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Seismic response characteristics of embedded structures considering cross interaction

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ABSTRACT: The seismic response characteristics of an embedded nuclear reactor building considering through-the-soil cross-interaction effects of adjacent structures have been evaluated using three analysis methods. The dynamic response characteristics of the reactor building may be affected by the existence of adjacent heavy building and soil between the structures.

1 INTRODUCTION

A detailed understanding of dynamic interaction effects is required in aseismic design of structures. These effects may be very important in particular for the large-scale massive structures. In the evaluation of dynamic characteristics of closely spaced structures as typically seen in a nuclear power plant, it may be necessary to consider the effects of dynamic cross-interaction among the structures in addition to the interaction effects between the soil and individual structure. Especially through-the-soil cross-interaction effects may be expected to be significant when the structures have portions embedded in the ground.

In the present study, the authors attempt to evaluate the seismic response characteristics of an embedded nuclear reactor building considering the cross-interaction effects of adjacent structures. The layout of the structures to be analyzed is illustrated in Fig. 1. These three buildings are assumed to be embedded in a two-layered elastic half space.

Three analysis methods are employed in this study; three dimensional boundary element method (3D-BEM), two dimensional finite element method (2D-FEM), and the so-called sway-rocking method (SR). After verifying the validity of these three methods of analysis, the effects of the number of the adjacent structures, the vibrating directions, and the influences of the existence of soil between the structures on the dynamic response characteristics of the reactor building, are mainly discussed.

2 OUTLINE OF ANALYSIS METHODS

The dynamic response of the reactor building (abbreviated as R/B in figures) constructed close to the turbine building (as T/B) and the control building (as C/B) are analyzed in this study. Figure 1 shows the geometry of these three buildings. The surrounding soil of the structures is assumed to comprise a surface layer and a supporting half space. The physical properties of the soil are also indicated in the Fig. 1. An

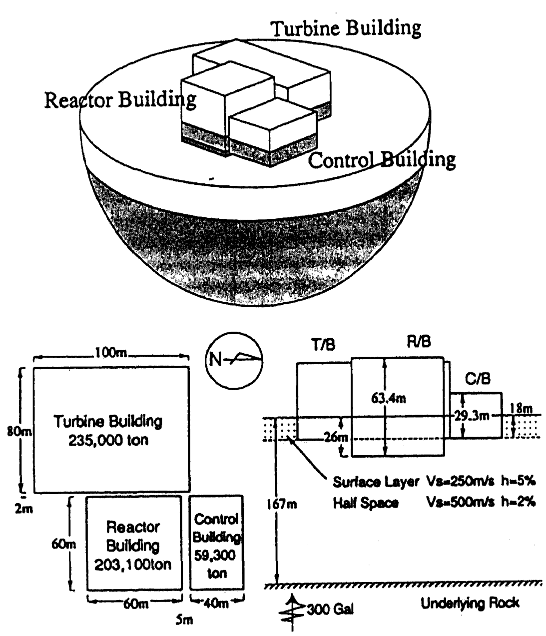

Fig.1 Building layout of analysis model

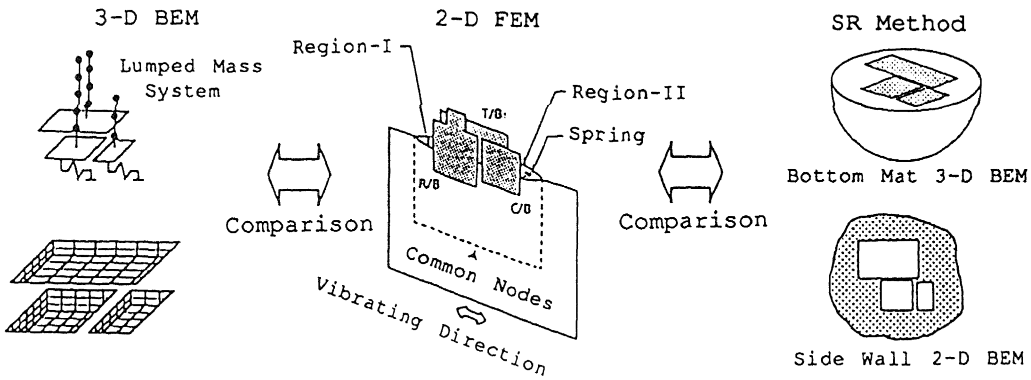

Fig.2 Outline of three analysis methods

artificially generated motion is employed here as the input earthquake motion. The input motion, whose maximum acceleration is normalized to be 300 cm/sec^2, is prescribed at 167 m in depth from the ground surface.

