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SOIL-STRUCTURE-INTERACTION ANALYSIS IN FREQUENCY DOMAIN USING FIXED BASE EIGENVALUES

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ABSTRACT:

Dynamic soil-structure-interaction analyses are usually performed in the frequency domain. Solutions for large buildings require much computer time because of the many degrees of freedom that are needed to represent the dynamic behaviour of the structure.

The method presented takes advantage of the fact, that for seismic loading the behaviour of the structure can be represented by only a few natural modes. Thus the number of the equations of motion that have to be solved are drastically reduced.

1 INTRODUCTION

Dynamic analyses of structures are usually performed using modal decomposition. However, when the underlying soil is included in the analysis the task becomes complicated due to the variation of foundation stiffness with frequency. Also the orthogonality condition for damping is not satisfied for the complete soil-structure-system.

Therefore it would be desirable to solve the problem in the frequency domain, but using an appropriate formulation for the structure i.e., a linear combination of a few vibrational modes of the structure fixed at its base. The number of modes needed to represent the behaviour of the structure is drastically smaller than the number of degrees of freedom in the equations of motion.

An advantage of the proposed method /1/ is the fact, that variations in soil properties can be studied very easily because the structural analysis has to be done only once if the structural model does not change.

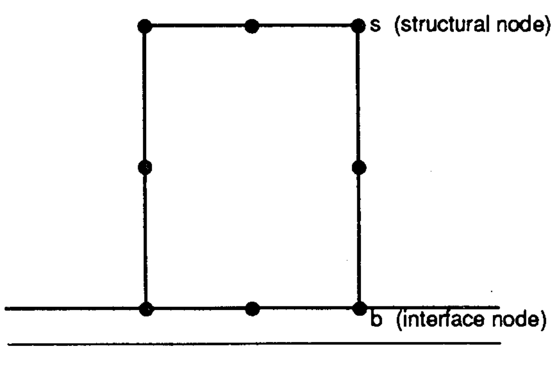

Fig. 1 Structure-soil system

2 SUBSTRUCTURE METHOD IN FREQUENCY DOMAIN

The basic equations of motion for a structure-soil system (fig. 1) are:

$$\begin{bmatrix} S_{ss} & S_{sb} \\ S_{bs} & S_{bb}+X \end{bmatrix} \begin{bmatrix} u_s^t \\ u_b^t \end{bmatrix} = \begin{bmatrix} 0 \\ X u_f \end{bmatrix} \tag{1}$$

The nodes on the structure-soil interface are denoted with the subscript b and the nodes of the structure itself with s. The vector u^t contains the total displacement amplitudes. The matrix $S = K - \omega^2 M$ represents the dynamic stiffness matrix of the structure. The unbounded soil region is respresented by the frequency dependent impedance matrix X. The load vector is given by the freefield motion u_b multiplied by the impedance matrix X.

The method is implemented in the computer code SASSI /2/. The frequency domain analysis with SASSI is performed using the complex response method and finite element technique for structure and soil. Thus damping is accounted for by forming all stiffness matrices using complex moduli. Transient motions are handled by Fast Fourier Transform techniques. The equations of motion are solved only for a selected number of frequencies. Intermediate values are calculated by a special interpolation scheme.

3 QUASI-STATIC TRANSMISSION OF BASE RESPONSE MOTION

The first step to reduce the number of equations of motion is to split up the total displacement amplitudes of the structure into quasi-static displacements introduced by the base response motion and dynamic displacements of the structural nodes (Eq. 2)

$$u_s^t = u_s^s + u_s^d \tag{2}$$

The quasi-static displacements follow from the static part of the equilibrium equations for the structural nodes:

$$K_{ss} u_s^s + K_{sb} u_b^t = 0 \tag{3}$$

$$u_s^s = -K_{ss}^{-1} K_{sb} u_b^t = T_{sb} u_b^t \tag{4}$$

Equations 2 and 4 lead to the following transformation matrix for the total displacement amplitudes:

$$\begin{bmatrix} u_s^t \\ u_b^t \end{bmatrix} = \begin{bmatrix} I & T_{sb} \\ & I \end{bmatrix} \begin{bmatrix} u_s^d \\ u_b^t \end{bmatrix} \tag{5}$$

4 TRANSFORMATION TO MODAL AMPLITUDES OF FIXED-BASED STRUCTURE

The degrees of freedom for the vector u_s^d in equation 5 can be reduced using modal amplitudes of the structure fixed at its base:

$$\begin{bmatrix} u_s^d \\ \\ u_b^t \end{bmatrix} = \begin{bmatrix} \Phi & \\ & \\ & I \end{bmatrix} \begin{bmatrix} z \\ \\ u_b^t \end{bmatrix} \tag{6}$$

In this transformation z represents the vector of modal amplitudes. A new formulation for the equations of motion can be established, which has to be solved for each frequency w:

$$\begin{bmatrix} \Phi^T S_{ss}\Phi & -\omega^2 \Phi^T (M_{sb} + M_{ss} T_{sb}) \\ -\omega^2 (M_{bs} + T_{sb}^T M_{ss})\Phi & S_{bs} T_{sb} + S_{bb} + X \\ & -\omega^2 T_{sb}^T (M_{sb} + M_{ss} T_{sb}) \end{bmatrix} \begin{bmatrix} z \\ u_b^t \\ \end{bmatrix} = \begin{bmatrix} 0 \\ X u_f \\ \end{bmatrix} \tag{7}$$

The number of these equations is much smaller than in the original formulation. The dynamic behaviour of the structure fixed at its base can be studied by determining the frequencies, the mode shapes and the modal masses.

