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. The physical explaination, the accuracy and the efficiency of various boundary element methods (the indirect boundary element method, the direct boundary element method) 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, no matter offset is introduced or not. Generally a large number of sources are required. This is the major difficulty *in the application of the boundary element* methods. In the case of a rigid foundation, the 6×6 *impedance* matrix and the input motion can be effectively obtained by introducing an equivalent rigid-body motion suggested in this paper.

1. PHYSICAL EXPLAINATION OF BOUNDARY ELEMENT METHODS

Refer to Fig.(1). The boundary element methods may be explained as:

Select a set of loads to act in the free field in shuch a way that the boundary conditions over surface Sg can be well represented. By the knowlege of Green functions, the impedance functions can be obtained by calculating the tractions and displacements over surface Sg 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 connecting with work.

2. FORMULATIONS OF THE IMPEDANCE MATRIX

Discretizing the displacements and tractions over surface Sg, the boundary integral *equitions 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*

$$K = G^{-1} H^{T} \tag{1}$$

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

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 F_D (forces for keeping the foundation fixed under seismic incidences) can be obtained.

$$F_D = K\ U_f\ -\ F_f \tag{3}$$

where U_f and F_f are displacements and consistent forces in the free field caused by the incident waves defined on surface Sg.

A relevent formulation is (in this case the offset is no permissible)

$$F_D = G\ U_f \tag{4}$$

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

$$K^* = T\ K\ T \tag{5}$$

where T represents a rigid-body motion influnce matrix.

5. EQUIVALENT RIGID-BODY MOTION

On the fact that the prescribed rigid body displacements on *surface Sg 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

$$Ue = (T^{T} T)^{-1}\ T^{T} U \tag{6}$$

We can 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

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

Similarly the input motion vecters F_D^* can be calculated as

$$F_D^* = K^* Un\ -\ F_f^* \tag{8}$$

where $Un = (T^{T} T)^{-1}\ T^{T} U_f$. $F_D^* = T\ F_D$, $F_f^* = T\ F_f$. Equition (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 surface Sg) *and offset (distance frome sources to* surface Sg). See Fig 3.

In Fig 2, 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 increases the distortion in two and three dimensional problems, especielly 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 singularity of the Green functions, the observation meshs near sources should be small enough, say less than 1/2 of the offset; while may be rough in other places.

The modeling of sources concerns with the behavior of 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 disadventages of the boundary element method come from the singular Green functions. They may be overcome by using linear distributed loads instead of concetrited 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 certain problem.

7. RESULTS AND CONCLUSIONS

Refer to Fig.(3), numerical calculations are conducted in frequency domain for a cylinder rigid foundation, embedded in a layered viscoelastic media with a rigid rock at a certain depth. Modeling of sources and observations are presented in Fig.(4)

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.(5) with frequency from 0 to 10 Hz. Results are compared to those obtained by the finite element method with use of the so-called! transmitting boundary method.

It may be seen in Fig.(5) 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 efficint comparing to the finite element methods in the soil-structure interaction problems. When a offset is taken, the indirect boundary element method has adventage over the direct boundary element method. The difficulties in calculating Green functions and the demaind of a large number of sources state the need of further improving.

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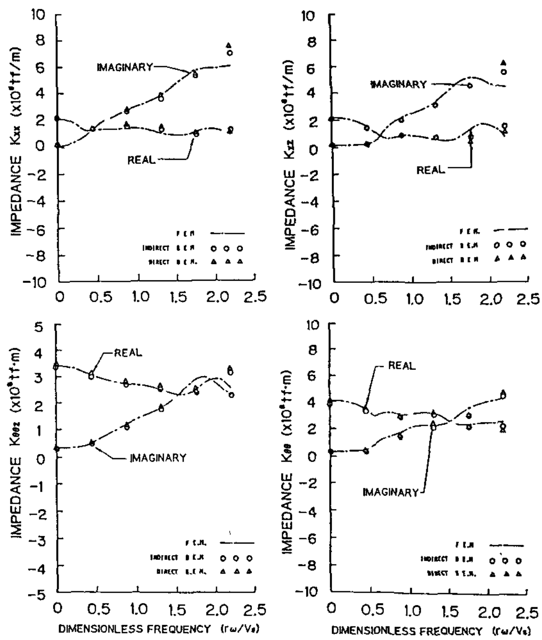


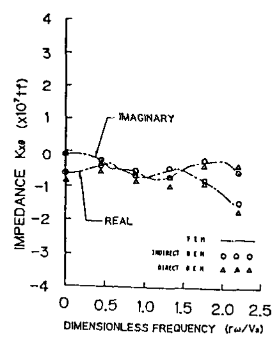


Fig. 5

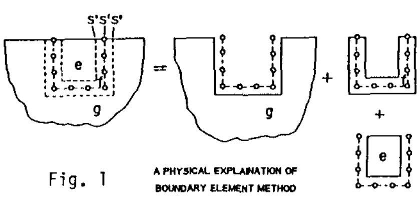


Fig. 1

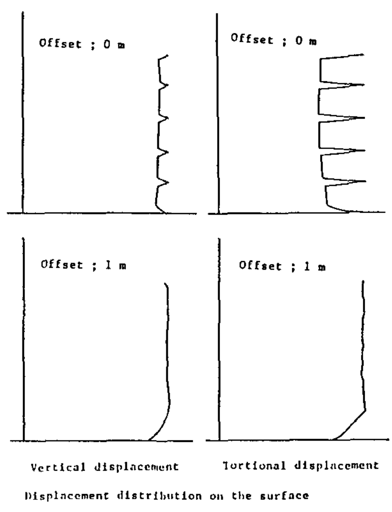
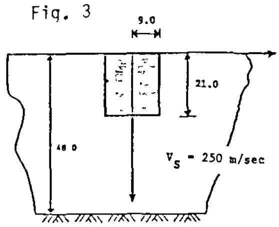


Fig. 2

Fig. 3



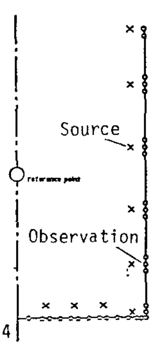


Fig. 4