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Auto-Generation Technique of Near-Far Field Soil and Effective Seismic Load for Domain Reduction Method

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1. Introduction

Two earthquakes in Korea have increased interest in earthquake resistance among Korean construction companies and public organizations. Specifically, seismic design and seismic safety evaluation for social infrastructure are becoming more prominent. Seismic design requires precise analysis through seismic analysis, as most structures are huge. Seismic analysis involves considering the response resulting from the interaction between the soil and the structure [1]. Two methods for analyzing soil-structure interaction(SSI) are the direct method and the substructure method [1]. The direct method requires modeling a large near-surface area to obtain an accurate solution, which is disadvantageous due to the required analysis time and resources. To address these issues, substructure methods have been proposed. Several substructure methods are available, including the flexible volume method and the exterior rigid boundary method. The flexible volume method is a frequency domain analysis technique that has been developed as a representative SSI analysis program and is widely used to date [2]. However, one disadvantage of this approach is that it can be challenging to perform analyses that require many interaction nodes. KIESSI-3D, a SSI program, has been verified for three decades using the exterior rigid boundary method [3]. It provides accurate responses and parallel analysis technique for the high-speed solution. Recent research has developed methods for automatically generating the finite elements of the near-field, backfill, and far-field, and KIESSI-TD has been released [4].

Numerous studies have been also conducted on the precise SSI analysis with various nonlinearities in time domain. It is crucial to determine efficient and effective seismic forces and apply effective energy absorbing boundary conditions. This study developed a preprocessing program to generate the effective seismic forces in the frequency domain, and automatically transform them to the input data for the time-domain SSI analysis.

2. Methods and Results

2.1 Domain Reduction Method

The domain reduction method was developed for the time-domain SSI analysis technique proposed by ASCE [1]. It calculates the effective seismic force due to the input seismic wave at the boundary of the far-field soil and converts it into seismic load to reduce the near-field soil area [5]. This method has been widely used for time-domain SSI analysis in domestic and foreign [6, 7].

To determine the effective seismic force of DRM, subtract the reaction force obtained in the $\mathbf{\Omega}^{\mathrm{DRM}}$ domain of the fixed boundary structural system from the total system, as shown in Figure 1. This will obtain the radiation system of the structure where the incident seismic waves are eliminated. This method allows for obtaining the same response as the response of the total system for the displacements $\delta\mathbf{u}_i$ and $\delta\mathbf{u}_b$ of the $\mathbf{\Omega}$ domain by the load obtained from the $\mathbf{\Omega}^{\mathrm{DRM}}$ domain.

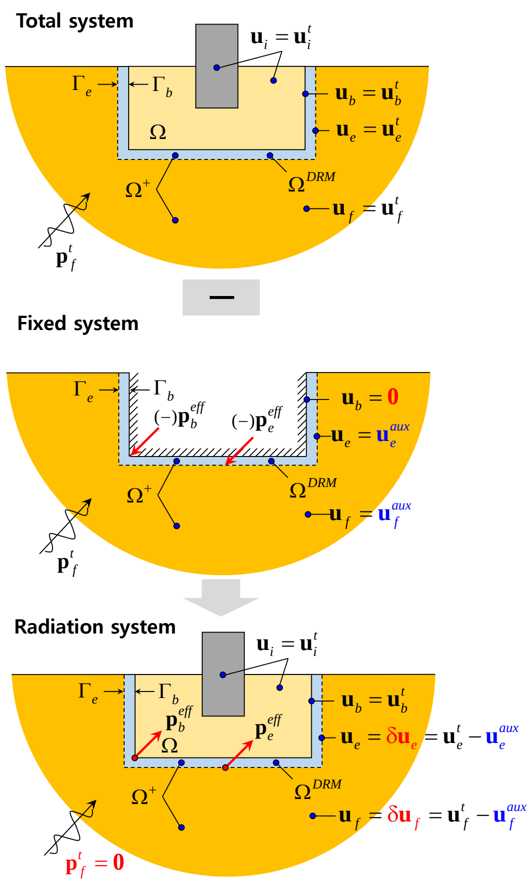


Fig. 1. Conceptual diagram for the determination effective seismic forces by DRM.

