I-407 DYNAMIC SOIL-STRUCTURE INTERACTION ANALYSIS BY THE BOUNDARY ELEMENT METHODS

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ABSTRACT

Soil-structure interaction problem as characterized by impedance functions is studied by applying Green functions. Problems in the numerical calculations are discussed.

Because of the singularity of the Green functions, the displacements and tractions on the interface between the foundation and the soil can hardly be represented accurately. Generally a large number of sources are required. This is the major difficulty of applying the boundary element methods. In the case of a rigid foundation, the 6X6 impedance matrix and the input motion can be effectively obtained by introducing an equivalent rigid-body motion suggested in this paper.

1. PHYSICAL EXPLANATION OF BOUNDARY ELEMENT METHODS

Defining the interface between the foundation and the soil as S, the boundary element methods can be explained as:

Select a set of loads, which will act in the free field, in such a way that the boundary conditions over the surface S can be well represented. By the knowledge of Green functions, the impedance functions can be obtained, by calculating the tractions and displacements over the surface S produced by the selected loads.

The direct boundary element method and the indirect boundary element method differ in how to represent the boundary conditions. In the direct boundary elemet method, the boundary conditions are satisfied at a certain number of points; in the indirect boundary element method, the boundary conditions are satisfied in an average sense in relation to the work.

2. FORMULATIONS OF THE IMPEDANCE MATRIX

Discretizing the displacements and tractions over the surface S, the boundary integral equations can be written in matrix form. The well-known formulations of the impedance matrix K for direct boundary element method and indirect boundary element method can be written respectively as,

$$K = G^{-1} H^{T} \quad (1)$$

$$K = H\ (G^{T} H)^{-1} H^{T} \quad (2)$$

where G and H correspond to Green functions for displacements and consistent forces respectively.

3. FORMULATIONS OF INPUT MOTION

Using the impedance matrix the equivalent driving force vecters Fp (forces for keeping the foundation fixed under seismic incidences) can be obtained.

$$Fp = K\ Ui - Fi \quad (3)$$

Ui and Fi are displacements and consistent forces in the free field, caused by the incident waves defined on the surface S.

A relevent formulation is

$$Fp = G\ Ui \quad (4)$$

4. RIGID FOUNDATION

In the case of a rigid foundation, we are interested in the 6X6 impedance matrix K^* connecting the equivalent displacements $U^*=(Ux,Uy,Uz,Qx,Qy,Qz)$ and forces $F^*=(Fx,Fy,Fz,Mx,My,Mz)$. K^* can be obtained by,

$$K^* = T^{T} K\ T \quad (5)$$

where T represents a rigid-body motion influnce matrix.

5. EQUIVALENT RIGID-BODY MOTION

Considering the fact that the prescribed rigid body displacements on the surface S can hardly be represented by limited number of singular solutions, an equivalent rigid-body motion is suggested here to modify the results. Introducing a rigid-body displacement Ue as,

$$U_e^* = (T^{T} T)^{-1} T^{T} U \quad (6)$$

we can then prove that the equivalent force vecters F^* corresponding to U, are identical to those corresponding to U_e^*. Here U may not be rigid-body displacements. As K in Eq.(2) is sysmetric, then,

$$\begin{aligned} & T^{T} K\ U - T^{T} K\ T\ Ue \\ = & T^{T} K\ U - T^{T} T\ (T^{T} T)^{-1} T^{T} K\ U \\ = & 0 \end{aligned} \quad (7)$$

Similarly the input motion vecters F_p^* can be calculated as,

$$F_p^* = K^* Ui^* - Fi^* \quad (8)$$

where $Ui^* = (T^{T} T)^{-1} T^{T} Ui$, $Fp^* = T^{T} Fp$, $Fi^* = T^{T} Fi$. Equation (8) is obtained by Iguchi(1982), Luco(1986) by different approachs.

6. NUMERICAL INVESTIGATION

In order to conduct the numerical calculation effectively, we will discuss three variables: the sources (selected loads), observations (meshs on the surface S) and offset (distance from sources to the surface S). See Fig 2.

In Fig 1, the displacements on the surface of a cylinder calculated in the case of offset=0.0 and 1.0 meter are plotted. It is understood that the boundary is distorted in both cases. An offset may increase the distortion, especially when there are corners in the foundation. Because of the singularity of Green functions, reducing the offset will cause difficulties in numerical calculation.

Depending on the behaviore of the Green functions, the observation meshs near sources should be small enough, say less than 1/2 of the offset; while they may be rough in other places.

The modelling of sources concerns the Green functions and the whole geometry of the foundation. Also because of the singularity of Green functions, in order to get reliable results, generally a large number of sources are required.

