Sensitivity of Different SSI Parameters on the Floor Response Spectra of a Typical Nuclear Reactor Building

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ABSTRACT

The sensitivity of several critical soil-structure interaction (SSI) parameters on the floor response spectra (FRS) of a typical nuclear reactor building has been examined. These parameters are: computation of impedance functions using different approaches, deconvolution effects (reductions in ground motion with depth), and, strain dependency of soil dynamic properties.

1 INTRODUCTION

Seismic responses of buildings, founded on soil, are generally affected by the interactions between the soil and the structure. This is particularly true of nuclear reactor buildings founded on soil. The reactor buildings are typically massive, rigid reinforced concrete buildings with fundamental frequency in the range of 5-10 Hz. These buildings are also deeply embedded in the soil -- from 40 ft to 60 ft below grade. The seismic responses of such a building, embedded in a deep competent soil deposit (shear wave velocity range of 1000 - 2000 fps), are significantly affected by the SSI phenomena. In the current study, the effect of some of the SSI parameters on the floor acceleration response spectrum (FRS) were studied. The FRS is an important seismic response parameter for a nuclear reactor building as it is used as input for the seismic evaluation of equipment and piping.

2 DESCRIPTION OF THE REACTOR BUILDING AND THE SITE

The typical reactor building, chosen for this study, is a complex reinforced concrete building. It houses the reactor and associated equipment and piping needed for the operation of the reactor. This building is deeply embedded, and is supported on a 10 ft thick 220 ft by 230 ft base mat 52 ft below grade. The embedded portion of the building is reasonably regular and very stiff. It has thick perimeter and interior walls connected by thick competent floor slabs. The portion of the building above grade has an irregular outline consisting of various compartments, shafts and stairwells that extend to various elevations up to 148 ft above grade.

The geology of the site consists of a sandy soil deposit about 1,050 ft thick over basement rock. The low-strain shear wave velocities at the site,

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as derived from the borehole blow-count data, are presented in Table 1. This shows that the soil shear wave velocities in the upper 300 ft of soil are in the 740-1300 fps range.

3 SSI PARAMETERS

SSI effects will contribute significantly to the seismic responses of the reactor building. Embedment of the building in the soil will change the structural frequencies and mass participation factors from a fixed-base to a soil-structure system. Field observations have shown that free-field input motions, specified at the top of grade, vary and are generally reduced with depth below soil surface. Furthermore, the foundation mat of the reactor building, which is relatively rigid compared to the surrounding soil, filters out some of the high frequency content of the input motion. The dynamic soil properties, such as shear modulus and material damping, are functions of soil shear strain levels which vary with the seismic motions. The effects of all the above-mentioned phenomena, in general, reduce the SSI responses in the structure.

Calculation of soil impedances is a major part of SSI analysis and can affect SSI responses. The rigorous calculation of soil impedance functions, considering variations in soil dynamic properties with depth, i.e., soil layering effects, requires considerable numerical computations. There are also standard impedance functions reported in the literature which may be directly used in SSI calculations. Such functions are generally based on simplifying assumptions, but, may give reasonable results in many cases.

4 SSI MODELS

To study the effects of some of the phenomena described above, two SSI models of the reactor building were developed. The first model was developed using computer code SASSI (Lysmer, 1988). This model rigorously considers the soil layering effects in impedance calculations. The second model was developed using computer code AEC/LASSI (1990). This model uses empirical lumped-parameter soil impedance functions derived by Kausel (1979).

The SASSI model of the reactor building is presented in Figure 1. Since the circular foundation has two axes of symmetry, a quarter model, was developed for analysis. The embedded outer walls, between grade (elev. 0 ft) and top of the base mat (elev. -40 ft) and the 10-ft thick basemat were modeled with 8-node three dimensional solid elements. The soil within the embedded portion of the building, which has been excavated, was also modeled with 8-node three-dimensional solid elements. Soil below grade is modeled as a series of semi-infinite elastic horizontal layers over a semi-infinite elastic half-space.

