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# A Study on Variability of Soil-Structure Interaction in Seismic Fragility Analysis of Nuclear Power Plant Structures

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## 1. Introduction

In seismic fragility analysis of structure, conservatism in each of the parameters that affects the capacity or the seismic response is quantified by a factor of safety. The variability associated with each factor of safety is also quantified. EPRI Report TR-103959 [1] provides guidance for quantification of the variability of structural capacities and responses.

This study focuses on the variability of seismic response of structures due to soil-structure interaction (SSI) effects. Reference 1 presents two recommendable approaches to investigate the effects on the response due to uncertainty in the soil properties.

This study analyzes correlation of the two approaches. For the purpose, parametric analyses are performed for the typical SSI model using SASSI computer program [2]. The fundamental frequencies of SSI system which are obtained by analysis and calculated by using formulae in engineering guidance [1,3] are compared each other.

## 2. Guidance for Soil Property Uncertainty

ASCE 4-98 [3] and reference 1 provide guidance to account for effects on the seismic response due to uncertainties in soil property. They recommend performing 3 SSI analyses using the median soil shear modulus and plus and minus 1 standard deviation soil shear modulus. Alternatively, when only 1 SSI analysis is performed, the equations in ATC 3-06 [4] are used to determine where the structure frequency variability influences the building response.

In the first approach, three sets of low strain soil properties are needed including the “Best Estimate” (BE) properties. “Upper Bound” (UB) and “Lower Bound” (LB) properties are developed by multiplying and dividing the BE properties by the uncertainty factor, $1\pm C_V$, where $C_V$ is coefficient of variation. According to these bounds, the UB and LB shear moduli are determined by the following equations.

$$G_{UB} = G_{BE} \times (1 + C_V) \tag{1}$$

$$G_{UB} = G_{BE} \times \frac{1}{(1 + C_V)} \tag{2}$$

In alternate approach, equation (3) and (4) can be used to estimate the soil-structure system fundamental frequency at the plus and minus one standard deviations of soil shear modulus values. The upper bound frequency, $f_U$ and the lower bound frequency, $f_L$ can be estimated by the following equations [1, 4]:

$$f_U = f_1 / \sqrt{1 + \frac{1}{(1+C_V)}\left[\left(\frac{f_1}{f_{SSI}}\right)^2 - 1\right]} \tag{3}$$

$$f_L = f_1 / \sqrt{1 + (1+C_V)\left[\left(\frac{f_1}{f_{SSI}}\right)^2 - 1\right]} \tag{4}$$

where $f_1$ is the fundamental frequency of the structure when fixed at the base and $f_{SSI}$ is the fundamental frequency of the soil-structure system from the single best estimate analysis.

## 3. Parametric SSI Analyses

Parametric SSI analyses are performed to investigate the consistency between the frequencies obtained by SSI analysis and calculated by using equation (3) and (4).

### *3.1 Soil Properties*

Seven soil or rock properties are selected and combined with typical four NPP structures to construct SSI models. Table I shows soil properties selected for this study.

Table I: Soil Properties

| $V_s$ (m/sec) | Mass Density ($kg*s^2/m^4$) | Shear Modulus (GPa) | Poisson’s Ratio | Damping Factor (%) |
|---|---|---|---|---|
| 400 | 1,907 | 0.298 | 0.3 | 5 |
| 600 | 2,010 | 0.743 | 0.3 | 3 |
| 900 | 2,010 | 1.671 | 0.3 | 3 |
| 1,350 | 2,113 | 3.948 | 0.3 | 2 |
| 2,050 | 2,113 | 8.882 | 0.3 | 2 |
| 2,440 | 2,216 | 13.071 | 0.3 | 2 |
| 3,050 | 2,216 | 20.423 | 0.3 | 2 |

The coefficient of variation, $C_V$, on the shear modulus should be based on the site-specific data; however, the $C_V$ of 0.5 is used in this study. Seven soil conditions whose shear wave velocity gradually varies (approximately 1.5 times) are selected as shown in Table 1.

### *3.2 Structural Model*

Containment structure of the Korean Standard NPP is chosen to combine with various soil conditions.

