Wave Scattering Effect in Soil-Structure Interaction

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1 INTRODUCTION

For solving a three-dimensional soil-structure interaction in practical way, the authors have been developing a series of computer codes HASSI(from version 1 to 7) under a hybrid concept in which the dynamic properties of the structure and a finite region of the foundation soil in the near-field surrounding the foundation are modelled with finite elements; and the dynamic characteristics of the far-field are represented by a complex frequency-dependent boundary impedance matrix at the hemispherical near-field boundary.

The latest version, HASSI-7, can consider the nonlinear behavior of soil by the equivalent linearization method which is popular in frequency domain method of analysis. Through many correlation studies using Lotung and Kazusaminato experimental data, it has been shown that HASSI-program approach can effectively predict the dynamic response of a three-dimensional soil - structure system under either forced vibration or earthquake excitation (Penzien et al. 1987; Katayama. 1988; Katayama et al. 1989).

The previous HASSI computer programs have been assuming the spatial variations of the free-field motions over the cavity surface are negligible, thus defining a uniform three-component time-history over the structure-soil interface(hereafter called as "rigid base assumption"); and its application to actual soil-structure system may give erroneous results when the radius of the foundation cavity and/or the embedment depth are not negligibly small relative to the wave length of components of free-field ground motions significant for the system. To avoid such error, the computer program HASSI-8 has been developed which implements into HASSI-7 the rigorous formulation recognizing the spatial variations of the free-field ground motions over the cavity surface left upon removal of the structure, including wave scattering effects(hereafter called as "flexible base assumption").

Through analyses of a typical prototype reactor building and foundation system by the both HASSI-7 and HASSI-8, the possible influence of variation of input free-field motions and wave scattering effects on the response of the soil-structure system are examined.

2 OUTLINE OF MODELLING FOR WAVE SCATTERING

Following the substructuring method already used in HASSI-7, the complete near-field system, as shown in Fig. 1, is divided into Regions S, I, and N, and is subjected to the total interaction forces $\underline{P}_f^t$ on the hemispherical N/F interface. The total forces and the resulting total displacements $\underline{u}_j^t$(j=b,c,i,e,n, and f) within the regions and at the interfaces in Fig. 1 include the effects of free-field motion, soil-structure interaction, and wave scattering.

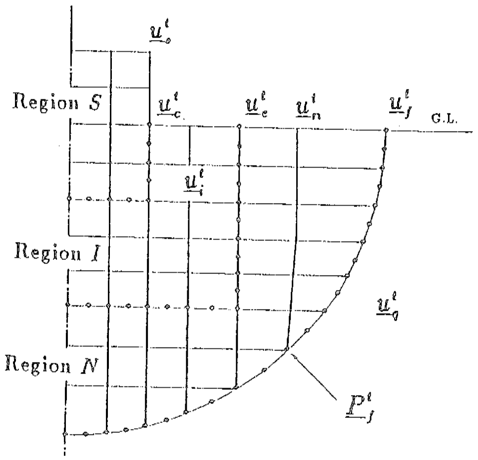

Fig. 1 Complete near-field system

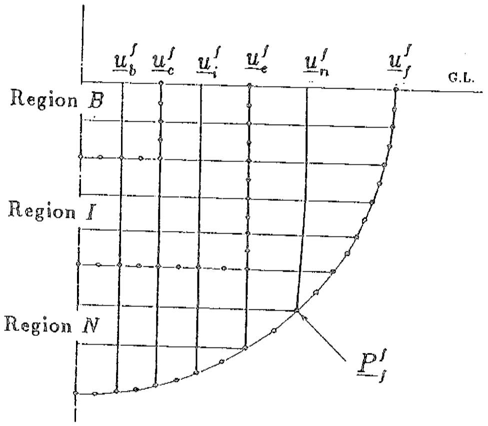

Fig. 2 Free-field system

Consider here the near-field soil system without any surface cavity, as is shown in Fig. 2, subjected to the earthquake excitation forces $\underline{P}_f^f$ at the hemispherical boundary, where $\underline{u}_j^f$(j=b,c,i,e,n, and f) represents each free-field displacement within respective region or interface.