5 EXAMPLES

The method was verified with typical structural buildings of a nuclear power plant. The reactor building was modeled with beam elements and a rigid foundation plate (figure 2). Another building was modeled using plate elements (figure 3). Both are connected to a frequency dependent impedance matrix representing the unbounded soil region.

The response of the soil-structure system due to earthquake excitation is given by acceleration transfer functions. From these transfer functions acceleration time histories and force time histories can be calculated.

Transfer functions for typical nodes of the structural models calculated with variing number of mode shapes are shown in figures 4 to 6 and in figures 7 to 9. The results of the modified SASSI program are compared with those of the original version.

6 CONCLUSIONS

The analyses of soil-structure-interaction problems with large structural models often exceed the capacities of the computers.

The alternative formulation for the equations of motion enables an effective use of the computer code SASSI for large structural models. The computer time can be reduced significantly without substantial loss of accuracy.

7 REFERENCES

/1/ J.P.Wolf, Dynamic Soil-Structure-Interaction, Prentice-Hall

/2/ J.Lysmer, A Computer System for Dynamic Soil-Structure-Interaction Analysis, Report No. UCB JGT/81-02, University of California Berkeley

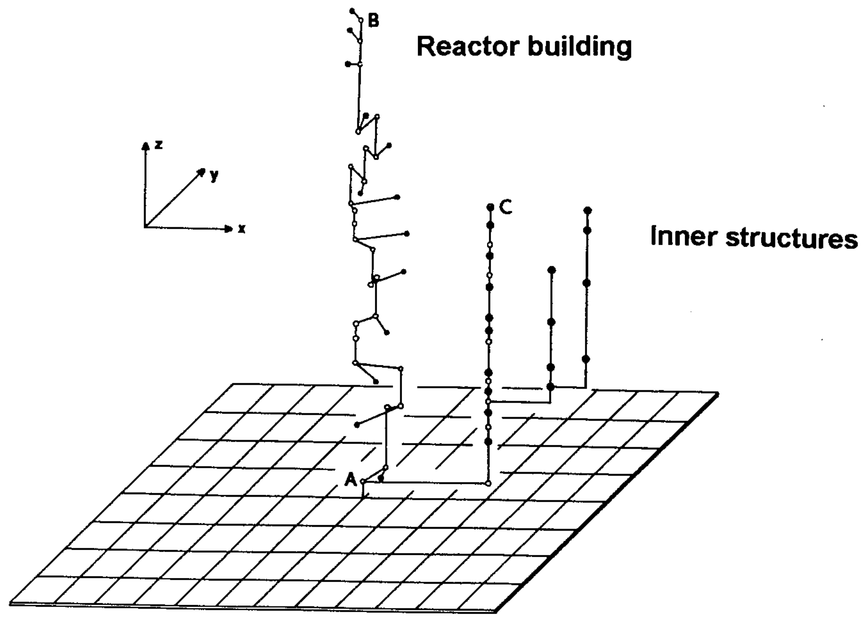

Fig. 2: Spatial beam model (rigid foundation plate)

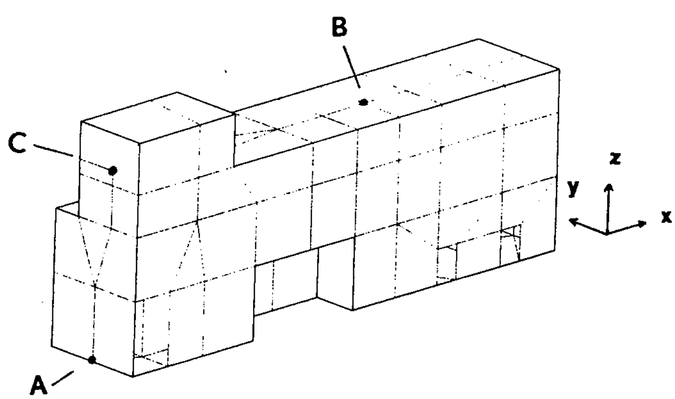

Fig.3 Spatial plate model

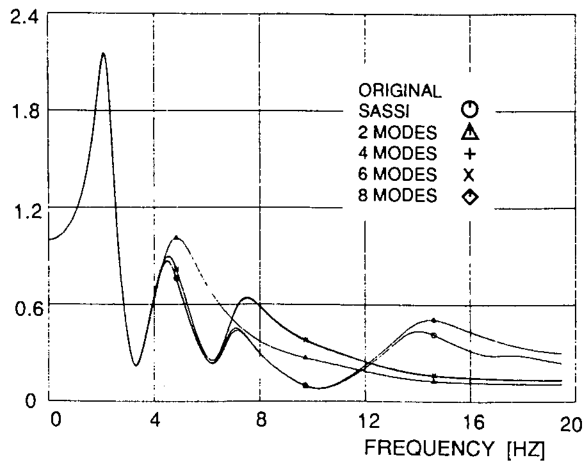

Fig. 4: Amplitudes of acceleration transfer functions, beam model,direction x, node A