The superstructure was modeled by a concentric lumped-mass model. The stiffness of the model between two elevations, included all the major structural walls. The stiffness of the equivalent beams in the model were specified by a shear area and moment of inertia. Mass of the concrete has been lumped at various elevations. The foundation mass of the reactor building was lumped at the node at elev. -20 ft. This node was then connected to the base mat at elev. -40 ft by rigid beams.

The lumped parameter model had the same superstructure configuration as the SASSI model. The effects of the soil, however, was represented by a 6 x 6 impedance matrix attached to the foundation mass node at elev. -20 ft.

5 SSI ANALYSES

Four cases were studied using the SASSI model. These cases are described below:

LN: Strain-independent, low-strain soil shear modulus and material damping were specified for different layers. The input time-history was specified at the foundation elevation of -50 ft, i.e. no modification of the motion due to deconvolution and scattering was considered.

HN: Strain-dependent (high strain) soil properties were used. No scattering was considered.

LS: Strain-independent, low-strain soil properties were used. The seismic input motion was specified at the free surface. Scattering and deconvolution effects were considered.

HS: The soil properties were specified to be the high-strain values. Scattering and deconvolution effects were considered.

The lumped-parameter (LP) model considered low-strain soil properties and no scattering effects. Since the lumped-parameter approach used only one value of soil shear modulus to calculate the soil impedances, the shear modulus values of different layers of Table 1 were averaged on a weighted basis to obtain the average shear modulus for the entire soil medium.

6 DISCUSSION OF RESULTS

Figures 2, and 3 present FRS at two elevations: elev. -20 ft, and elev. +148.67 ft. Elev. -20 ft corresponds to the center of mass of the embedded foundation, while elev. +148.67 ft corresponds to the top of the more flexible actuator tower.

Comparison of FRS for LP and LN cases in Figure 2 demonstrate the effects of rigorous vs. simplified modeling of soil impedances. These show that FRS for the two cases are close at lower elevation, but, at higher elevations significant difference occur. This is because the simplified empirical impedance formulations cannot always rigorously model soil layering effects, primarily for the rocking mode.

Comparison of LN and LS cases in Figure 3 demonstrates the effects of scattering. It is seen that significant reductions in the FRS occur due to scattering effects. Similarly, comparison of HN and HS cases again demonstrates the reductions due to scattering are significant. Comparison of FRS for LN and HN cases in Figure 3 demonstrates the effect of soil shear modulus reduction on the FRS. The high-strain case gives lower values consistently, but the reductions in the FRS are not significant in lower elevations. The FRS for LS and HS show similar trends.

7 CONCLUSIONS

The significant conclusions of the study, which are applicable to a deeply embedded very rigid nuclear reactor building, are as follows:

(1) The lumped-parameter approach of SSI calculations, which only uses a single value of soil shear modulus in impedance calculations, cannot properly compute the soil impedances for a soil deposit with irregularly varying properties with depth. An SSI approach, which can explicitly consider these variations, needs to be used in FRS calculations in such cases.

(2) FRS, generated considering strain-dependency of soil dynamic properties, are consistently lower than those generated using lower-strain values.

However, the differences between the two cases are not significant.

(3) FRS generated without considering scattering effects are highly conservative.

REFERENCES

Lysmer, J., et al., (1988). SASSI, A Computer Program for Dynamic Soil Structure Interaction Analysis, Users Manual, Vol. I.

Kausel, E., et al., (1979). Vertical and Torsional Stiffness of Cylindrical Footings, Publication No. R79-6, Dept. of Civil Engineering, MIT.

AEC/LASSI, (1990). A Lumped-Parameter Approach to Soil-Structure-Interaction Analysis, Users Manual.

