Analysis of Soil-Structure Interaction Considering Wave Incoherence

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1. Introduction

In general, earthquake response analysis of nuclear facilities with vertically propagating plane shear and compressional coherent seismic waves produces conservative in-structure responses. Wave incoherence can reduce earthquake responses of structures on soil as well as rock sites. Due to the complexity of the soil-structure interaction (SSI) treatment of the incoherent wave field, simple models to estimate foundation motion, including the effects of incoherence, shall not be used [1].

In this study, an approach to consider the effects of wave incoherence in SSI analysis is proposed and applied to nonlinear SSI analysis of a nuclear power plant (NPP) containment structure.

2. Generation of incoherent ground motions

Incoherent ground motions are generated using a spectral-representation-based algorithm [2]. Fig. 1 shows a flow chart for the generation. In this study, the Modified Kanai-Tajimi power spectral density (PSD) function and the coherency function by Luco and Wong in Fig. 2 are considered. Examples of the generated incoherent ground motions are shown in Fig. 3
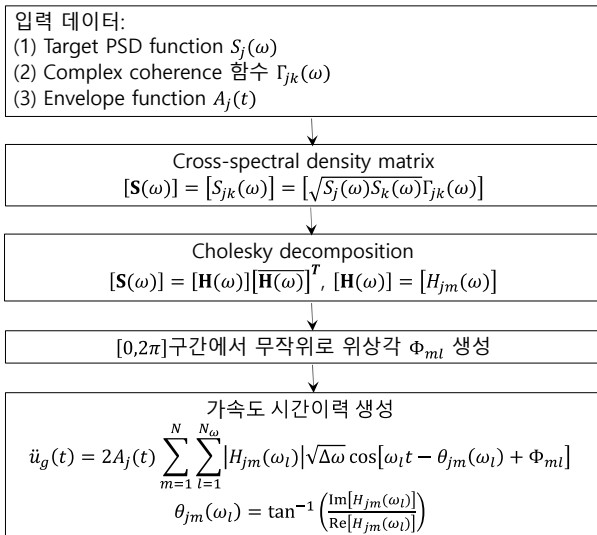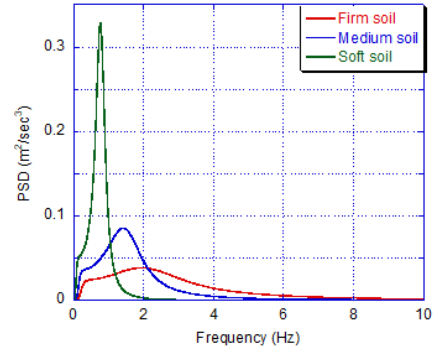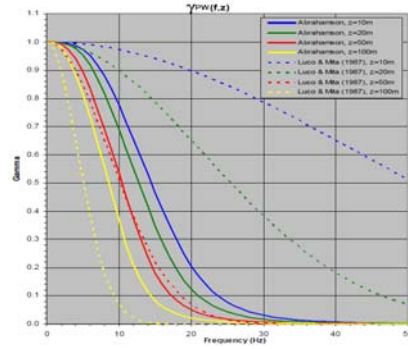

(a) Modified Kanai-Tajimi PSD function

(b) Coherency function by
Fig. 2 PSD function and coherency function

입력 데이터:
(1) Target PSD function $S_j(\omega)$
(2) Complex coherence 함수 $\Gamma_{jk}(\omega)$
(3) Envelope function $A_j(t)$

Cross-spectral density matrix
$$[\mathbf{S}(\omega)] = [S_{jk}(\omega)] = \left[\sqrt{S_j(\omega)S_k(\omega)}\Gamma_{jk}(\omega)\right]$$

Cholesky decomposition
$$[\mathbf{S}(\omega)] = [\mathbf{H}(\omega)]\left[\overline{\mathbf{H}(\omega)}\right]^T, \ [\mathbf{H}(\omega)] = [H_{jm}(\omega)]$$

$[0,2\pi]$구간에서 무작위로 위상각 Φ_{ml} 생성

가속도 시간이력 생성
$$\ddot{u}_g(t) = 2A_j(t)\sum_{m=1}^{N}\sum_{l=1}^{N_\omega}|H_{jm}(\omega_l)|\sqrt{\Delta\omega}\cos[\omega_l t - \theta_{jm}(\omega_l) + \Phi_{ml}]$$
$$\theta_{jm}(\omega_l) = \tan^{-1}\left(\frac{\mathrm{Im}[H_{jm}(\omega_l)]}{\mathrm{Re}[H_{jm}(\omega_l)]}\right)$$

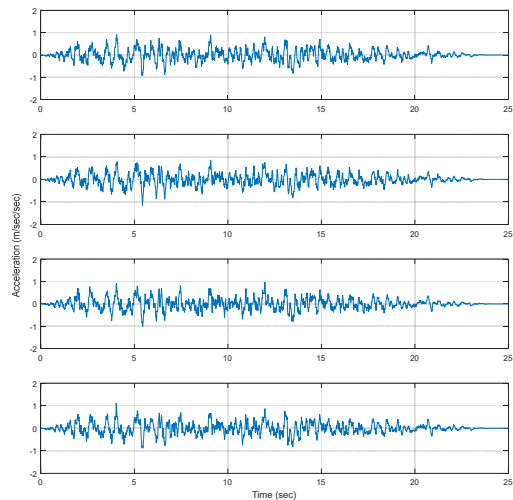Fig. 1. Flow chart for the generation of incoherent ground motions

Fig. 3 Generated incoherent ground motions

3. Effective earthquake forces

Free-field analysis is performed when the generated incoherent ground motions are incident to an NPP site [3]. The generated incoherent ground motions are decomposed into their components in the wavenumber-frequency domain. Free-field responses to the components are calculated by solving a corresponding one-dimensional wave equation. Then, effective earthquake forces are evaluated from the free-field analysis.