The three buildings are modeled by the lumped-mass systems. The 3-D BEM, the 2-D FEM, and the sway-rocking method are employed to evaluate structure-soil-structure interaction effects. The branch model is used in the 2-D FEM analysis to account for the three dimensional interaction effects between the structures (Emori et al. 1983). The transmitting boundaries on both sides of the finite element region and the viscous boundary on the bottom are considered. The viscous boundary in the anti-plane direction is considered to add three dimensional effects in the 2-D FEM analysis.

In the sway-rocking model, the cross-interaction effects are evaluated through the surface layer and through the supporting half space separately. The whole impedance matrix is constructed by the combination of the side wall impedance calculated by the 2-D BEM and the bottom mat impedance evaluated by the 3-D BEM model without considering embedments (Tanaka et al. 1986). The soil between the structures is modeled by the soil-column and the rigidity of each soil-column is included in the whole impedance matrix. The foundation input motions to the employed sway-rocking analysis are calculated with the aid of the one-dimensional wave propagation theory (Yano et al. 1988).

The 3-D BEM can evaluate the cross interaction effects rigorously (Yoshida and Takahashi 1988). It is true, however, that it has some computational restrictions as for the realistic modeling in the high frequency range. The conceptual figures of these three analysis methods are illustrated in Fig. 2.

3 NUMERICAL RESULTS AND DISCUSSIONS

3.1 Verification of analysis methods

To verify the validity of the employed methods of analysis, comparisons of the transfer functions and the maximum response acceleration using the single-reactor model and the three-building model are made. In the following analyses, the embedded portions of the structures are supposed to be rigid and the foundations are assumed to be bonded to the surrounding soil. Figure 3 shows the transfer functions to the input motion for the single-reactor model and figure 4 indicates the maximum acceleration of the reactor building evaluated by these three methods. From these figures, though the sway-rocking method tends to give slightly conservative results, it can be seen that the results by the 2-D FEM and the sway-rocking method show good agreements with those by the 3-D BEM.

The transfer functions and the distributions of the maximum acceleration of the reactor building for the three building model are presented in Figs. 5 and 6, respectively. These figures show the analysis results in the N-S direction. The results by the 2-D FEM and the sway-rocking method exhibit fair agreements with those by the 3-D BEM in this case as well. The validity of the results by the 2-D FEM and the sway-rocking method employed in this study may be certificated through the comparison with the results by the 3-D BEM which can evaluate the cross interaction effects rigorously.

3.2 Effects of number of structures and vibrating directions

It is expected that the dynamic characteristics of the reactor building may vary with the number and the properties of the adjacent buildings. Studies on the number of the adjacent buildings and the

