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Estimation of site-specific ground motion coherency function using geotechnical dynamic analysis

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ABSTRACT

The ground motion coherency function describes spatial incoherency of ground motions with frequency and separation distances. The ground motion coherency function is the one of essential input parameters of the incoherent soil-structure interaction (SSI) analysis on nuclear power plant structures. Since 1990s, various ground motion coherency functions have been provided by previous researches based on several dense seismic array data. The seismic wave incoherence is induced by the near surface scattering of seismic wave passing nonhomogeneous geotechnical material. Therefore, ground motion coherency function is a site-specific characteristic of the site. In this study, procedures to estimate the site-specific ground motion coherency function using the geotechnical dynamic analysis were proposed and verified with earthquake recordings from the dense seismic array located in Korea and the dynamic experimental program.

1. INTRODUCTION

The seismic wave incoherence affect the seismic response of the structure for high-frequency range. The incoherent soil-structure interaction (SSI) analysis method have been suggested to estimate the seismic response of the structure considering the seismic wave incoherence effect. The seismic wave incoherence can be characterized by the ground motion coherency function (Zerva, 2009). The ground motion coherency function describes the spatial incoherency of ground motion with frequency and separation distance. Various ground motion coherency functions have been suggested by previous researches based on dense seismic array recordings since 1990s (Zerva, 2009; EPRI, 2007). Ground motion coherency functions are affected by the site conditions including rock quality and spatial variability because the seismic wave incoherence is induced by scattering of the seismic wave in near-surface. Thus, the ground motion coherency function based on the dense seismic array has limitations in

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considering specific site conditions of the target structure. For this reason, various studies based on the numerical simulation have been presented to determine site-specific seismic wave incoherence (Zentner, 2016; Ghiocel et al., 2017; Haber et al., 2018; Svay, 2018; Chang et al., 2021; Lee et al., 2024). In this study, procedures to estimate the site-specific ground motion coherency function using the geotechnical dynamic analysis were proposed and verified with earthquake recordings from the dense seismic array located in Korea and the dynamic experimental program.

2. METHODOLOGIES AND PROCEDURES

Procedures used in this study are summarized in Fig. 1. Shear wave velocity and density of the sites were determined from geophysical survey program including borehole seismic survey. The spatial variability parameters (e.g., median, coefficient of variation, and correlation length) of shear wave velocity data were derived from the geophysical survey data. Multiple 2-D random field numerical models for the derived spatial variability parameters were generated based on the Karhunen-Loève expansion. Meanwhile, multiple input ground motions were selected from earthquake recording database. A logic tree was organized using the generated random field models and the selected input ground motions. Geotechnical dynamic analysis were conducted on each branch of the logic tree. The ground motion coherency function was determined by the regression analysis on plane-wave coherency data based on the methodologies described in Abrahamson (2007).

