechanical theory of hydration swelling in smectitic clays is proposed. The clay is treated as a three-scale swelling system wherein macroscopic governing equations are derived by upscaling the microstructure. At the microscale the model has two phases, the disjoint clay platelets and adsorbed water (water between the platelets). At the intermediate (meso) scale (the homogenized microscale) the model consists of clay particles (adsorbed water plus clay platelets) and bulk water. At the macroscale the medium is treated as an homogenized swelling mixture of clay particles and bulk-phase water with thermodynamic properties defined everywhere within the macroscopic body. In Part I, the mesoscopic model governing the swelling of the clay particles is derived using a mixture-theoretic approach and the Coleman and Noll method of exploitation of the entropy inequality. Application of this procedure leads to two-scale governing equations which generalize the classical thermoelastic consolidation model of non-swelling media, as they exhibit additional physico-chemical and viscous-type terms accounting for hydration stresses between the adsorbed fluid and the clay minerals. In Part II the two-scale model is applied to a bentonitic clay used for engineered barrier of nuclear waste repository. The clay buffer is assumed to have monomodal character with most of the water essentially adsorbed. Further, partial results toward a three-scale thermomechanical macroscopic model including the bulk phase next to the swelling particles are derived by homogenizing the two-scale model with the bulk water. A notable consequence of this three-scale approach is that it provides a rational basis for the appearance of a generalized inter-phase mass transfer between adsorbed and bulk water. Copyright © 1999 John Wiley & Sons, Ltd.

Key words: swelling clay; mixture theory; physico-chemical effects; second law of thermodynamics; internal variables

1. INTRODUCTION

Swelling porous media such as 2-1 lattice clays, hydrophilic polymers and shales are ubiquitous in many aspects of life. For example, in foundation engineering the clay soil swells and heaves upward causing damage to the foundations of buildings, bridges, highways, and runways. In oil and gas production swelling shales consists of 75 per cent of drilled formations and have been responsible for 90 per cent of wellbore instability problems. The response of bentonitic-based compacted swelling clays under thermomechanical effects has received great attention in recent years because of their use as sealing materials to inhibit the migration of contaminants from

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Contract/grant sponsor: CNP_q/Brazil; contract/grant number: 300810/91-1

CCC 0363–9061/99/070673–24$17.50 *Received 5 July 1997*
 Revised 9 June 1998