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Probabilistic Soil-Structure Interaction Analysis of Nuclear Power Plant Structures

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1. Introduction

For the important structure like Nuclear Power Plant (NPP), soil-structure interaction (SSI) can largely affect on the seismic response of the structure. In addition, consideration of uncertainty in SSI is also important. In this paper, in order to consider uncertainties in SSI analysis, probabilistic SSI analysis of NPP structure is conducted. Uncertainty of Soil profiles is considered, which is the most significant source of uncertainty in any SSI analysis. For the probabilistic SSI analysis, 30 soil profiles by Latin Hypercube Sampling (LHS) are used.

For considering both soil properties and structural nonlinearity, SSI analysis is conducted in frequency- and time-domain simultaneously. In order to consider the soil effect effectively, soil impedance function which obtained by frequency domain analysis is used as a sway-rocking model of the structure. On the other hand, structural analysis is conducted in time domain for considering nonlinear behavior of the structure. In this paper, the in-structure response spectrum (ISRS) by using an SSI analysis method which can consider both soil effect and structural nonlinearity is compared with the ISRS from ACS SASSI, a widely used software for SSI analysis. By comparing the ISRS, the method used in this paper is numerically verified. And probabilistic SSI analysis is conducted by using the verified method.

2. Numerical model

2.1. Structural model

In order to reduce computational costs, Nuclear Power Plant (NPP) structure is simplified as a 65.8 m tall beam-stick model in Fig. 1. It is based on OPR 1000 which is an in-service reactor containment building structure in Korea. Generally, reactor containment building is composed of the containment shell and the internal structure. However, only the containment shell is used in this paper. The dominant frequency of the numerical model is about 6 Hz.

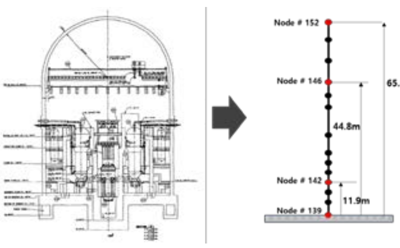

Fig. 1. Simplified beam-stick model [1]

2.2. Soil profiles

Generic soil profiles for the APR1400 standard design by KEPCO (Korea Electric Power Corporation) is adopted for the SSI analysis of the method verification [2]. It is suggested for the seismic analysis of APR 1400, which is an embedded NPP structure. In order to consider a surface structure model, an embedded soil layer is ignored.

For the probabilistic SSI analysis, soil profile of Hanbit units 3&4 containment reactor building site is used [3].

Table I: Soil Profiles

	Generic Soil for APR1400	Hanbit units 3&4
Average shear wave velocity	1431 m/s	2532 m/s

2.3. Input motion

USNRC R.G. 1.60 is used for an input ground motion. By using EQUAKE module from ACS SASSI, a time history acceleration is generated. The peak ground acceleration (PGA) is anchored 0.3g.

2.4. SSI analysis methodology (multi-step method)

The seismic response of NPP structure is largely affect by soil effect and structural nonlinearity. In order to consider both simultaneously, SSI analysis should be conducted in frequency- and time-domain. Soil effect can be effectively considered by frequency domain analysis. Nonlinear behavior of structure, however, need to be conducted in time-domain.

Therefore, soil impedance function by frequency-domain analysis is used as a sway-rocking model of the structure and structural analysis is done in time-domain. Soil impedance in frequency-domain is transformed to impulse response in time-domain by eq. (1) [4].

$$\begin{Bmatrix} D(\omega_1) \\ \vdots \\ D(\omega_N) \end{Bmatrix} = \left[[\bar{C}_{Kb}] \; [\bar{C}_{cb}] \; \{\bar{C}_{Mb}\} \right] \cdot \begin{Bmatrix} \{G_{Kb}\} \\ \{G_{cb}\} \\ G_{Mb} \end{Bmatrix} \quad (1)$$

In this paper, soil impedance function is obtained by ACS SASSI and transformed into impulse response (m, c, k) in Fig. 2.

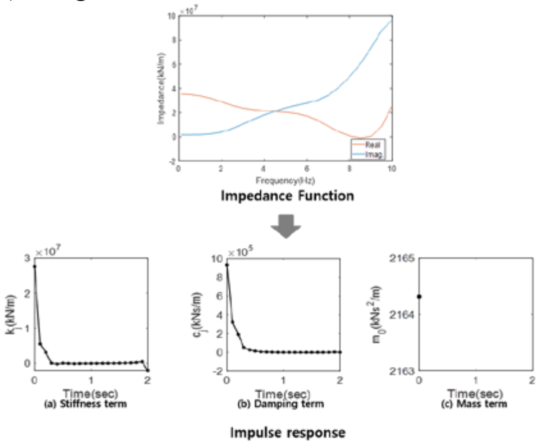

Fig. 2. Transform (Impedance function to Impulse response)

Structural analysis is conducted by using Newmark β method with considering impulse response as a sway-rocking model of the structure.

