Floor Response Spectra of Nuclear Containment Building with Soil-Structure Interaction

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1. Introduction

This paper presents a seismic analysis technique for a 3D soil-structure interaction(SSI) system in frequency domain, based on the finite element formulation incorporating frequency-dependent dynamic infinite elements for the far field soil region. Earthquake input motions are regarded as traveling SV-wave which is vertically incident from a far-field soil region. In which, the equivalent earthquake forces in the frequency domain are calculated using the exterior rigid boundary method and the free field response analysis. For the application, floor response spectra analyses for nuclear containment building on a soil medium is carried out, the obtained results are compared with the free field response by other solution.

2. Equation of motion

The discretized equation of motion for earthquake analysis of SSI system shown figure 1 is set down[1];

$$\begin{bmatrix} \mathbf{S}_{nn} & \mathbf{S}_{ne} & 0 \\ \mathbf{S}_{en} & \mathbf{S}_{ee}+\bar{\mathbf{S}}_{ee} & \bar{\mathbf{S}}_{ef} \\ 0 & \bar{\mathbf{S}}_{fe} & \bar{\mathbf{S}}_{ff} \end{bmatrix} \begin{Bmatrix} \mathbf{U}_n \\ \mathbf{U}_e \\ \mathbf{U}_f \end{Bmatrix} = \begin{Bmatrix} 0 \\ \mathbf{p}_e(\omega)\mathbf{X}_c(\omega) \\ 0 \end{Bmatrix} \qquad (1)$$

$$\bar{\mathbf{S}}(\omega) = (1+i2\beta_d)\bar{\mathbf{K}}(\omega) - \omega^2\bar{\mathbf{M}}(\omega)$$

where $\mathbf{S}(\omega)$ is the dynamic stiffness matrix with hysteretic damping($\beta_d^{(e)}$) effect; $\mathbf{K}^{(e)}(\omega)$ and $\mathbf{M}^{(e)}(\omega)$ are the stiffness and mass matrices of a element; $\mathbf{p}_e(\omega)$ is the equivalent earthquake force factor along the interface Γ_e; subscript n stands for the degrees of freedom (DOF) of the structure and the near field soil region; e denotes the DOF along the interface; and superscript f denotes the far field soil region. $\bar{\mathbf{S}}(\omega)$, $\bar{\mathbf{K}}^{(e)}(\omega)$ and $\bar{\mathbf{M}}^{(e)}(\omega)$ are the elementary matrices corresponding to the far field; $\mathbf{X}_c(\omega)$ is the Fourier spectrum of the input control motion $\ddot{x}_c(t)$.

3. Equivalent earthquake forces

The exterior rigid boundary method is applicable to estimate the equivalent earthquake force along the interface in this study. Shown in the figure 2, the force vector $\mathbf{p}_e$ could be calculated using the result of free field analysis and the dynamic stiffness of far-field region. This scheme makes the earthquake forces by calculating the reaction force($-\mathbf{r}_e$) against the movement of the interface($\mathbf{u}_e$ =0), while the unit control motion $\mathbf{X}_c(\omega)=1$ is subjected to free field system. Therefore the earthquake inputs are regarded as traveling waves vertically incident to the near field soil region[2].

$$\mathbf{p}_e(\omega) = \mathbf{r}_e(\omega) - \mathbf{A}\mathbf{t}_e^{(f)}(\omega) \qquad (2)$$

where the reaction force $\mathbf{r}_e$ can be calculated as

$$\mathbf{r}_e(\omega) = \left[\bar{\mathbf{S}}_{ee}^F(\omega) - \bar{\mathbf{S}}_{ef}^F(\omega)\left[\bar{\mathbf{S}}_{ff}^F(\omega)\right]^{-1}\bar{\mathbf{S}}_{fe}^F(\omega)\right]\mathbf{U}_e^{(f)}(\omega) \qquad (3)$$

4. Floor response spectra of nuclear building

The displacement fields of the SSI system subjected to a seismic excitation can be represented by Fourier time-frequency transformation formula as following.

$$\mathbf{u}_a(t) = \frac{1}{2\pi}\int_{-\infty}^{\infty}\mathbf{U}_a(\omega)e^{i\omega t}d\omega \qquad (4)$$

(6)

And then the floor response spectrum of the nuclear containment building shown as figure 3 can be calculated, using the convolution method as follows;

$$RS_a(\omega,\beta) \cong \max_t \left| -\omega\int_0^t \ddot{u}_a(\tau)e^{-\beta\omega(1-\tau)}\sin\omega(1-\tau)d\tau \right| \qquad (5)$$

Figure 4 shows the Elcentro-NS earthquake signal and response spectrum. When the earthquake is subjected to the containment system, we calculate and obtain the responses as figure 5. The responses present the time history and floor response spectrum of inner structure(node 1) in containment building, and show the remarkable solution, compared with that of SASSI[3].

5. Conclusion

The analysis was performed by adopting the 3D coupled FE-IE method for the horizontally layered soil medium and incident SV wave. Equivalent earthquake forces are applied along the interface boundary between near and far fields. The present methodology could be effectively applied in the floor response spectrum of nuclear containment building with soil-structure interaction system subjected to earthquake load.