All the disadvantages of the boundary element methods come from the application of singular Green functions. They may can be overcome by using linear distributed loads instead of concentrited ones. This requires further improving of Green functions. So in the application of boundary element method, it is important to consider the physical characristics of each problem.

7. RESULTS AND CONCLUSIONS

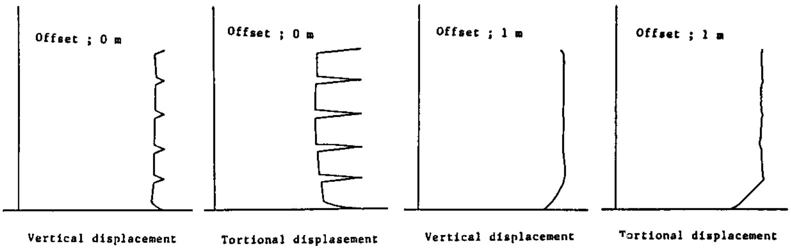
Refer to Fig.3, numerical calculations are conducted in the frequency domain for a cylinder rigid foundation, embedded in a layered viscoelastic media with a rigid rock at a certain depth. Modelling of sources and observations are presented in Fig.2

The Green functions for ring loads obtained by E. Kausel are used. These solutions are based on a discretization of the medium in the direction of layering, which results in a formulation yielding algebraic expressions, whose integral transforms can readily be evaluated (no numerical integration necessary).

The five complex impedance functions calculated by both direct boundary element method and indirect boundary element method, are plotted in Fig.4 with the frequency from 0.0 to 10.0 Hz. Results are compared to those obtained by the finite element method with use of the so-called transmitting boundary method.

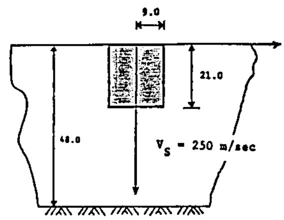
It can be seen in Fig.4 that there is a close agreement between the finite element method and the boundary element methods. The only significant differences appear at high frequencies where the finite element method results are slightly lower.

The boundary element methods are reliable and efficient compared to the finite element methods in the soil-structure interaction problems. the indirect boundary element method has advantages over the direct boundary element method. The difficulties in calculating Green functions and the demand of a large number of sources state the need of further improving.



Displacements distribution on the surface of the cylinder

Fig 1 for offset=0.0 and 1.0



Axisymmetric foundation-soil system

Fig 3

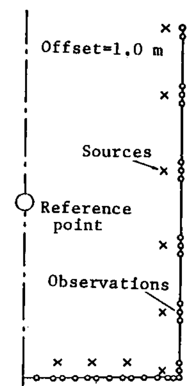
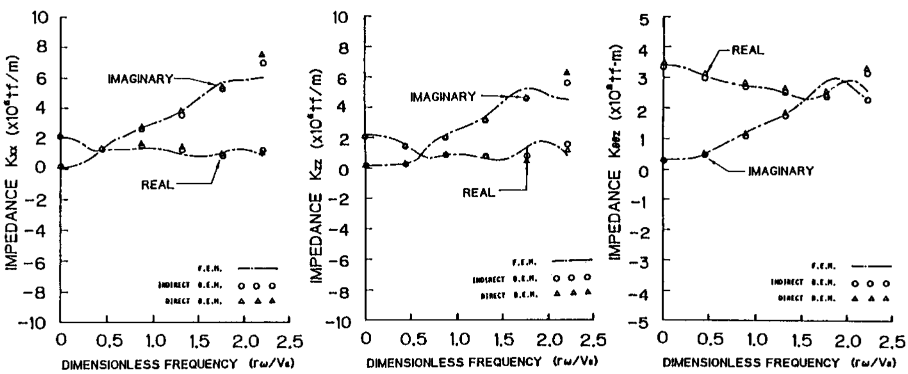


Fig 2 Offset, observations and reference point



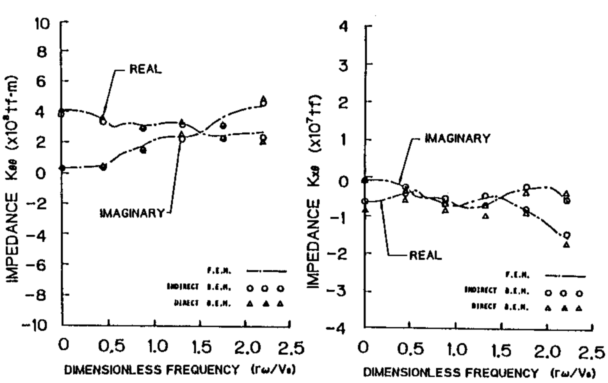


Fig 4 Impedance functions

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