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A parametric study of SSSI effects for typical NPP structures

Lee, L.H., Lee, Y.I., Lee, G.H.
Korea Power Engineering Company, Inc., Seoul, Korea

ABSTRACT: This paper presents parametric study results of the dynamic structure-soil-structure interaction(SSSI) effects for typical nuclear power plant structures built in Korea. Three building structures and three site conditions are considered in the study. Distance ratio and mass ratio are considered as critical parameters. As a result, it is found that the effects of SSSI phenomenon are more significant for lighter structures with small distance ratios, and generally this phenomenon can be ignored for buildings with large distance ratios or for buildings founded on stiff stratum. However, if dynamic characteristics of the structure are similar to the adjacent structure, the structural response could be influenced by SSSI effects even though the buildings are on a stiff site. Therefore, the effects of SSSI should be considered for this condition.

1 INTRODUCTION

If buildings are in close proximity to each other, the seismic structural response may be affected by the vibration of adjacent structures through the soil. This phenomenon is denoted: structure-soil-structure interaction(SSSI); and is caused by coupling behavior of structures through the surrounding soil. It may be of potential significance at a nuclear power plant(NPP) because of small distances between the large massive structures.

Study of SSSI effects was first examined in the 1960's for the vibration effect of a rigid mass on an elastic half space to that of an adjacent mass. In the 1970's, two dimensional SSSI analyses were performed for several types of structures. In the 1980's, three dimensional analyses were performed, and secondary parameters such as building alignment effects and embedment effects of structures were evaluated. Generally speaking, however, this phenomena is somewhat beyond our comprehension with established studies showing reciprocal results from time to time.

In this study, the SSSI effects of a typical NPP structures in Korea is evaluated for various site conditions using a three dimensional SSSI analysis approach.

2 PARAMETRIC ANALYSIS

2.1 *Assumptions*

1. Buildings are in alignment.
2. The building basemat is rigid and bonded to the ground.
3. The building is surface-founded on an elastic half space site.

4. Behavior of soil and structure is linear elastic.
5. Seismic wave propagation is in the vertical direction.

2.2 *Parameters considered in the study*

Primary parameters in the SSSI study are relative distance and relative mass of the two structures. In addition, alignment of the basemat, direction of the seismic wave, and structure embedment are usually treated as secondary parameters for a SSSI study.

In this study, the primary parameters, i.e. distance ratio and mass ratio, are considered for the three structure combinations: containment-fuel(CB-FB), containment-auxiliary(CB-AB), and fuel-auxiliary(FB-AB) buildings, and for three site conditions: stiff soil(SS), soft rock(SR) and medium rock(MR).

The center to center distance ratio(DR) considered in the analyses are 1.0, 1.5, 2.0, and 3.0 times the diameter of the containment basemat. The mass ratios of the fuel building and auxiliary building to the containment building are 0.35 and 2.90, respectively.

2.3 *Building descriptions and analytical model*

The containment building consists of a cylindrical shell having a hemispherical dome and reinforced concrete internal structures. The entire structure is founded on a circular reinforced concrete slab which is 49m in diameter. The auxiliary building is a conventional reinforced concrete shear wall structure 39m in height and has a basemat size of 99m × 67m. The fuel building is also a reinforced concrete shear wall structure 29m in height and has a basemat size of 33m × 38m.

Building structures are idealized as lumped mass stick models as shown in Figure 1. In structural modeling, equipment masses and pool water masses are lumped at the proper locations in the structural model. Table 1 shows the fundamental frequency of the structures and their total weights.

The foundation model for the rigid foundation assumption is shown in Figure 2 where the discretization is that used in the calculation of the impedance functions representing dynamic stiffness and damping of the site.

2.4 *Site conditions*

Site conditions considered in the study are stiff soil, highly weathered rock classified as soft rock and moderately weathered rock classified as medium rock. Site properties are shown in Table 2.

2.5 *Seismic input motion*

The seismic input motions used in the study are artificially generated acceleration time histories having a duration of 20 seconds, a time step of 0.005 seconds and peak ground acceleration of 0.2g. These motions satisfy the regulatory requirements of U.S. Nuclear Regulatory Commissions(NRC), and meet the statistical independence criteria. Figure 3 shows an artificial acceleration time history subjected to the direction of the building alignment line.

2.6 *Method of analysis*

The substructure method of analysis is utilized to solve the SSSI problems. There are three steps in the analysis: 1) determination of foundation input motion, 2) determination of foundation impedance functions, and 3) analysis of the coupled soil-structure system.

For the analyses, the computer program SMACS is utilized. SMACS is a CLASSI-family program developed by Wong and Luco, and was developed during the project titled "Seismic Safety Margin Research Program" fund by the USNRC.

