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COMPUTATIONAL MODELING OF THREE-PHASE POROUS MEDIA

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ABSTRACT

A three-phase porous medium consists of a solid skeleton, pore liquid and pore gas. In a typical finite element solution of the dynamic equations governing the behavior of a three-phase porous media such as an unsaturated soil, the relative accelerations of the fluids are neglected and the equations are solved by considering the solid skeleton displacement ($\mathbf{u}$), pore liquid pressure (p^l), and pore gas pressure (p^g) as the nodal unknowns. This formulation is known as $\mathbf{u}\,p^l\,p^g$ formulation and is commonly used in computational geomechanics [4]. Four-noded quadrilateral elements with continuous bilinear interpolation functions for displacements and pressures have been used in the $\mathbf{u}\,p^l\,p^g$ formulation even though this violates the Babuska-Brezzi conditions for solvability and convergence. For certain high frequency problems such as blast loading, however, the effects of relative accelerations of the fluids may be significant. The consideration of the relative accelerations of liquid and gas phases leads to the complete finite element formulation for unsaturated soils, where $\mathbf{u}$, liquid displacement ($\mathbf{U}^l$), and gas displacement ($\mathbf{U}^g$) have to be considered as nodal unknowns. p^l and p^g can also be considered as nodal unknowns or solved as secondary element unknowns. In this presentation various finite element formulations for three-phase porous media are compared with each other for a problem involving earthquake loading of an unsaturated soil embankment.

Dynamic governing equations derived for large deformation problems in three-phase porous media are implemented into a finite element computer code called TeraDysac [2, 3]. The results from the simulation of an unsaturated Minco Silt embankment (Fig. 1) subjected to base shaking are presented here. The height of the embankment is 8.5 m and the base width is 17.5 m. The stress-strain behavior of the unsaturated soil was modeled using a bounding surface elastoplastic model [1]. The hydraulic conductivity of the soil for the given initial conditions is 1.02×10^{-10} m/s and can be considered very low. The applied horizontal base motion is shown in Fig. 2 and the predicted deformed shapes are shown in Fig. 1. Predicted matric suctions ($= p^g - p^l$) for a typical element are compared in Fig. 3. In these figures, “Complete” refers to the finite element formulation where the relative accelerations are taken into account and the nodal unknowns are $\mathbf{u}$, $\mathbf{U}^l$ and $\mathbf{U}^g$. Pore fluid pressures are treated as secondary element variables. “Partial” refers to the $\mathbf{u}\,p^l\,p^g$ formulation. “Reduced” is where both relative accelerations and relative velocities are neglected and the only nodal unknown is $\mathbf{u}$. Here also the pore fluid pressures are

calculated as secondary element unknowns. The reduced formulation simulates the undrained loading condition. Four-noded quadrilateral elements are used for all the predictions.

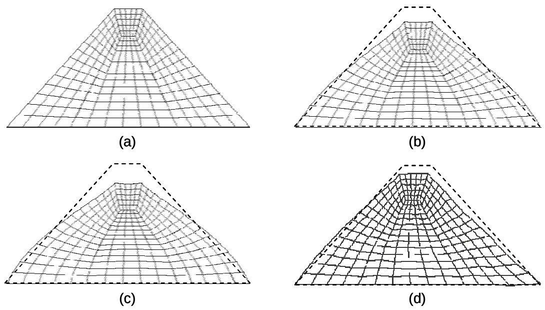

Figure 1: Initial and deformed meshes at 30 seconds (displacements magnified by 8) (a) initial mesh, (b) complete formulation, (c) reduced formulation, (d) partially reduced formulation

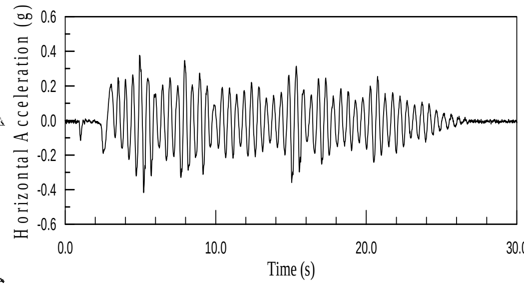

Figure 2: Input base acceleration-time history

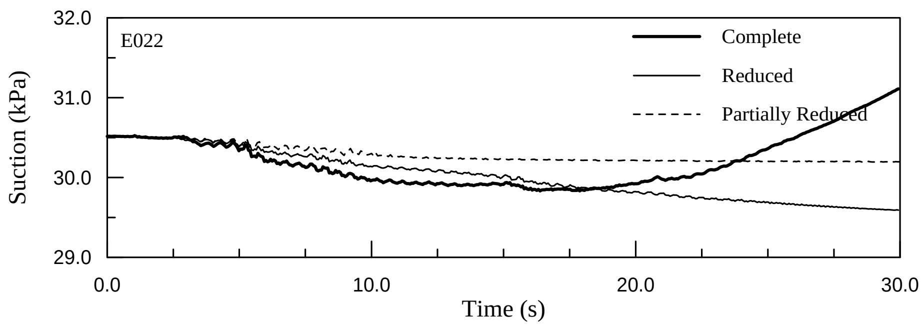

Figure 3: Suction changes for a typical element

As can be seen in Figs. 1 and 3, for this low hydraulic conductivity soil with no blast loading, the undrained reduced formulation and the complete formulation gives comparable results. Only the complete formulation that takes into account fluid movements, however, predicts changes in soil suction following major shaking. The partially reduced formulation predicts stiffer response than expected, likely due to the violation of the Babuska-Brezzi condition.

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