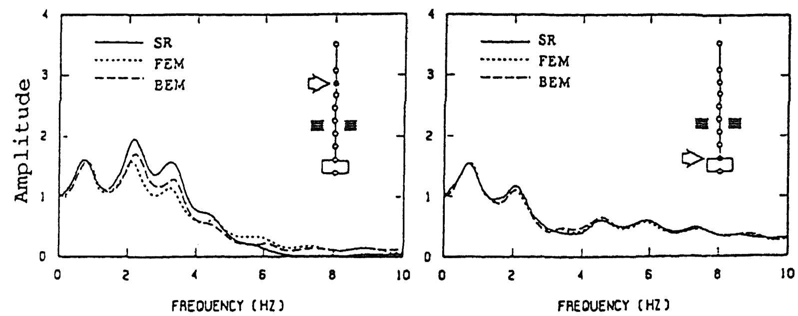

Fig.3 Transfer functions of R/B for single R/B model

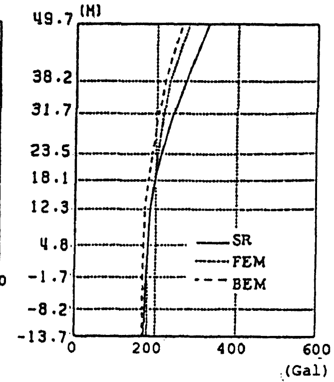

Fig.4 Maximum response acceleration of R/B single R/B model

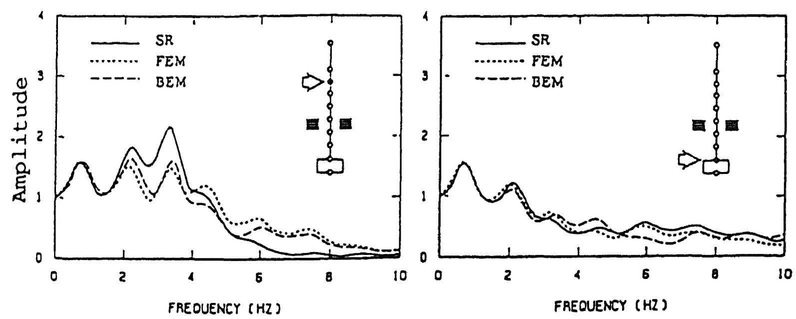

Fig.5 Transfer functions of R/B for three building model

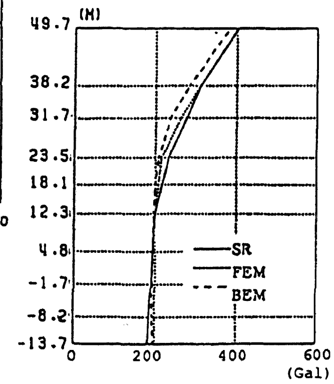

Fig.6 Maximum mesponse acceleration of R/B three building model (N-S direction)

effects of the vibrating directions are carried out using the 2-D FEM. The embedded portions of the structures are assumed to be flexible. An example of the mesh layout employed in the 2-D FEM is illustrated in Fig. 7. The transfer functions of the reactor building are presented in Fig. 8 for N-S direction and Fig. 9 for E-W direction, respectively. The maximum response acceleration and shear forces are also shown in Figs. 10 and 11. It should be noted from these figures that as the number of adjacent buildings increases, the response values of the reactor building above the ground level become large. On the other hand, the response shear forces of the embedded portion become small.

With regard to the vibrating direction, when the analysis is performed in E-W direction, that is, the turbine building exists in the longitudinal direction of the reactor building, the response values of the reactor building show little dependence on the existence of the transverse control building. On the other hand, when the turbine is in the transverse direction (N-S direction), however, the response values depend strongly on the existence of the turbine building. It may be concluded from these facts that a comparatively heavy building gives large effects on the dynamic response characteristics of the reactor building in spite of its vibrating direction.

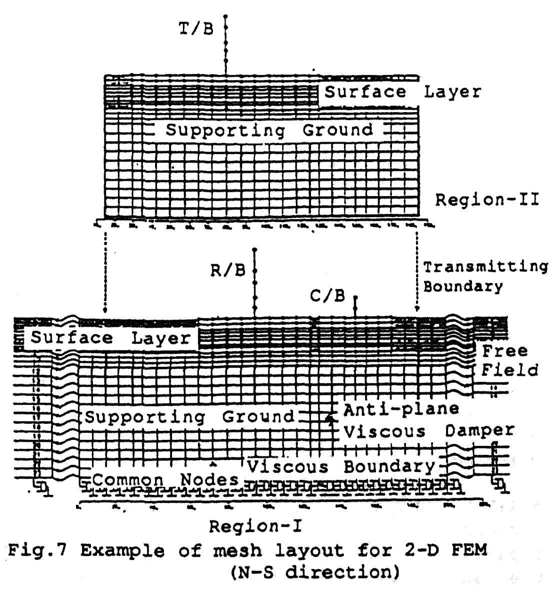

Fig.7 Example of mesh layout for 2-D FEM (N-S direction)

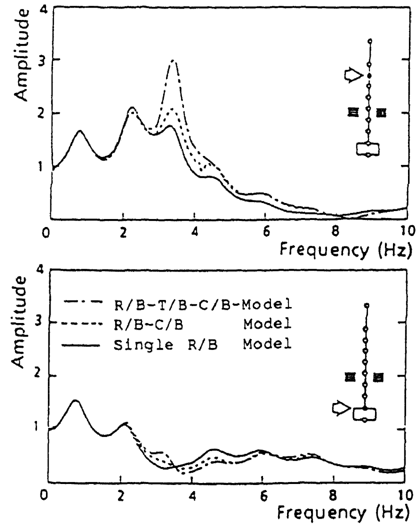

Fig.8 Transfer functions of R/B
(N-S direction)