When the region N is isolated from the above free-field soil system and making the Regions S and I as the substructure system being connected at the interface "e" with the free-field system after excavation of Regions B and I in Fig. 2, the equations of motions for the complete system in Fig. 1 can be converted into the form as

$$\begin{bmatrix} S_{oo}^S & S_{oc}^S & 0 & 0 & 0 & 0 \\ S_{co}^S & S_{cc}^{SI} & S_{ci}^I & S_{ce}^I & 0 & 0 \\ 0 & S_{ic}^I & S_{ii}^I & S_{ie}^I & 0 & 0 \\ 0 & S_{ec}^I & S_{ei}^I & S_{ee}^{IN} & S_{en}^N & S_{ef}^N \\ 0 & 0 & 0 & S_{ne}^N & S_{nn}^N & S_{nf}^N \\ 0 & 0 & 0 & S_{fe}^N & S_{fn}^N & (S_{ff}^N + G_{ff}) \end{bmatrix} \begin{Bmatrix} \underline{u}_o^t \\ \underline{u}_c^t \\ \underline{u}_i^t \\ \underline{u}_e^t \\ (\underline{u}_n^t - \underline{u}_n^f) \\ (\underline{u}_f^t - \underline{u}_f^f) \end{Bmatrix} = \begin{bmatrix} 0 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & -S_{en}^N & -S_{ef}^N \\ S_{ne}^N & 0 & 0 \\ S_{fe}^N & 0 & 0 \end{bmatrix} \begin{Bmatrix} \underline{u}_e^f \\ \underline{u}_n^f \\ \underline{u}_f^f \end{Bmatrix}$$

,

where the S matrices are the assembled impedance matrices corresponding to each region as shown in Fig. 1.

The force $\underline{P}_f^t$ in Fig. 1 can be expressed by using the far-field boundary impedance matrix G_{ff} to represent the near-field/far-field interface forces caused by SSI and scattering(due to embedment), but not including the free-field interface forces as

$$\underline{P}_f^t = \underline{P}_f^f - G_{ff}(\underline{u}_f^t - \underline{u}_f^f).$$

Because $\underline{u}_e^f$, $\underline{u}_n^f$, and $\underline{u}_f^f$ obtained from the free-field soil response analysis, this equation can be solved giving the total displacements in the DOF's of "s", "c", "i", and "e", and the relative displacements in the DOF's of "n" and "f". From what has been described, the general procedure leading to the formulation of this equation has considered the spatial variations of the free-field ground motions and has included the effects of both SSI and wave scattering.

The field observation records obtained at Model 2C of Kazusaminato site were again simulated by HASSI-8 and the results were almost identical to those obtained by HASSI-7 that had been reported in Katayama et al(1988); the capability to consider the wave scattering effects may not be effectively confirmed by the data because of small dimension and embedment of the model, however, the designated function implemented here was found as working well.

3 WAVE SCATTERING EFFECT EXPECTED FOR PROTOTYPE CONTAINMENT BUILDING

To estimate possible wave scattering effects on the response of prototype containment buildings of PWRs, a numerical soil-structure model as shown in Fig. 3 was adopted. The concrete cylindrical building of radius 19.5 m, height 72 m with embedment 19.5 m, wall thickness 1.0 m, and total weight 54,000 tons is representing a typical PWR reactor building. The foundation medium was assumed homogeneous and designated to have shear wave velocity of 250 m/s, 500 m/s, and 1,000 m/s, corresponding to each analysis model having identification name M1, M2, and M3. A three-component input ground motion was arbitralily selected and used for obtaining mainly transfer functions of the system. The analyses are assuming linear system and the maximum effective frequency range of results is 16 Hz.