### *3.3 Input Motion*

Natural frequencies of the SSI systems are computed by applying system identification techniques. The base excitation motion is the exponential sine sweep (sometimes the term "logarithmic sweep" is used instead) in which the frequency varies exponentially with time. The sine sweep excitation signal, $f_0$, could be expressed as function of time by [5]:

$$u(t) = A \cdot \sin[\varphi(t)] \quad (5)$$

where $A$ is the amplitude and $\varphi(t)$ is the augment phase of the sine. The angular position is given by:

$$\varphi(t) = 2\pi \frac{60 f_0}{\beta \ln(2)} (2^{\beta \frac{t}{60}} - 1) + \varphi_0 \quad (6)$$

where $\beta$ [oct/min] is the sweep rate, $\varphi_0$ is the integration constant equal to the initial angle at t=0 and $f_0$ [Hz] the starting frequency.

### *3.4 Analysis Results*

The transfer functions of the containment structure as shown in Fig. 1 were calculated from seismic response at the top of containment dome. The peaks for each mode are shifted to the high frequency region by increasing the shear modulus of soil.

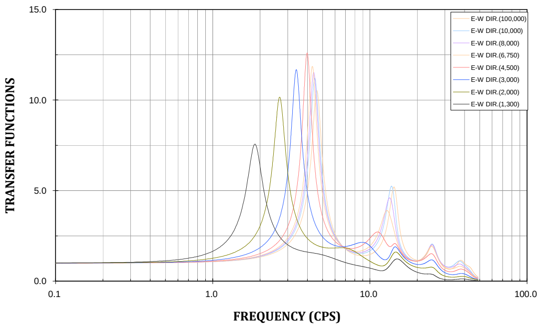


Fig. 1. Transfer Function for Containment Structure

Table II: Frequencies of Containment Structure

| Freq. / Vs | $f_U$ (Hz) | | $f_L$ (Hz) | |
|---|---|---|---|---|
| | Analysis | Calc. | Analysis | Calc. |
| 600m/sec | 3.61 | 3.28 | 2.10 | 2.59 |
| 900m/sec | 4.10 | 3.86 | 2.94 | 3.31 |
| 1350m/sec | 4.34 | 4.24 | 3.61 | 3.92 |
| 2050m/sec | 4.46 | 4.41 | 4.10 | 4.24 |

Table II shows frequencies of containment structure obtained by analyses and calculations. Fig. 2 and 3 show the frequency ratios, $f_U / f_1$ and $f_L / f_1$. As shown in Fig. 3 and 4, the differences of results obtained by two approaches are slight in the case of the containment structure.

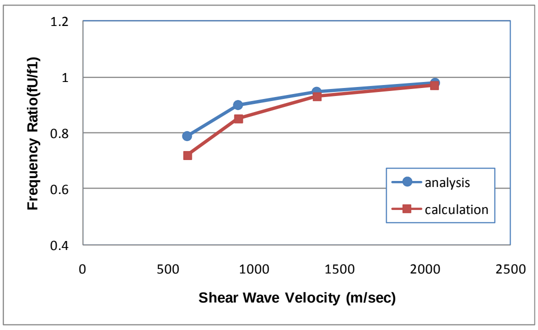


Fig. 2. Frequency Ratio, $f_U / f_1$

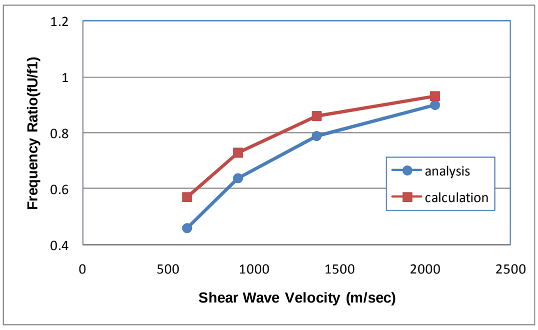


Fig. 3. Frequency Ratio, $f_L / f_1$

## 4. Conclusions

The formulae to estimate the upper bound and the lower bound frequencies according to the recommendations by EPRI [1] and ASCE [3] generally produce reasonable results when comparing the frequency results obtained by applying the approach that uses three SSI analyses to account for the soil variability. However, the frequency differencies are getting bigger when foundation soil properties are getting softer. Further study will be continuously preceded for the other typed structures and the different foundation soil conditions.

## REFERENCES

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