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COMPUTATIONAL MODELING OF LARGE DEFORMATION OF SATURATED SOILS USING AN ALE FINITE ELMENT METHOD

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1. INTRODUCTION

When conventional updated Lagrangian finite element methods are applied to computational modeling of large deformation problems (liquefaction-induced displacement and the cone penetration test, etc.), extensive mesh distortion and elements entanglement sometime arise, leads to less accurate results or even to an interruption of the calculation. In order to surmount these deficiencies, an arbitrary Lagrangian-Eulerian (ALE) finite element method is adopted in this paper.

2. GOVERNING EQUATIONS

Based on Biot's theory and the u-p formulation, the governing equations for saturated soils, an equilibrium equation and a continuity equation, are briefly presented in this section.

3. ALE KINEMATICS

The ALE method was first developed in fluid mechanics. It has been successfully applied to fluid-structure coupling problems and nonlinear solid mechanics. However, the ALE finite element formulation for porous media has not been well established.

In an ALE analysis, the computational reference system (finite element mesh) is neither attached to the material nor fixed in space. The mesh is deformed as in Lagrangian formulation, but independently from the material body as in Eulerian formulation and keeping the mesh regularity.

4. CONSTITUTIVE RELATIONS

A fluidal-elasto-plastic constitutive model is employed for the saturated soils. The Jaumann stress rate, which gives an objective measure of stress rate is adopted for considering large deformation. The grid time derivative of stress is found using the Jaumann stress rate. The constitutive model can be employed without complicated modification in the ALE finite element analysis.

5. THE COUPLED ALE FORMULATIONS

The ALE procedures in literatures can be divided in coupled and operator-split ALE formulations. Using an incremental approach, coupled ALE finite element formulations for saturated soils are derived.

6. THE OPERATOR-SPLIT ALE METHOD

The operator-split ALE method consists of two steps, a Lagrangian step and a Eulerian step. First, the finite element mesh follows the material deformation in the Lagrangian step, and a pure updated Lagrangian procedure step is done. Secondly, mesh smoothing is performed and the state variables then is remapped from the Lagrangian mesh to the new reference mesh to complete the Eulerian step.

7. NUMERICAL EXAMPLE

A FORTRAN computer code has been developed to implement the operator-split ALE method described in the preceding sections. With this program, numerical simulation of responses of an embankment to an earthquake motion is carried out. The numerical example shows that the proposed scheme can overcome numerical difficulties caused by severely distortion and entanglement of elements, which often occurs in large deformation analyses by the classical updated Lagrangian formulation.

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