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Practical Numerical Approach for Nonlinear Soil-Structure Interaction Analysis of a NPP Containment Building

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1. Introduction

The effects of soil-structure interaction (SSI) are evident in the dynamic response of massive and stiff structures installed in relatively flexible ground. One of the typical examples is the nuclear power plant (NPP) containment building. When structural safety of the building is evaluated, therefore, dynamic analysis must be carried out considering soil-structure interactions.

When soil-structure interaction is considered, the energy radiation through the unbounded soil must be represented by appropriate models. Usually, the energy radiation can be taken into rigorous consideration in the frequency domain. The consistent transmitting boundaries, boundary element methods, and infinite elements are numerical approaches which are frequently employed for the energy radiation into infinity.

Since nonlinearities in a system can influence significantly its dynamic behaviors, the necessity for nonlinear soil-structure interaction analysis is increasing recently. Nonlinear behaviors in a mechanical system can be best represented by nonlinear finite elements in the time domain. Thus, the accuracy and efficiency of nonlinear soil-structure interaction analysis depend on how accurately and efficiently the energy radiation into infinity can be considered in the time domain. The high-order absorbing boundary conditions and perfectly matched layers have been developed for the accurate and efficient nonlinear analysis in the time domain. However, special considerations must be given for their implementations and only highly-educated engineers can make the best use of the numerical models.

In this study, a "practical" numerical approach for nonlinear soil-structure interaction analysis of a NPP containment building installed in poroelastic soil is proposed. The proposed approach is based on mid-point integrated finite elements and viscous boundary. When compared with the mentioned numerical models, the proposed approach is accurate, efficient, and easy to be implemented for nonlinear soil-structure interaction analysis.

2. Representation of a SSI System

A soil-structure interaction system can be represented as shown in Fig. 1. The structure and the near-field region of the soil are represented by conventional finite elements. Various nonlinear behaviors in the sub-system can be considered. The far-field region of soil is represented by mid-point integrated finite elements and viscous boundary [1]. N mid-point integrated finite elements are employed in order to model the far-field region. The length of the elements is L_x / N. Then, a viscous boundary is attached to the end of elements in order to represent the infinite domain of the media.

The mid-point integrated finite elements can be expressed in the same way as the conventional finite elements. The only differences are the linearly varying displacements and the mid-point integrated integration rule. The viscous boundary can be represented by a simple mechanical damper. Therefore, they can be implemented without difficulty. Nonlinear soil-structure interaction problems can be solved with existing numerical codes modified slightly in order to implement the mid-point integrated finite elements and viscous boundary. Thus, the proposed model can be considered "practical" for numerical analysis of nonlinear dynamic problems in infinite media including nonlinear soil-structure interaction problems.

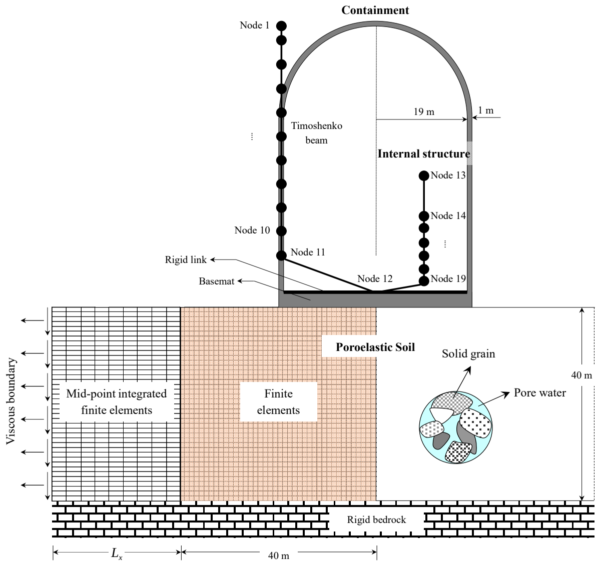

Fig. 1. Representation of a SSI system

3. Application

Nonlinear earthquake responses of a NPP containment building installed on poroelastic soil (Fig. 1) are obtained using the proposed numerical approach. Properties of the considered soil-strcuture interaction system are given in Lee [2] and Lee et al. [3]. In order to represent the far-field region, mid-point integrated finite elements and viscous boundary are attached to the near-field region. In this application, the parameters L_x = 480 m and N = 9 for the mid-point integrated finite elements.

Static loads due to the self-weights of the structural system and the soil are applied. Then, El Centro earthquake motion is applied as the surface ground motion of free-field soil. Earthquake responses of the system are obtained using the time-marching method based on the constant acceleration method.

Fig. 2 shows the equivalent plastic strain in the soil at the end of the calculation. The stress concentrations and plastic behavior around the corners of the rigid foundation can be observed. Fig. 3 shows the mean effective stress at the Gaussian quadrature point in the element where the maximum equivalent plastic strain occurs. It can be observed that the nonlinear response deviates from the linear behavior.

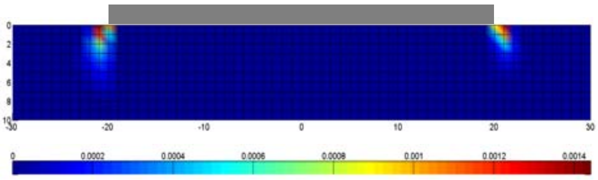

Fig. 2. Equivalent plastic strains in the soil

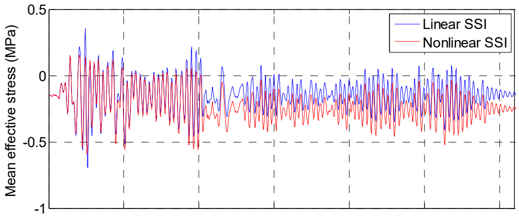

Fig. 3. Mean effective stress in the soil

4. Conclusion

In this study, a "practical" numerical approach for nonlinear soil-structure interaction of a NPP containment building installed in a poroelastic soil was proposed. In order to represent the energy radiation through soil, its far-field region is represented by mid-point integrated finite elements and viscous boundary. The mid-point integrated finite elements can be expressed in the same way as the conventional finite elements. The viscous boundary can be represented by a simple mechanical damper. Therefore, nonlinear soil-structure interaction problems can be solved with existing numerical codes modified slightly in order to implement the mid-point integrated finite elements and viscous boundary. Thus, the proposed model can be considered "practical" for numerical analysis of nonlinear dynamic problems in infinite media including nonlinear soil-structure interaction problems.

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