3 DISCUSSIONS

As the results of the prescribed parametric SSSI analyses, 5% damping floor response spectra(FRS) are generated at the top of each structure. The evaluations of the SSSI effects are made by comparing the FRS.

Figures 4 and 5 show the FRS comparison at the top of containment dome and fuel building for the case of a distance ratio of 1.0 with a stiff soil site. It can be seen from the figures that SSSI effects have a significant influence on the fuel building response which is the smaller structure in the analysis. However, SSSI effects dramatically deceased as the distance ratio and soil stiffness increase as shown in Figures 6 and 7. Similar trends can also be found in SSSI analysis for the combination of containment and auxiliary building as shown in Figures 8.

From the above results, it is generally concluded that the SSSI effects influence the response of a smaller structure founded on a soil site when a larger structure is in close proximity, while it can be ignored if the center to center distance of the two basemats is larger than 1.5 times the containment basemat dimension, or for buildings founded on rock sites.

On the other hand, the response of the containment internal structure is significantly affected by SSSI phenomena under conditions of a medium rock site and distance ratio of 1.5 (Figure 9) than under the conditions of a soil site and distance ratio of 1.0 (Figure 10). The same trend can be found in the response of the fuel building for the same conditions as noted above (Figure 11). It is judged that, in the soil site, the frequency of the containment internal structure differs from that of the fuel building due to coupling effect of the internal structure with the containment shell and foundation. However, in the rock sites, resonance effects due to the similar frequencies of the two structures appears since the internal structural mode becomes isolated from the containment shell and basemat as the site stratum becomes stiffer. Therefore, if the dynamic characteristics of the adjacent two structures are similar, the SSSI effect must be checked carefully.

Figure 12 shows the mass effect of the adjacent structure. As can be seen from the figure, the response of the fuel building changes as the adjacent structure mass increases. In addition, the SSSI effects have a different trend between the low and high frequency range of the FRS. In the low frequency range which is considered the more soil-dominant mode, SSSI effects reduce the peak response, while in the high frequency range which is considered the more structure-dominant mode, SSSI effects increase the peak response. It is judged that the reason of these trends is due to surcharge effects for the adjacent structure.

4 CONCLUSION

In this study, various parametric studies to evaluate SSSI effects are performed for closely spaced typical NPP structures. As a result, the following conclusions can be drawn:

1. SSSI effects influence the response of relatively light structures while response of heavier structures is not affected.
2. SSSI effects are minor when the distance between the two foundation centers is greater than 1.5 times the larger foundation diameter or the site conditions are stiff.

3. When structures that have similar dynamic characteristics are in close proximity to each other the SSSI effects appear in response when site stiffness increases.

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Table 1. Building properties

Structure		Fundamental Frequency (Hz)	Total Weights (ton)
Containment Building(CB)	Shell & Dome	4.5	68,200
	Internal Str.	12.0	
Auxiliary Building (AB)		6.2	197,500
Fuel Building (FB)		11.8	24,200

Table 2. Site properties

Properties	Stiff Soil (SS)	Soft Rock (SR)	Medium Rock (MR)
Unit Weight (t/m^3)	2.1	2.3	2.5
Possion's Ratio	0.35	0.25	0.20
Shear Wave Velocity (m/s)	300	600	1,100
Material Damping	10%	5%	2%