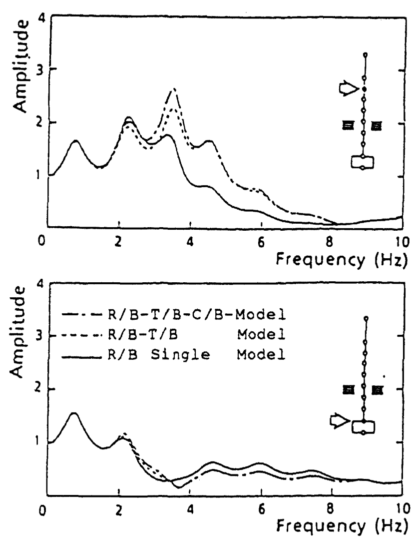

Fig.9 Transfer functions of R/B
(E-W direction)

3.3 Influences of soil between structures

The influences of the existence of soil between structures are investigated using the sway-rocking method. The embedded portions of the structures are assumed to be flexible and the friction between the foundations and the surrounding soil is neglected in the analysis. Three analysis models considered are shown in Fig. 12: model fully filled with the soil between the structures (called as Fully Filled Model in figures), model filled with the soil between the reactor and the control building but no

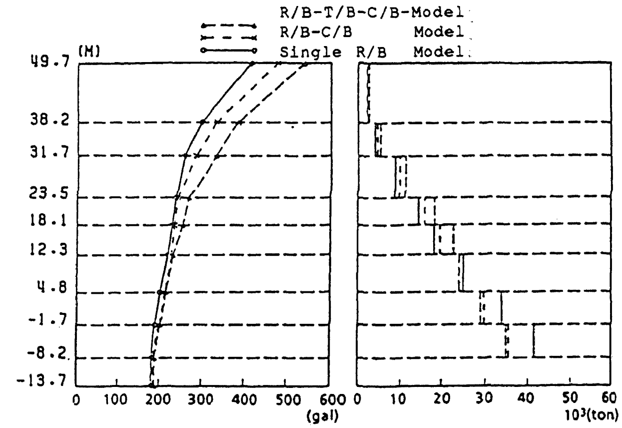

Fig.10 Maximum response acceleration and shear forces of R/B (N-S direction)

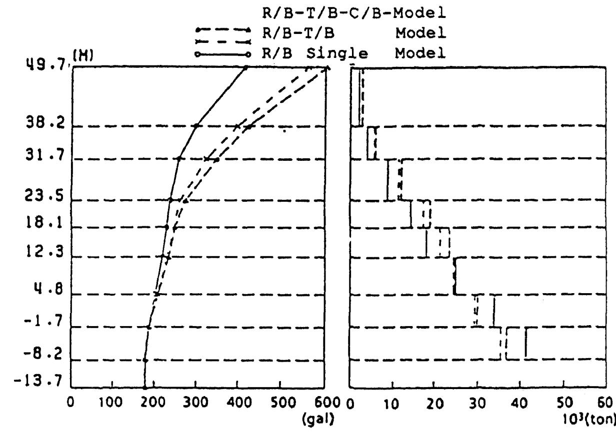

Fig.11 Maximum response acceleration and shear forces of R/B (E-W direction)

soil between the reactor and the turbine building (as Partially Filled Model), and model without the soil between the structures (as Separated Model).

Figure 13 presents the transfer functions of each structure to the input motion at the ground level in N-S direction. It is clear from this figure that the soil between the structures gives some effects to average the dynamic response characteristics of each structure. The distributions of the maximum acceleration and shear forces of the reactor building are presented in Figs. 14. It can be recognized from these figures that the maximum acceleration of the embedded portions doesn't depend on the existence of soil between the structures, while the acceleration of upper structure does. It should be noted that the maximum shear forces under the ground level show the smallest values in the case of the fully filled model.

This work shows that the existence of soil between structures changes the dynamic characteristics of each structure. Also it indicates that the seismic response values of the structures are influenced by the cross-interaction effects through the soil between the structures.

3.4 Earhtquake response characteristics of T/B and C/B

In the above sections the earthquake response characteristics of R/B are discussed. In this section, those of the remaining T/B and C/B are briefly described.