This shows that the response of the DRM method is the same as that of a large near-field region, even if a reduced near-field region is used. Additionally, in the case of the DRM, the effective seismic force is determined where the SSI effect is insignificant. However, the SSI effect can cause radiation waves to propagate far-field boundary in models with significant SSI effects. To solve this problem, it is important to determine the seismic forces including the SSI effect. Thus, this study presents a technique for determining the effective seismic force in the frequency domain SSI analysis system.

2.2 Determine Method for Effective Seismic Load

The KIESSI-3D program was used to determine the effective seismic forces through a frequency domain SSI analysis. The program was applied to consider the input seismic wave, and obtain the resulting acceleration, velocity, and displacement responses in the Ω^{DRM} including the SSI effect. The soil responses were multiplied by the dynamic stiffness matrix S in the Ω^{DRM}, as shown in Equation (1), to determine the seismic forces for the DRM. Using these forces to perform the time-domain SSI analysis results in almost no radiated waves. This reduces the load on the energy-absorbing boundary and improves the accuracy and convergence of the solution.

$$\begin{Bmatrix} p_b^{eff} \\ p_e^{eff} \end{Bmatrix} = \begin{Bmatrix} S_{be}^{\Omega^+} u_e^{aux} \\ -S_{eb}^{\Omega^+} u_b^{aux} \end{Bmatrix} = \begin{Bmatrix} S_{be}^{\Omega^{DRM}} u_e^{aux} \\ -S_{eb}^{\Omega^{DRM}} u_b^{aux} \end{Bmatrix} \qquad (1)$$

2.3 Analysis of Free-Field Problem

To verify the validation of the determination of effective seismic forces, seismic response analysis was performed for the free-field problem at a domestic nuclear power site, as shown in Figure 2. Therefore, site response analysis, frequency domain SSI analysis, and time domain SSI analysis were performed. The KIESSI-3D program was used for the frequency domain SSI analysis and time domain SSI analysis. KEISSI-TD can apply the DRM effective seismic force in the time domain analysis, using the conventional artificial boundary as like the absorbing boundary condition (ABC). The Figure 3 shows that the acceleration response spectra obtained from the DRM was very identical, when compared to the response obtained from the SHAKE analysis. This confirms the implementation of the technique for the automatic generation of finite elements in nearfield and the effective seismic force on Ω^{DRM} using the KEISSI-TD.

3. Conclusions

A preprocessing program was developed to automatically determine the effective seismic forces for the domain reduction method, considering the SSI effects. The seismic response to the free-field problem was compared and found to be very identical, with an error of less than 3%. The KIESSI-TD program was found to be applicable to time-domain SSI analysis.

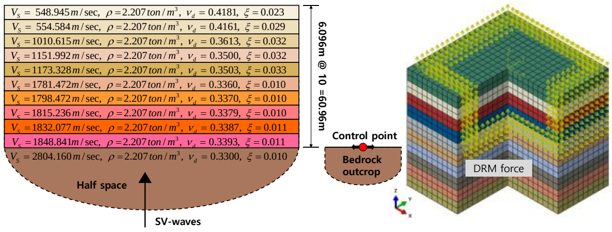
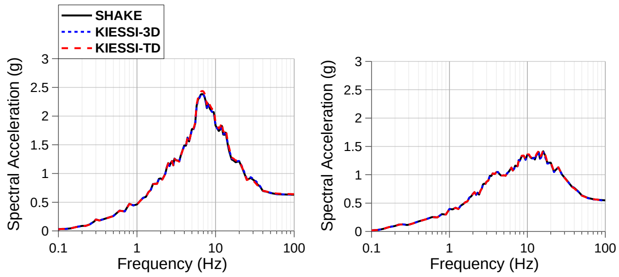


Fig. 2. Soil condition and analysis model of free-field problem



(a) Horizontal direction (b) Vertical direction

Fig. 3. Result of free-field analysis problem (response spectra by damping ratio 5%)

Table I: Error of response spectra (ref. solution=SHAKE)

	KIESSI-3D	KIESSI-TD
Horizontal	1.10%	2.21%
Vertical	0.62%	0.87%

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