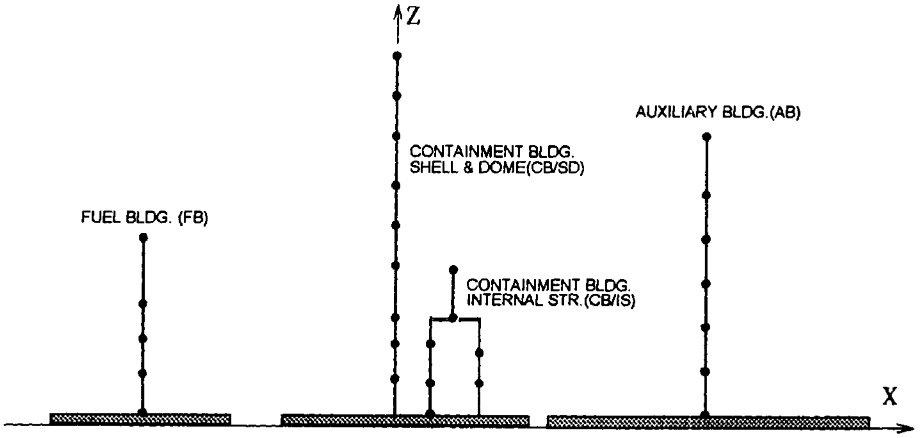

Fig. 1. Building structure model

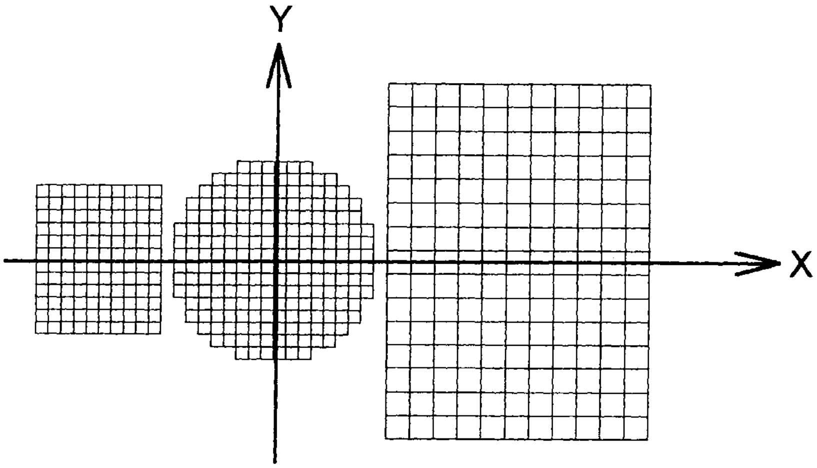

Fig. 2. Building foundation model

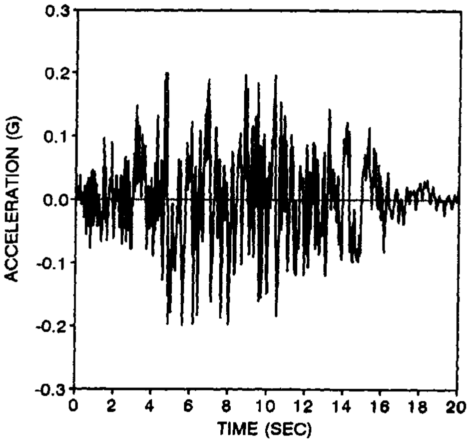

Fig. 3. Typical seismic input motion

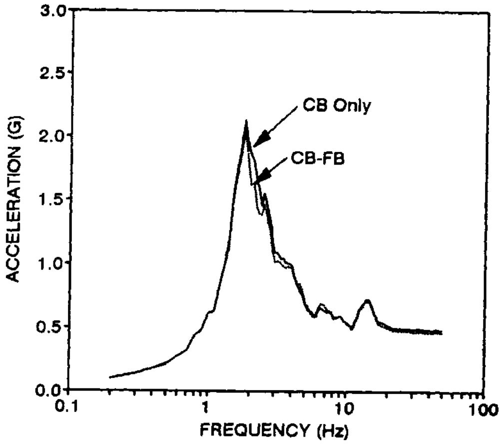

Fig. 4. FRS comparison at cont. dome
(CB-FB, SS, DR=1.0)

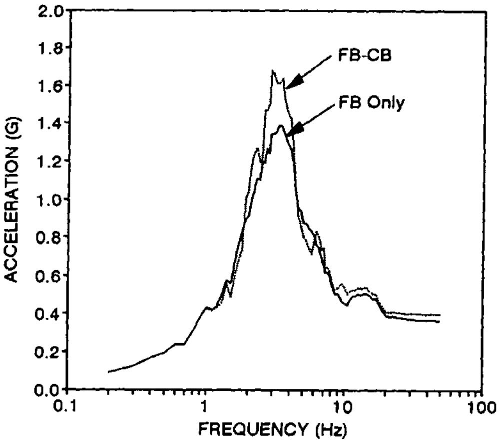

Fig. 5. FRS comparison at fuel bldg.
(FB-CB, SS, DR=1.0)

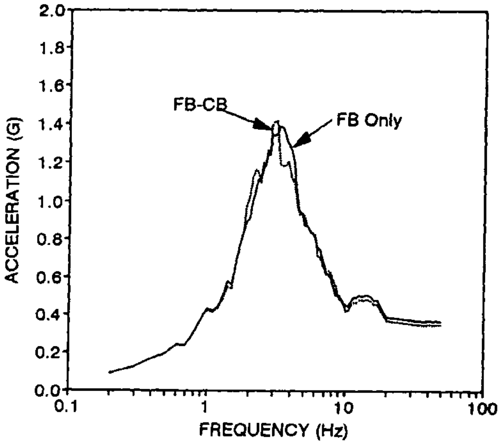

Fig. 6. FRS comparison at fuel bldg.
(FB-CB, SS, DR=1.5)

