H-ADAPTIVE FE APPLIED TO 3-D NONLINEAR ANALYSIS OF LIQUEFIABLE GROUND WITH LARGE DEFORMATION

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1. INTRODUCTION

In a nonlinear dynamic finite element (FE) analysis of liquefiable saturated ground with large deformation, large stress and strain errors developed in elements when a coarse element size is used for spatial discretization. To reduce these errors in the elements the size of elements should be decreased using a proper mesh refinement technique. Adaptive mesh refinement is one of promising methods to deal with these errors and to improve the accuracy of finite element method (FEM).

A fission procedure of the element belong to the *h*-adaptive mesh refinement is applied to the three dimensional dynamic FE analysis in which water saturated soil behavior is analyzed using the u-p formulation and updated Lagrangian method. A posterior error in the element is estimated by evaluating the L_2 norm of stress error and superconvergent patch recovery (SPR) scheme.

2. GOVERNING EQUATIONS

An effective cyclic elasto-plastic model based on Biot's two-phase mixture theory and the kinematic hardening rule is adopted to simulate material nonlinearity of saturated soil. Updated Lagrange method was used in 3-D mixed FEM-FDM equations with u-p form to deal with large deformation. The dynamic equations are solved with Newmark- β method.

3. ERROR ESTIMATION AND SPR

A posterior error is estimated based on superconvergent patch recovery technique for the linear hexahedra element in FE analysis of saturated soil. The error is defined as the difference between the exact value and FEM solution, and evaluated by L_2 norm of percentage stress error.

Because it is impossible to obtain the exact stress, rather accurate value is calculated by smoothing scheme to evaluate the error. The SPR scheme is used to smooth the variables. The elements surrounding an assembly node combine a patch. The smoothed value of assembly node in polynomial expansion is

$$\bar{\sigma}* = \{P\}\{a\}^T$$

For linear hexahedra elements

$$\{P\} = \{1, x, y, z, xy, yz, zx, xyz\}$$

$$\{a\} = \{a_1, a_2, a_3, \cdots, a_8\}$$

Using FEM solution of elements in the patch, {a} is solved from the equation below:

$$\sum_{i=1}^{n}\{P^T(x_i, y_i)P(x_i, y_i)\}\{a\} = \sum_{i=1}^{n}\sigma^h(x_i, y_i)\{P^T(x_i, y_i)\}$$

The rate of convergence of this method is demonstrated by a numerical example.

4. MESH REFINEMENT

After the error estimation, the mesh is refined according to the distribution of the error. If the relative error of an element exceeds a given limit, the element is fissioned into eight elements. When an element is fissioned next to unfissioned elements, slave nodes are created. The motion and force of the slave node is governed by the constraint of compatibility and equilibrium.

5. NUMERICAL EXAMPLES

A numerical example, the seismic response of liquefiable ground, is analyzed. The advantage of our method for liquefiable soil is shown.

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