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A CONSTITUTIVE FRAMEWORK FOR DOUBLE-POROSITY MATERIALS WITH EVOLVING INTERNAL STRUCTURE

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Summary. Natural geomaterials often exhibit pore size distributions with two dominant porosity scales. Examples include fractured rocks where the dominant porosities are those of the fractures and rock matrix, and aggregated soils where the dominant porosities are those of the micropores and macropores. We develop a constitutive framework for this type of materials that covers both steady-state and transient fluid flow responses. The framework relies on a thermodynamically consistent effective stress previously developed for porous media with two dominant porosity scales. We show that this effective stress is equivalent to the weighted sum of the individual effective stresses in the micropores and macropores, with the weighting done according to the pore fractions. This partitioning of the effective stress into two individual effective stresses allows fluid pressure dissipation at the macropores and micropores to be considered separately, with important implications for individual characterization of the hardening responses at the two pore scales. Experimental data suggest that the constitutive framework captures the laboratory responses of aggregated soils more accurately than those previously reported in the literature. Numerical simulations of boundary-value problems reveal the capability of the framework to capture the effect of secondary compression as the micropores discharge fluids into the macropores.

1 OVERVIEW OF WORK

This work deals with the behavior of aggregated soils depicted by the computed tomography volume of Fig. 1. The volume contains aggregates of reconstituted soil with much smaller intra-aggregate pores (micropores), as compared to the much larger inter-aggregate pores (macropores) that are visible in the figure. For the sake of clarity, we use the concept of ‘dual permeability’ in which fluid may flow not only through the larger macropores but also through the smaller micropores, as well as between contacting aggregates through their contact areas. Fluid may also be exchanged between the micropores and macropores through the surface of the aggregates exposed to the inter-aggregate pores. The macropores define the internal structure of the volume. As the volume is compressed both the macropores and micropores can compact, but the compaction of the macropores is more dominant during the early stages of compression. As the macropores are squeezed the internal structure disappears, leaving behind a volume with only the micropores and similar material behavior to that of the reconstituted soil.

2 NUMERICAL EXAMPLE

This example illustrates the effect of secondary compression on the time-dependent tilting of a seven-storey tower. The finite element mesh for this example is shown in Fig. 2. The foundation of the tower consists of a 10 m-thick sand

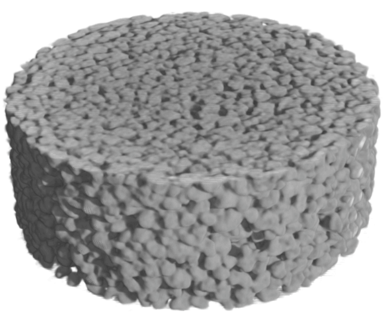

Figure 1: Reconstructed computed tomography volume of an aggregated silty clay, diameter = 80 mm, height = 35 mm. The aggregates are composed of much smaller silty clay solid particles with intra-aggregate pores. Visible spaces between aggregates are the inter-aggregate pores. After Borja and Koliji [1].

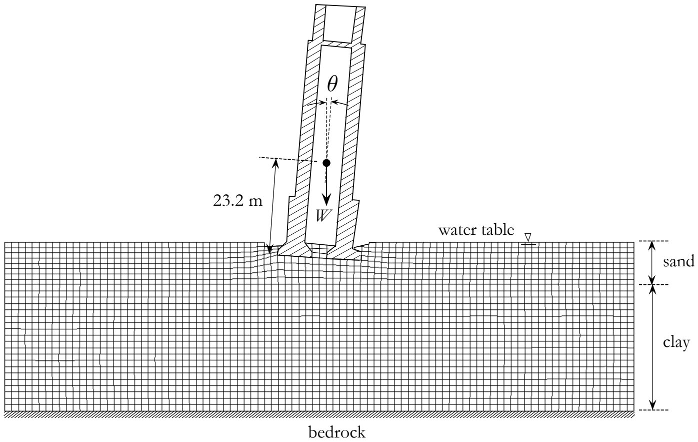

Figure 2: Finite element mesh for leaning tower example with secondary compression.

layer underlain by a 30 m-thick clay layer. Under the clay layer is a rigid, impermeable bedrock. The ground water table is located at the top of the sand layer. The tower is assumed to be rigid, and the clay is assumed to have properties similar to those of Pancone clay in Pisa, which exhibits double porosity, see Callisto and Calabresi [2]. Results of the analysis (not shown) suggest the time-history of tilt of the tower with two stages: a primary consolidation stage in which water from the macropores drains into the top surface, and a secondary compression stage (not to be confused with secondary consolidation, or creep) in which water from the micropores drains into the macropores.

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