In Figs. 15 and 16, the distribution of the maximum acceleration and the shear forces of T/B and C/B are shown for the cases of the fully filled model and the separated model for NS direction based on the S/R model. In these figures, the results are compared with those of the single models of each structure. The maximum acceleration of the embedded portions of T/B are almost the same for all cases, but those of upper structure are affected by the cross interaction through the soil. The same trends are seen for C/B. It should be emphasized that the shear forces of the embedded portions of T/B and C/B are the smallest in the case of the fully filled model and the largest in the case of each

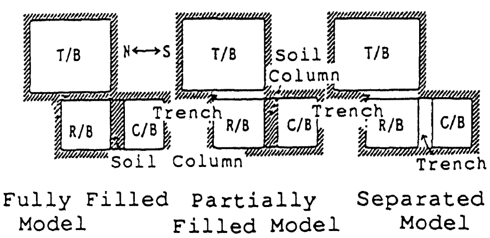

Fig.12 Analysis model employed in SR method

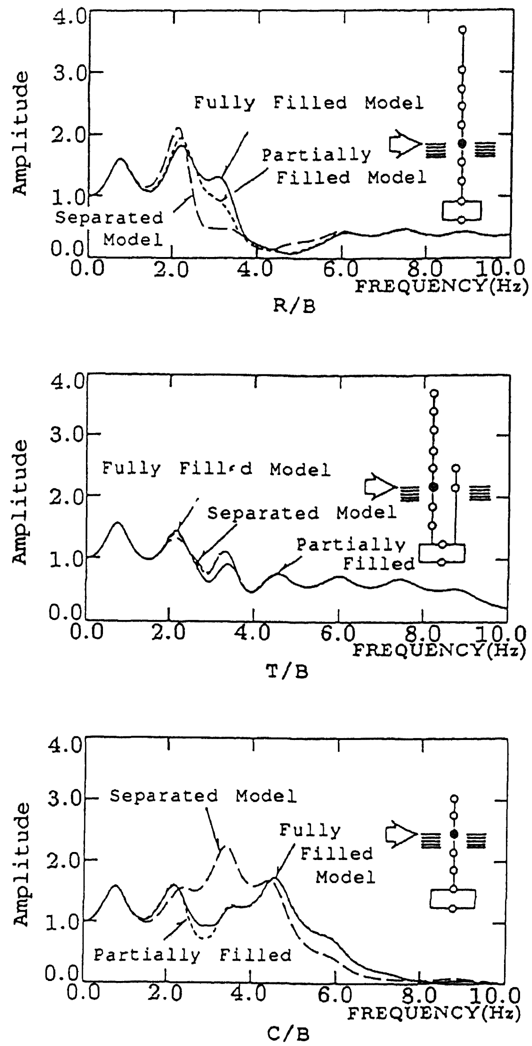

Fig.13 Transfer functions of each structure at ground level (N-S direction)