REFERENSE

[1] Seo C.G., Yun C.B., Kim J.M., "Three-dimensional frequency dependent infinite elements for soil-structure-interaction", Engineering Structures, Vol. 29, 2007, pp 3106-3120.
[2] Zhao C., Valliappan S., "An efficient wave input procedure for infinite media", Communications in Numerical Methods in Eng., Vol. 9, 1993, pp 407-415.
[3] Lysmer J et. al., "SASSI: A System for Analysis of Soil-Structure Interaction", User's Manual, University of California, Berkeley, 1988

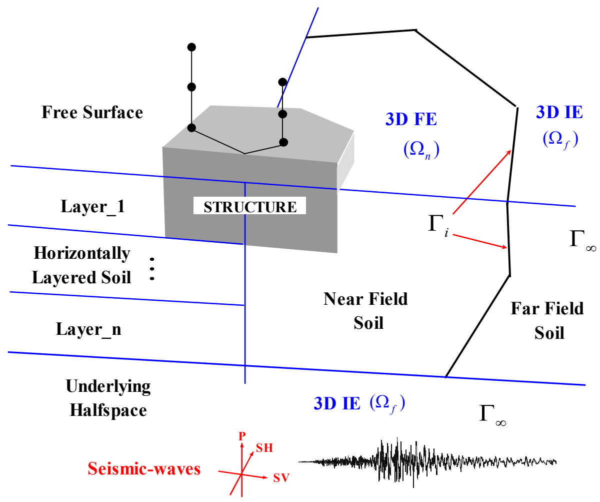

Figure 1. Schematic diagram of 3D SSI system subjected by vertically incident seismic waves

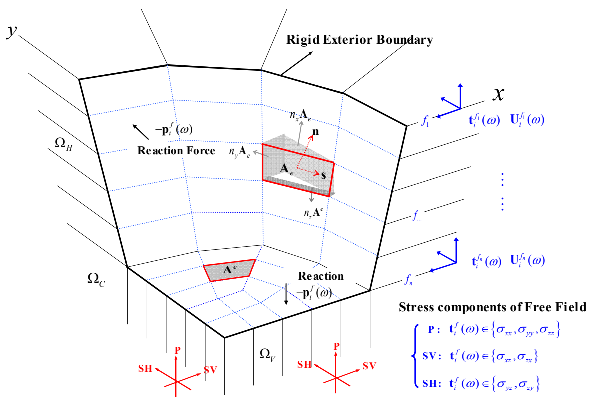

Figure 2. Equivalent earthquake forces of rigid exterior boundary method

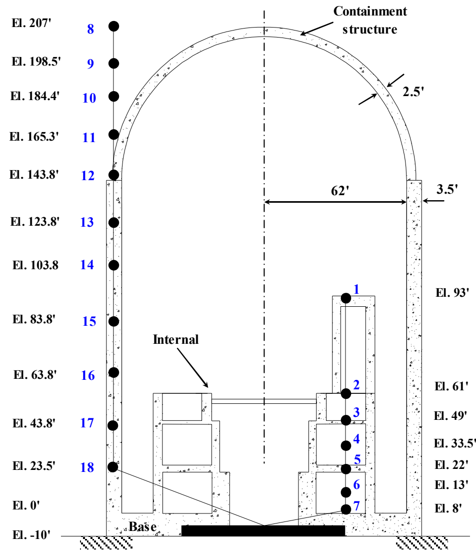

Figure 3. Lumped mass stick models of the containment and internal structures

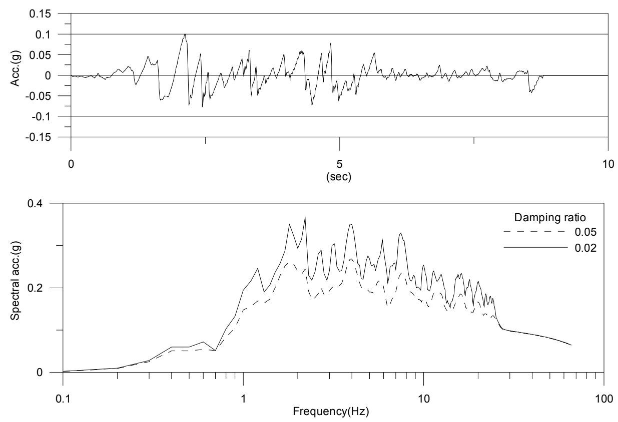

Figure 4. Time history and response spectrum of Elcentro-NS

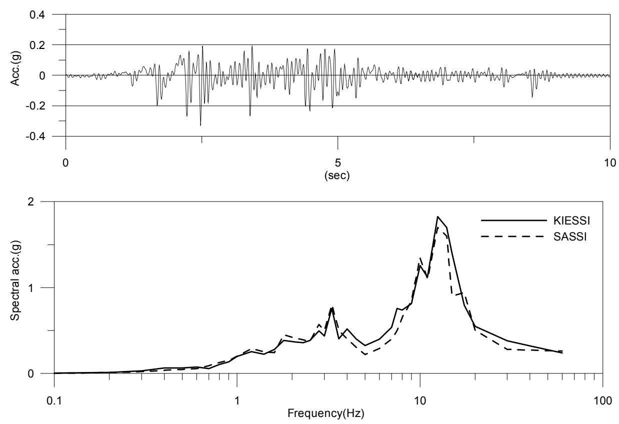

Figure 5. Time history and floor response spectrum of inner structure in the nuclear containment(node 1)