3. Results

The seismic response of the linear structure considering SSI effects by multi-step method is compared with the result from ACS SASSI. Multi-step method is verified by comparing the ISRS of the NPP structure at four different heights are shown in Fig. 3.

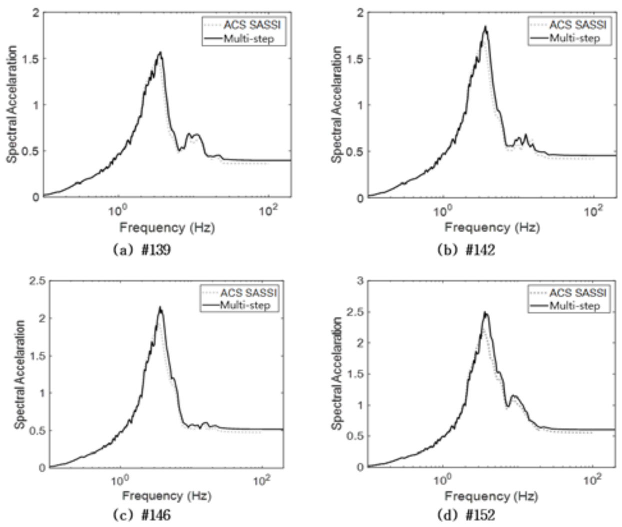

Fig. 3. ISRS (ACS SASSI vs. Multi-step)

ISRS has a peak at the dominant frequency of the structure which is about 6Hz at four points. The result shows small frequency shift and amplitude difference, but it shows similar trend. The differences are caused by the modeling process of the structure between two different analysis software. As a result, multi-step method is properly conducted with considering soil properties effectively.

4. Probabilistic SSI analysis

By using a verified multi-step method, a probabilistic SSI analysis is done for considering uncertainty of soil profile. In this paper, only the shear wave velocity of the soil profile is considered as a parameter which is lognormally distributed. 30 soil profile samples from LHS method is used for probabilistic SSI analysis. The ISRS at three different heights of the structure are compared with deterministic ISRS in Fig. 4.

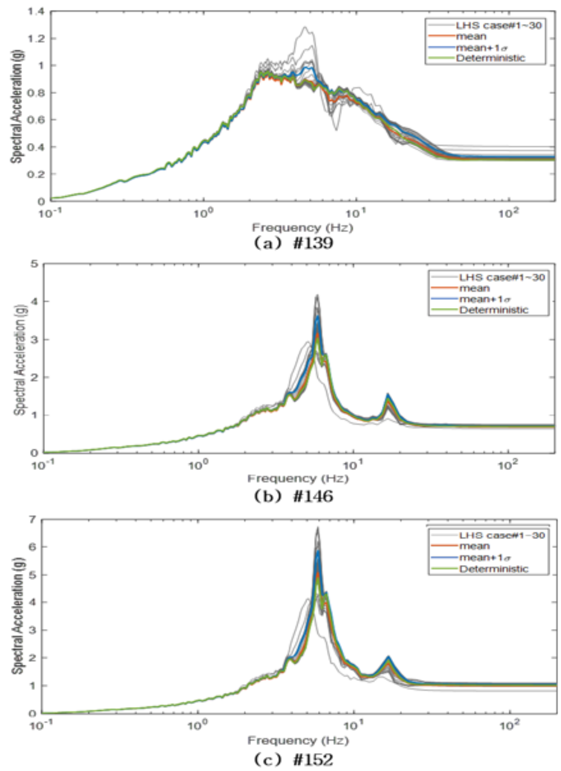

Fig. 4. Probabilistic ISRS

6. Conclusion

A multi-step method, suggested for consider frequency dependent soil properties and structural nonlinearity simultaneously, is verified by comparing ISRS with ACS SASSI. In this paper, in order to verify the method, structure is assumed as a linear structure. This method can effectively consider soil properties and it can be applied for nonlinear structure by using Newton-Raphson iteration method.

Uncertainties of the SSI analysis affect on the seismic response of the NPP structure is unignorable. Therefore, probabilistic SSI analysis should be conducted for the safety of the structure. By using the multi-step method, probabilistic SSI analysis of the nonlinear structure is expected to be conducted in short computational time.

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