4. Soil-structure interaction analysis

Soil-structure interaction analysis of an NPP containment structure in Fig. 4 is performed when the generated incoherent ground motions are applied to its site. Material nonlinearity in soil is considered using the Drucker-Prager model. Fig. 5 shows plastic responses in soil due to coherent and incoherent ground motions.
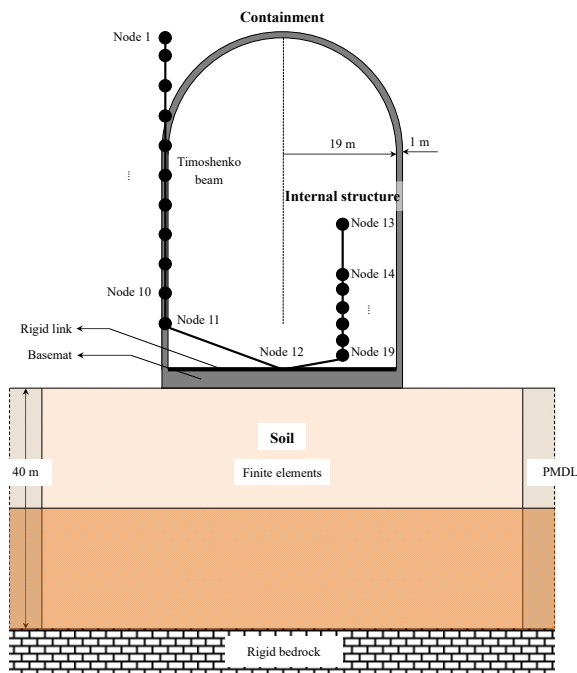

Fig. 4 NPP containment structure

5. Conclusion

In this study, an approach to consider the effects of wave incoherence in SSI analysis was proposed and applied to nonlinear SSI analysis of a nuclear power plant (NPP) containment structure. It can be observed that the incoherent ground motions can influence earthquake responses of an NPP containment structure significantly.
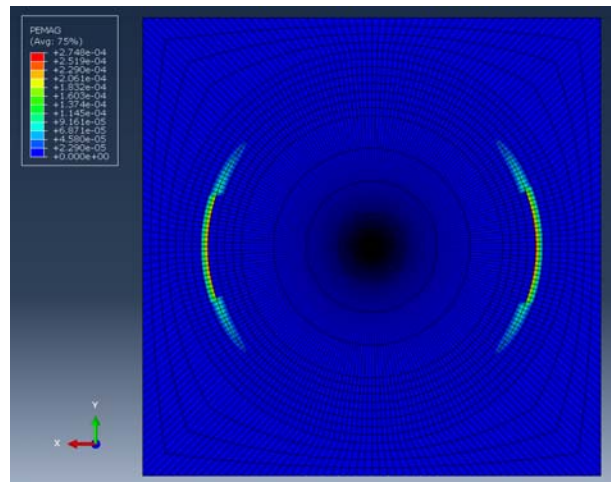
(a) Coherent ground motions
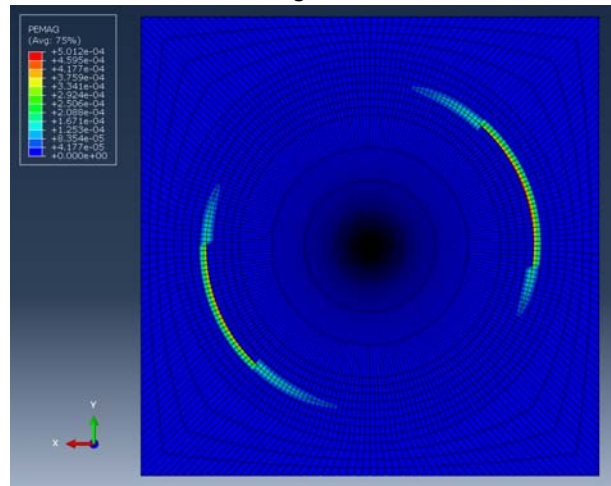
(b) Incoherent ground motions

Fig. 5 Plastic response in soil

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[1] ASCE, Seismic Analysis of Safety-Related Nuclear Structures, ASCE/SEI 4-16, American Society of Civil Engineers, 2016.
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[3] J.M. de O. Barbosa, E. Kausel, The thin-layer method in a cross-anisotropic 3D space, International Journal for Numerical Methods in Engineering, Vol. 89, pp. 537-560, 2012.