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STABILIZED FINITE ELEMENT FORMULATION FOR SATURATED SOILS UNDER CYCLIC LOADING

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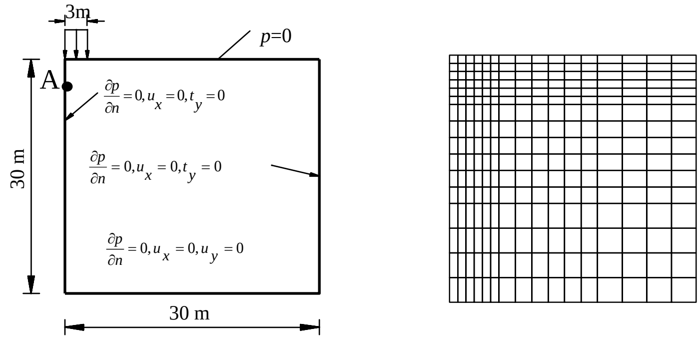
ABSTRACT

Extensive research has been devoted during the past few decades to coupled dynamic analysis of soil - pore fluid interaction problems. The problems are generally formulated in terms of the displacement of the solid phase $\boldsymbol{u}$ and the pore-water pressure p under certain assumptions [1]. The numerical solution procedure for solving such a $\boldsymbol{u} - p$ formulation with a general direct implicit time-stepping algorithm was discussed fully in Ref. [2]. It requires that the interpolation functions for u and p in the finite element discretization must fulfill the Babuska-Brezzi conditions or the much simpler Zienkiewicz-Taylor patch test in the limit of nearly incompressible pore fluid and small permeability. Only certain combinations of shape functions for $\boldsymbol{u}$ and p variables are permissible for the mixed formulation. In particular, when both the permeability and compressibility of the pore fluid tend to zero, the solution will 'lock' or oscillate wildly unless the displacements are interpolated from their nodal values by polynomials one order higher than those used for the pressure.

Such difficulties can be avoided by the staggered implicit-implicit algorithm and the direct α-method which were introduced by Huang *et al.* [3]. Several examples were given in Huang *et al.* [3] concerning with the solution of transient problems as well as of the final steady states obtained by the staggered implicit-implicit algorithm and direct -method. Those were mainly used for modeling elastic porous media on uniform and non-uniform meshes subjected to a surface step loading. Indeed, the analysis of examples with step loadings is not quite typical for dynamic problems, which numerical errors caused by numerical stability problems may be gradually accumulated for the examples with cyclic loadings. Due to the necessity to show the effectiveness of the proposed stabilization techniques for cyclic loading problems, a numerical example regarding an elastic saturated soil foundation subjected to a surface cyclic loading is presented.

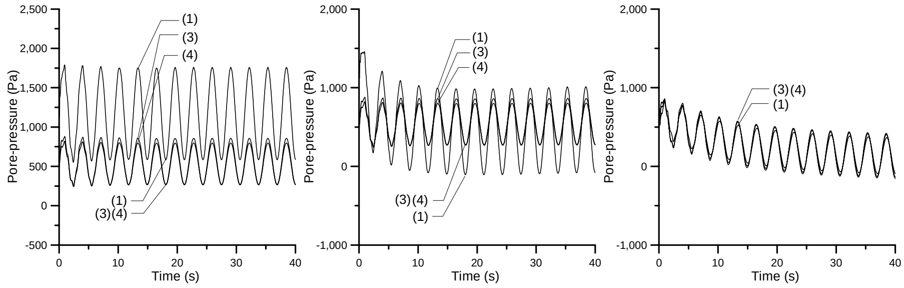
Figs. 1 and 2 show the geometry and boundary conditions, finite element mesh as well as the comparisons of the computed pore-pressure obtained by using three different algorithms (1 – direct implicit algorithm, 3 – staggered implicit-implicit algorithm with

local δ, 4 – direct α-method), which have demonstrated a good performance of the proposed stabilization procedure.



(a) (b)

Fig.1. A soil foundation subjected to a surface cyclic loading: (a) geometry and boundary conditions; (b)finite element mesh.



(a) (b) (c)

Fig. 2. Pore pressure solutions using various algorithms (Node A): (a) $k = 0.0$; (b) $k = 1.0 \times 10^{-6} m/s$; (c) $k = 1.0 \times 10^{-4} m/s$.

It must be pointed out here that the extension of the stabilized procedures to the elasto-plastic problems is of significantly importance for practical purpose. Further research in the elasto-plastic analysis with a more complicated constitutive model based on the concept of bounding-surface plasticity is currently underway. It must be pointed out that the success in elasto-plastic problems is due to not only the introduction of the proposed stabilization method but also the use of adaptive remeshing or other suitable techniques such as the assumed strain method, etc.

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