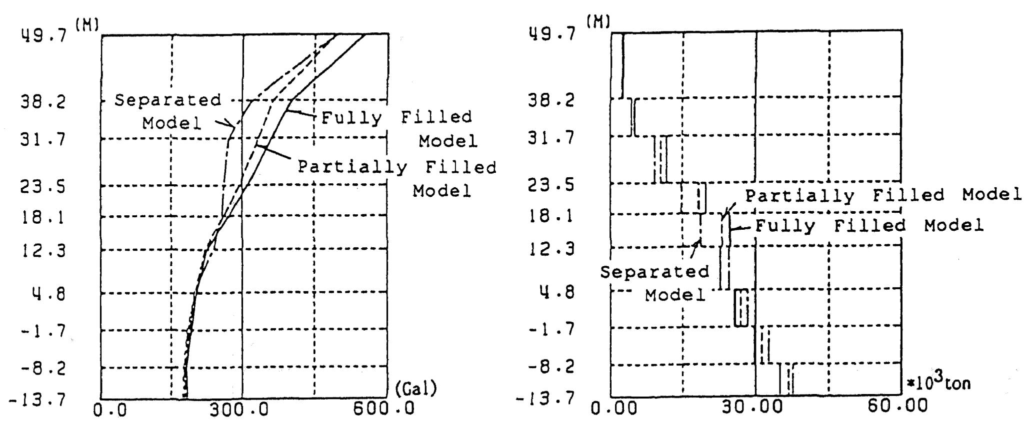

Fig.14 Maximum response acceleration and shear forces of R/B

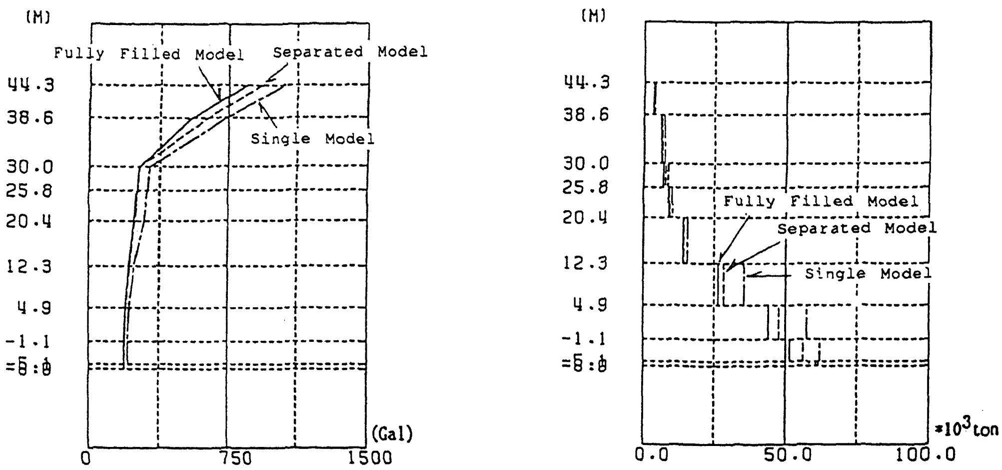

Fig.15 Maximum response acceleration and shear forces of T/B

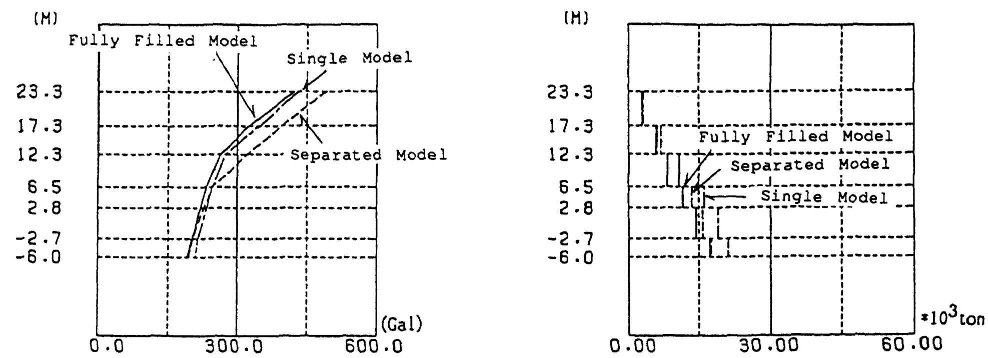

Fig.16 Maximum response acceleration and shear forces of C/B

single model. As described before, the same result is recognized for R/B with regard to the shear forces of the embedded portion.

It is suggested that the shear forces of the embedded portions are directly affected by the contact area of the structure with the surrounding soil.

4 CONCLUSIONS

The seismic response characteristics of an embedded nuclear reactor building considering through-the-soil cross-interaction effects of adjacent structures have been evaluated in the present paper. It has been shown that the dynamic response characteristics of the reactor building may be affected by the existence of adjacent heavy building and soil between the structures.

REFERENCES

Emori,T. et al. 1983. Study on the Interaction Analysis of the Soil and Structure with Stepped Mat Foundation. Proceedings of the Fifth Symposium on the Use of Computers in Building Engineering, Architectural Institute of Japan: 175-180 (in Japanese).

Tanaka, H. et al. 1986. Study on the Dynamic Cross Interaction for the Embedded Structures. Proceedings of the Seventh Japan Earthquake Engineering Symposium: 1009-1014.

Yano, A. et al. 1988. Seismic Design Model of Embedded Structures. Proceedings of the Ninth World Conference on Earthquake Engineering, Vol.VIII: 353-358.

Yoshida, K. and Takahashi, I. 1988. Dynamic Characteristics of an Embedded Foundation in a Multi-layered Half Space. Proceedings of Annual Meeting of Architectural Institute of Japan: 791-792 (in Japanese).