Fig. 4 shows the acceleration responses of the top of the building (node 1) for the models; in case of rigid base assumption, the maximum accelerations of the structure (in solid lines) will become larger than in the cases of flexible base assumption, probably due to fictitious excitation by a single free-field ground motion at

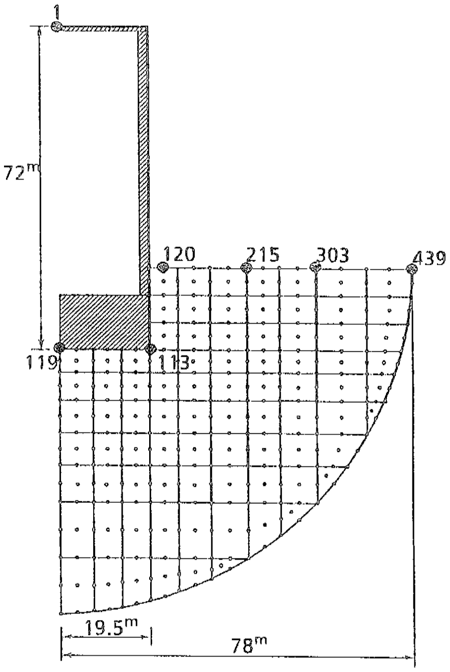

Fig. 3 Numerical model of PWR Reactor building

structure/soil interface. This tendency is most remarkable in the model M1 which has foundation soil of the minimum shear wave velocity among the models. Acceleration amplitude transfer functions of the models are shown in Fig. 5; the transfer function of M1 by rigid base assumption shows a remarkable amplification of high frequency components, which is consistent with the above results in response time-histories.

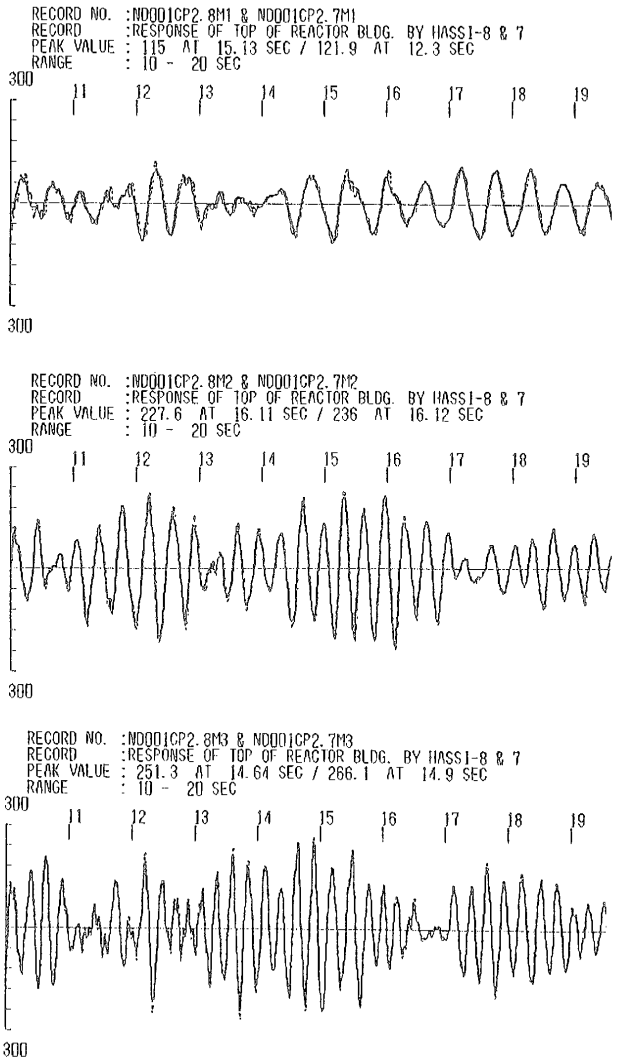

Fig. 4 Acceleration responses of Node 1 of Fig. 3; solid and chained line corresponds HASSI-8 and 7.