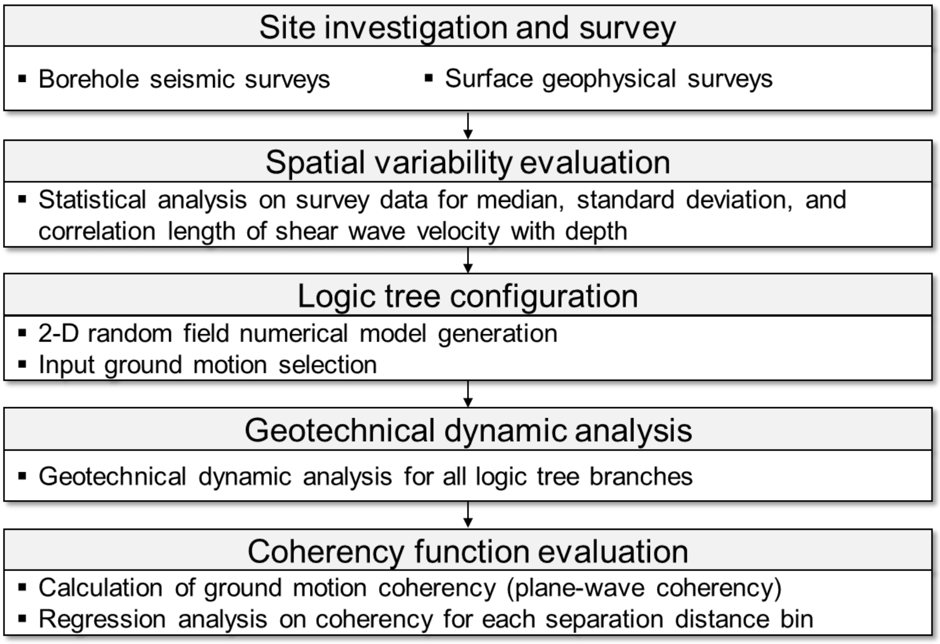


Fig. 1 Procedures used in this study

3. VERIFICATION USING EXPERIMENTAL PROGRAM

The KOCED dynamic geo-centrifuge test setup was used in this study (Fig. 2 (a)). The prototype of physical model and its properties are presented in Fig. 2 (b) and (c). For the physical model, the equivalent shear beam container was used to simulate semi-infinite soil layer responses (Lee et al., 2013; Choi et al., 2024). The spatial variability parameters of the shear wave velocity were obtained from bender element test and lab-scale cone penetration test data (Jeong et al., 2024). The surface ground motion coherency was measured by the linear array consisted of 15 accelerometer. Thirty 2-D random field model were generated to capture the uncertainty of the physical model while 8 ground motion were used as input ground motion for both of physical and numerical simulation. Fig. 2 (d) shows ground motion coherency functions base on the experimental results and the numerical simulation. The seismic wave incoherence estimated by numerical simulation was well matched with the experimental results.

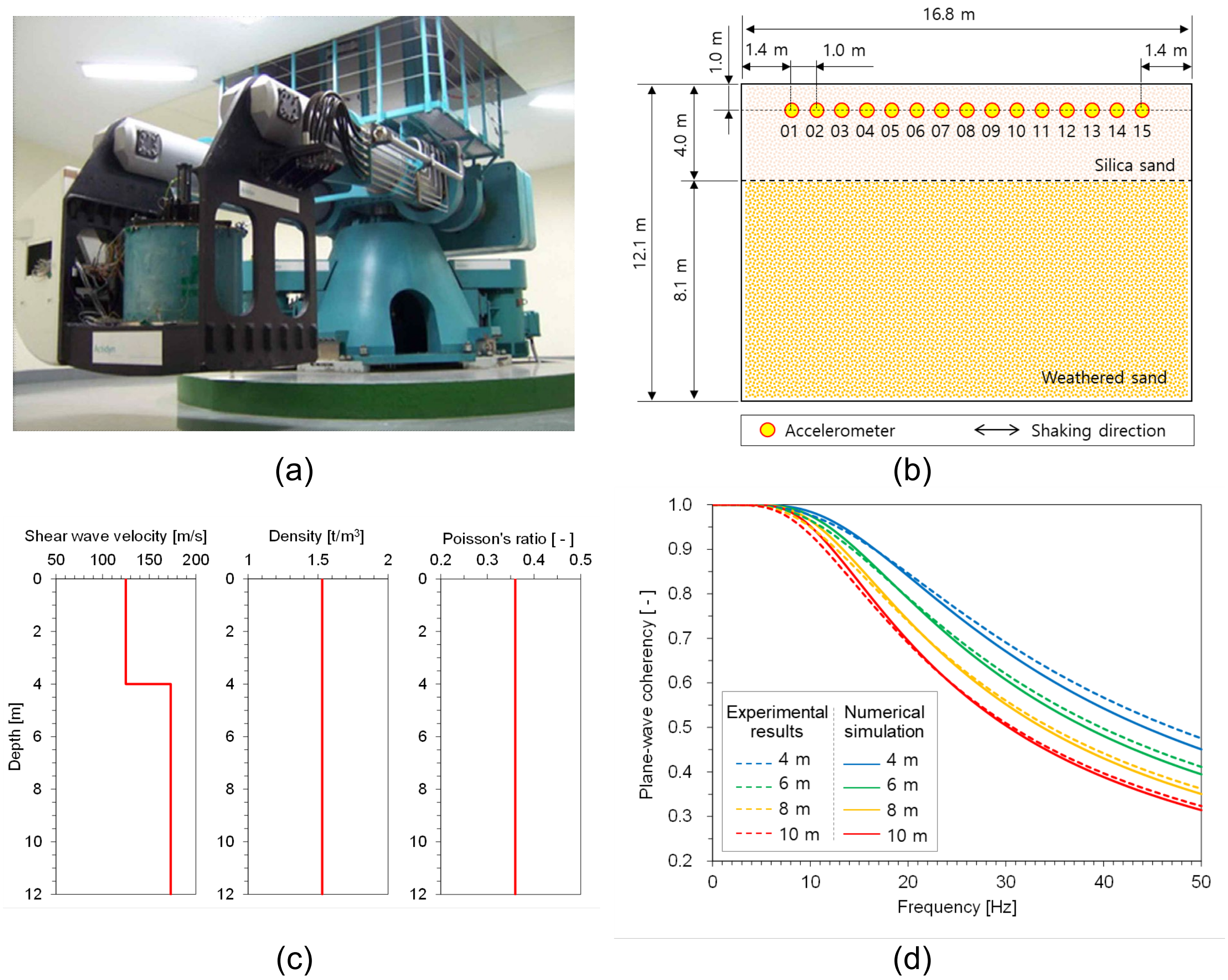
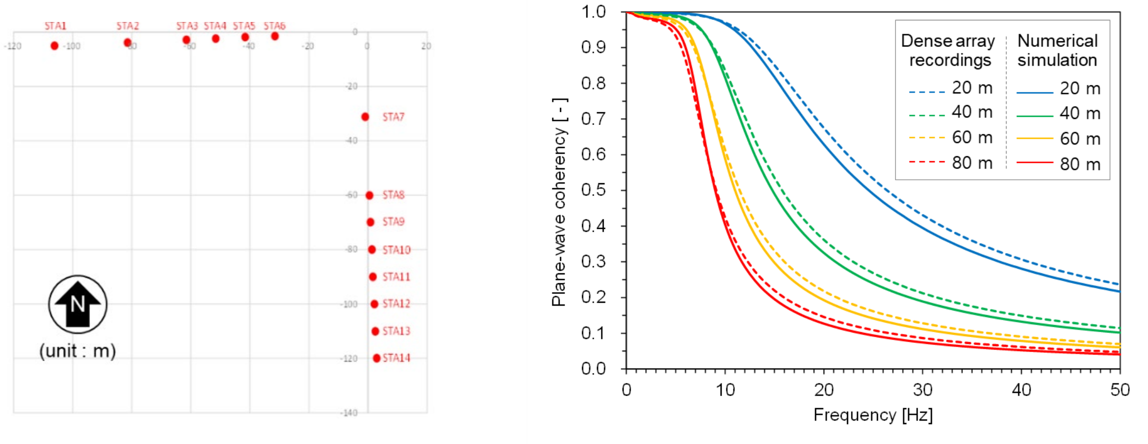