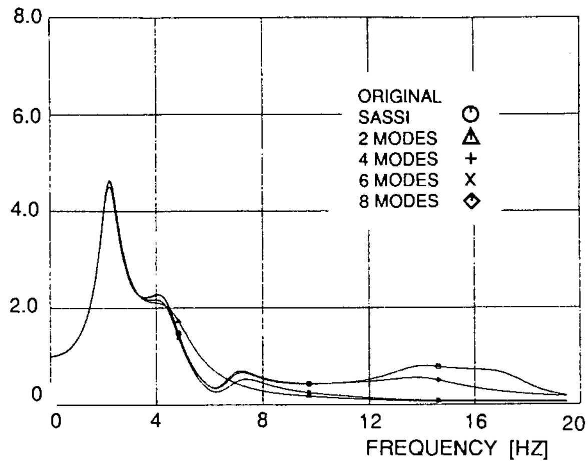

Fig. 5: Amplitudes of acceleration transfer functions, beam model, direction x, node B

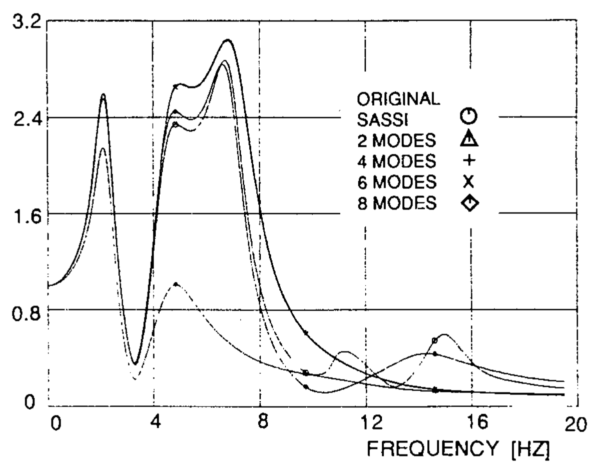

Fig. 6: Amplitudes of acceleration transfer functions, beam model, direction x, node C

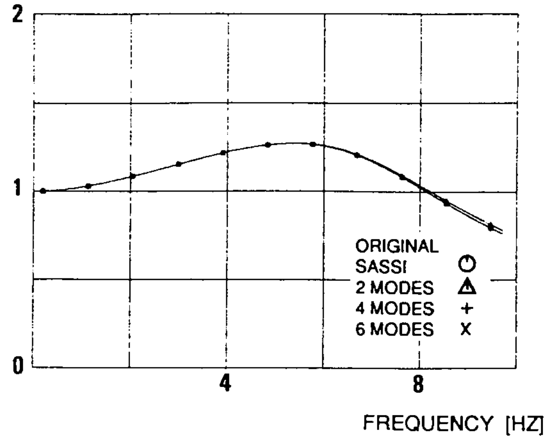

Fig. 7: Amplitudes of acceleration transfer functions, plate element model, direction y, node A

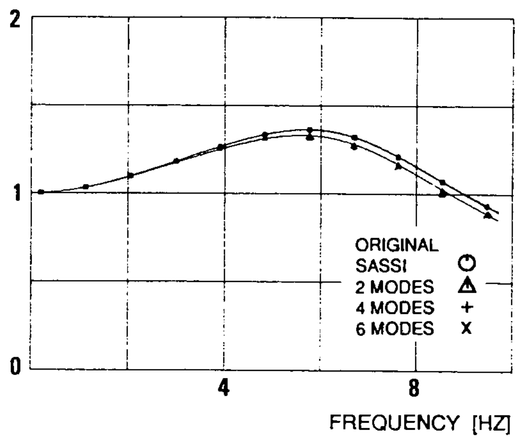

Fig. 8: Amplitudes of acceleration transfer functions, plate element model, direction y, node B

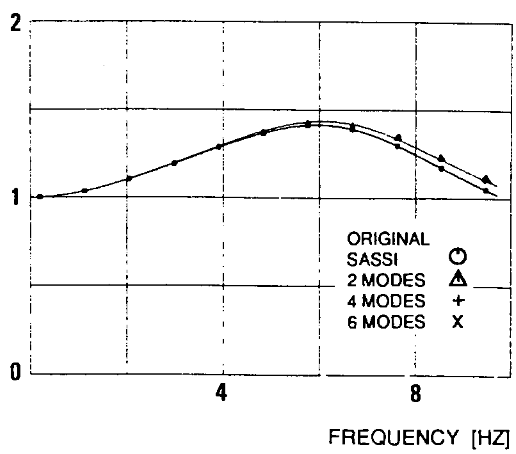

Fig. 9: Amplitudes of acceleration transfer functions, plate element model, direction y, node C