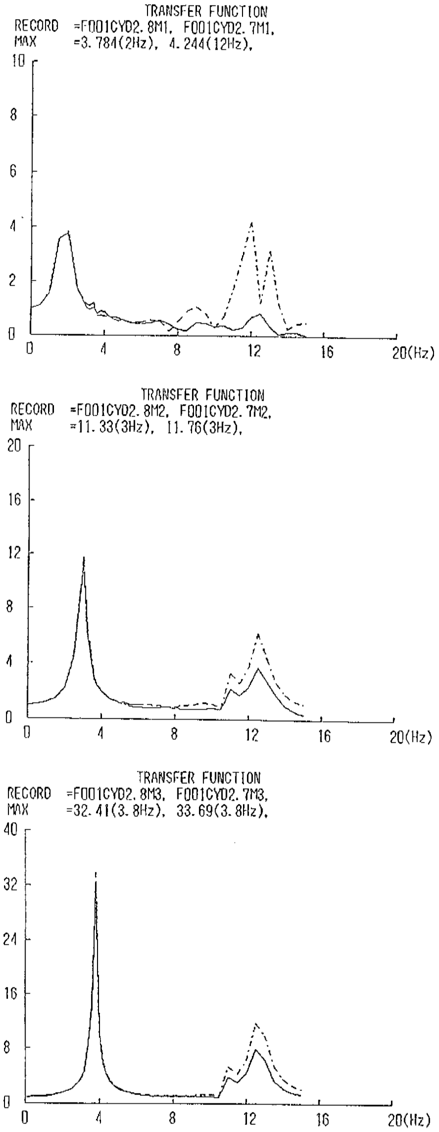

Fig. 5 Transfer functions of Node 1; line classification is same as Fig. 4.

Fig. 6 compares the acceleration amplitude transfer functions of the nodes of ground surface shown in Fig. 3; the rigid base assumption might have