Fig. 2 The experimental program of this study. (a) The KOCED geo-centrifuge facility in KAIST, Daejeon, Korea. (b) The prototype of the physical model. (c) Geotechnical properties of the physical model. (d) Ground motion coherency functions based on experimental results and the numerical simulation.

4. VERIFICATION USING DENSE SEISMIC ARRAY

Korea Hydro and Nuclear Power Co. Ltd. (KHNP) installed a dense seismic array to develop ground motion coherency function in 2021 (Kim et al., 2022). The L-shaped dense seismic array consists of 14 seismometer (velocity sensor) and the total size of the array is 150 m × 150 m (Fig. 3 (a)). The bedrock consists mainly of fresh andesitic tuff, and it is classified as from ‘fresh rock’ to ‘moderately weathered rock’. Geotechnical investigation and geophysical survey including borehole seismic surveys were performed to determine elastic wave structure beneath dense seismic array. The ground motion coherency function of the dense seismic array was evaluated using the procedures described in this study. Fig. 3 (b) shows preliminary ground motion coherency functions base on the dense seismic array and the numerical simulation. For the frequency greater than 10 Hz, the coherency function based on numerical simulation results were well matched with that derived from the earthquake recordings of dense array.



(a) (b)

Fig. 3 Dense seismic array program of this study. (a) Sensor locations of the dense seismic array. (b) Preliminary ground motion coherency functions based on dense seismic array and the numerical simulation (note: Ground motion coherency functions presented in this paper is not final results for the KHNP dense seismic array.).

5. CONCLUSIONS

In this study, procedures to estimate the site-specific ground motion coherency function using the geotechnical dynamic analysis were proposed. The dynamic geo-centrifuge test and dense seismic array recordings were used to verify the proposed procedures. For both of cases, ground motion coherency functions estimated by geotechnical dynamic analysis were well matched with ground motion coherency functions based on experimental and dense seismic array program. This study reveals that the site-specific ground motion coherency function can be provided by the geotechnical dynamic analysis.

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