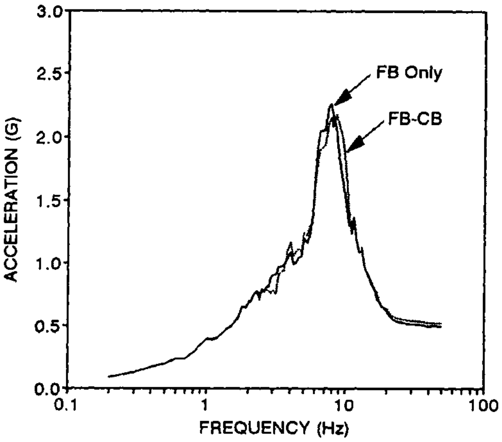

Fig. 7. FRS comparison at fuel bldg.
(FB-CB, SR, DR=1.0)

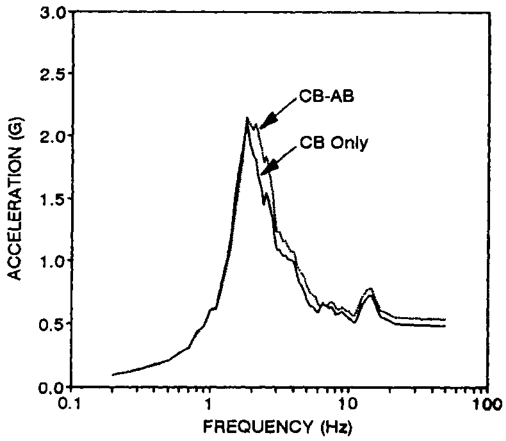

Fig. 8. FRS comparison at cont. dome
(CB-AB, SS, DR=1.5)

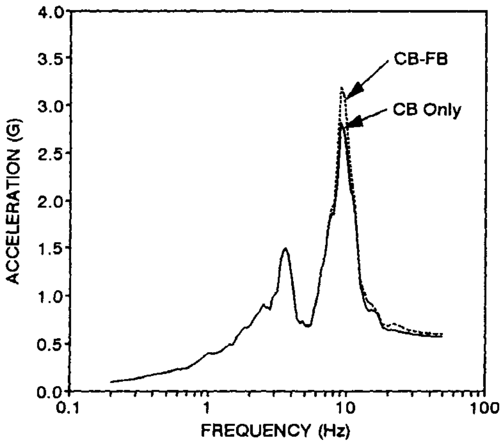

Fig. 9. FRS comparison at cont. internal
(CB-FB, MR, DR=1.5)

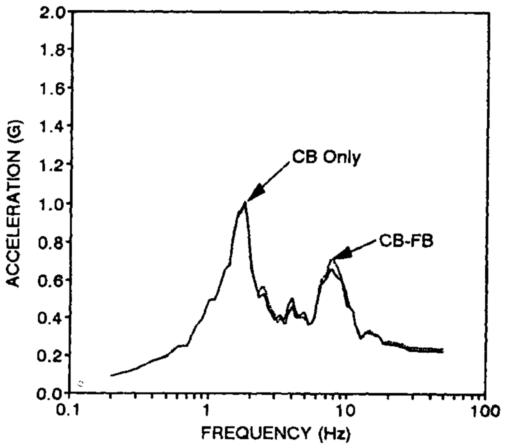

Fig. 10. FRS comparison at cont. internal
(CB-FB, SS, DR=1.0)

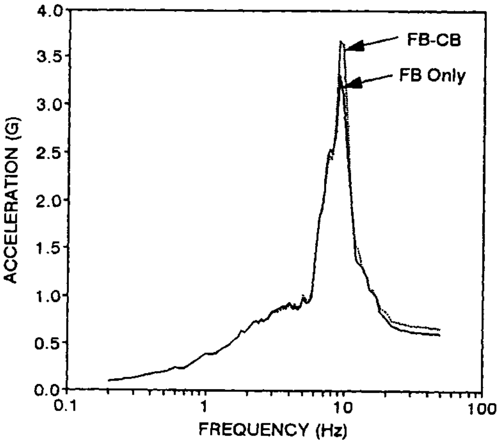

Fig. 11. FRS comparison at fuel bldg.
(FB-CB, MR, DR=1.5)

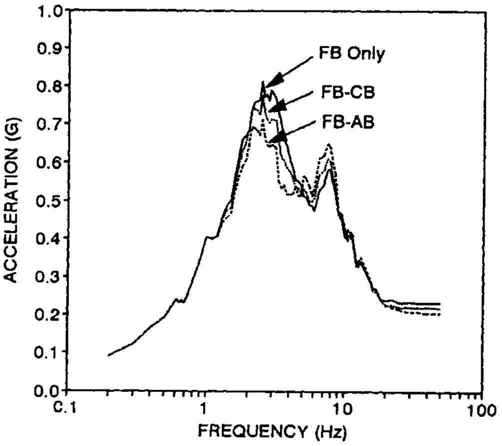

Fig. 12. FRS comparison at fuel bldg.
(FB-CB & FB-AB, SS, DR=1.5)