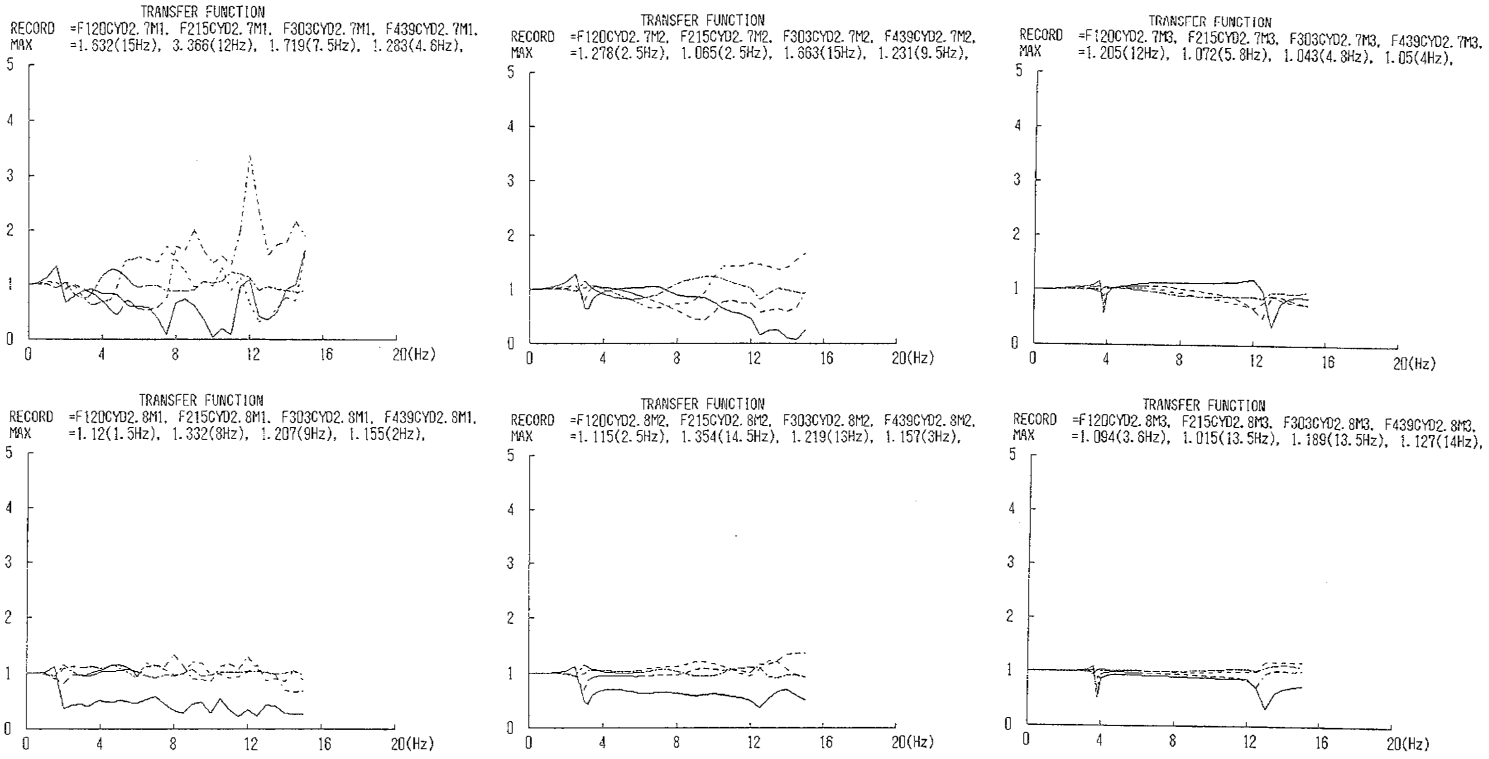

Fig. 6 Comparison of acceleration amplitude transfer functions of ground surface motions at Nodes 120, 215, 303, and 439, shown by solid, chained, dotted, and double chained lines, respectively.

affected anomalously the soil close to the structure(node 120 and 215), while the flexible base assumption gives always reasonable shape of transfer functions.

The above anomalous features in the response of the system are remarkable with the decrease of shear wave velocity of the foundation soil; e.g., when the wave length of the free-field ground motions decreases to become close to the dimension of the foundation or the embedment depth.

Current prototypes of the above models, reactor buildings of PWRs, have been constructed on the rocks having shear wave velocity larger than around 1,000 m/s and correspond to the above model M3. In this case, neither the rigid nor flexible base assumption may disturb the dynamic response of the system, however, when siting similar reactors on Quarternary soil deposits, the flexible base assumption is recommended to be hired in the analyses of dynamic response of these reactor buildings.

4 CONCLUSIONS

The authors have developed the nonlinear soil-structure interaction analysis program HASSI-8 which was completed by implementing the capabilities to consider both spatial variations of the free-field ground motions and wave scattering into HASSI-7.

A typical PWR reactor building with embedment depth equal to its foundation radius on soft to stiff soil was analyzed using the above both programs.

If spatial variations of free-field ground motions and wave scattering effects were neglected, the transfer function of the reactor building amplifies high frequency components anomolously and tends to give large acceleration response and the near-field soil measured at the ground surface showed anomalous response when the shear wave velocity of the foundation soil decreases to show the wave length close to the dimension of the foundation structure embedded by the same amount of depth equal to its radius.

The current PWR reactor buildings having similar dimensions and dynamic characteristics to the numerical model adopted here and having been constructed usually on the foundation rocks of which shear wave velocities are larger than 1,000 m/s, could be considered not sensitive to the spatial variation of free-field input ground motions due to embedment, including wave scattering effects.

5 REFERENCES

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