Table 1. Soil Properties At The Site

		Low Strain			High Strain	
Layer No.	Thickness (ft)	v_s (fps)	G (ksf)	β (%)	G(ksf)	β (%)
1	50	1013	3827	5	2728	6
2	50	925	3189	5	1511	11
3	50	1155	4974	5	2735	9
Half Space	--	1500	8385	5	4625	9

V_s = Shear Wave Velocity
G = Shear Modulus
β = Soil Material Damping

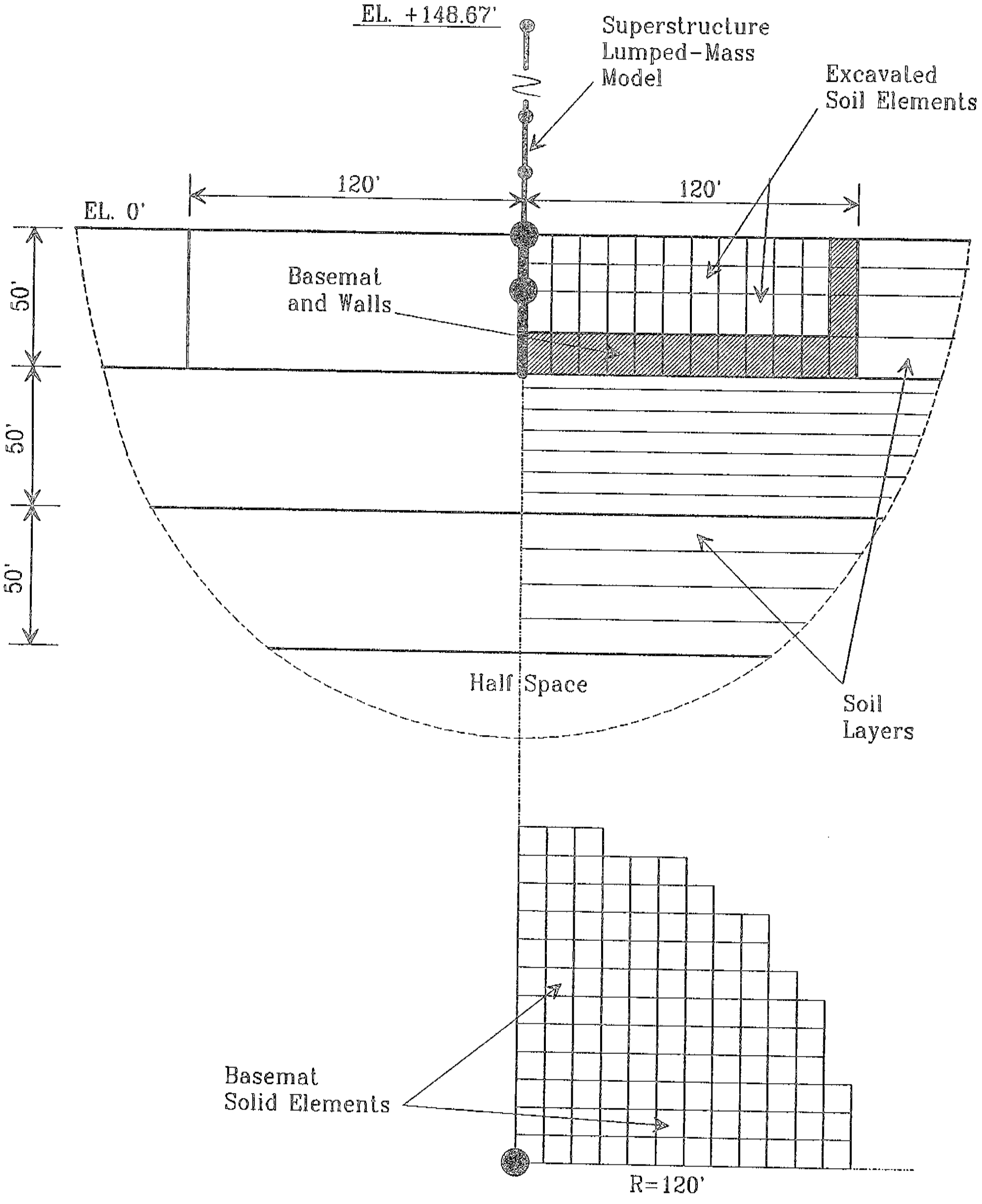

FIGURE 1 SASSI MODEL, GENERAL PLAN AND ELEVATION

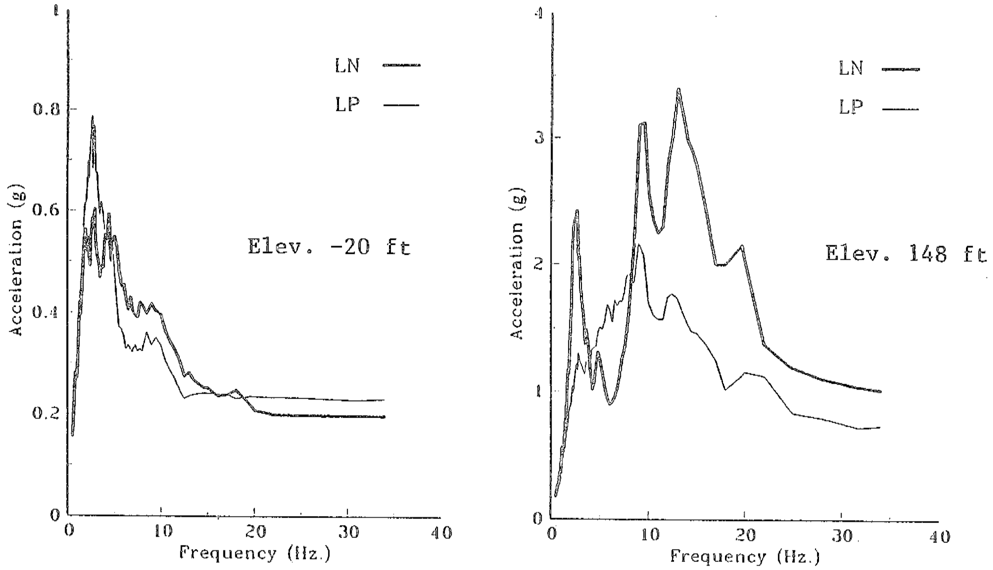

FIGURE 2 EFFECTS OF DIFFERENT SOIL IMPEDANCE FORMULATIONS ON FRS

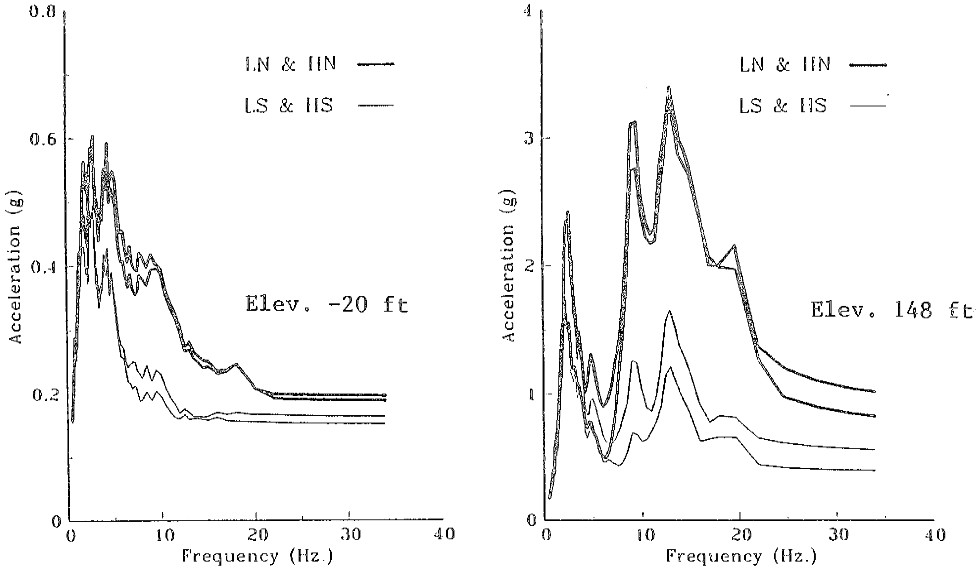

FIGURE 3 FRS FOR THE FOUR SASSI CASES