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EFFECT OF STRUCTURE ON STRONG GROUND MOTION AT SITE WITH COMPLICATED TOPOGRAPHY AND SUBSTRATA

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SUMMARY

Method to calculate the effect of structure on the ground motion accounting for the local configuration and viscoelastic substrata is presented. The boundary element equations are formulated for each medium. The relationship between the force and displacement at the foundation base is also formulated. They are solved simultaneously with the displacement and traction at the boundaries. Calculated results show that the ground motion is reduced slightly under most frequencies of excitation except under the natural frequencies of the structure. Under the natural frequencies the ground motion near the structure could be amplified while under the structure is reduced notably.

INTRODUCTION

One of the most important problems in earthquake engineering is to determine the seismic input pertinent to a site for important structures. By means of seismic hazard analysis a certain parameters quantifying the strong ground motion are evaluated corresponding to some level of the probability of exceedance. These parameters could be intensity, peak ground acceleration or peak ground velocity. The response spectra may anchored either with one of these parameters or directly with the magnitude and epicentral distance. The time history of the strong ground motion is necessary when the seismic response time history analysis for important structures is performed. Often the strong ground motion at a certain level is assumed to be unaffected by the existence of the structure and the site configuration. The strong ground motion at this level is obtained by converting the free field surface motion to that depth and served as the input for the subsequent analysis. In the present paper the effect of the structure on the ground motion is accounted for. The incident wave field is used as the input of the analysis and thus no ground motion at a certin depth is needed. The method presented in this paper differs with the effective input approach at two points. In the present method the foundation can be either rigid or deformable and the result obtained already including the soil-structure or structure-soil-structure interaction effect. The analysis can be either one-step or multistep. If the multistep method is used the motion obtained in the first step can be used both for the further analysis or as the input for the experimental verification of the structure directly.

THEORETICAL ANALYSIS

The boundary element method has been treated by many authors (Refs 1, 2, 3). Xu and Jiang (Ref. 4) analysed the effect of local configuration and substrata on strong ground motion. The present paper extends the analysis to include the effect of the structure. Here only the main idea and fundamental equations will be given.

For harmonic wave the displacement component can be expressed as $U_i \exp(i\omega t)$ and the equation of motion becomes

$$(V_p^2 - V_s^2)\, U_{j,ji} + V_s^2 U_{i,jj} + \omega^2 U_i = 0 \qquad (1)$$

where V_p and V_s are the P-wave velocity and S-wave velocity respectively. On the boundary the following integral equation holds:

$$C_{ij} U_j^p = \int_s (U_{ij} T_j - T_{ij} U_j)\, ds \qquad (2)$$

and

$$C_{ij} = \delta_{ij} + \int_e T_{ij}\, ds \qquad (3)$$

where e is the portion of the surface of a sphere centering at p on the boundary with infinitesimal radius outside the region considered. On a smooth boundary $C_{ij} = (1/2)\delta_{ij}$. U_{ij} is the Green's function or the solution to

$$(V_p^2 - V_s^2) U_{k,kj} + V_s^2 U_{j,kk} + \omega^2 U_j + \delta(x-X)\,\delta_{ij} = 0 \qquad (4)$$

where X is the position vector of p, i, j=1, 2, 3. T_{ij} is the corresponding traction component on the boundary. i is the direction of the body force $\rho f = e_i \exp(i\omega t)$.
For the region where the known incident waves exit the following equation is used

$$C_{ij}(U_j^p - U_{(f)j}^p) = \int_s [U_{ij}(T_j - T_{(f)j}) - T_{ij}(U_j - U_{(f)j})]\, ds \qquad (5)$$

where the subscript (f) means the incident free field wave.

For a Voigt material the complex material constants $\overline{\lambda}$, $\overline{\mu}$ and wave velocities $\overline{V_p}$, $\overline{V_s}$ are used to replace the elastic material constants λ, μ and wave velocities V_p, V_s respectively,

$$\overline{V_p} = [(\overline{\lambda} + \overline{\mu})/\rho]^{1/2} = V_p(1 + i/Q_\lambda)^{1/2} \qquad (6)$$

$$\overline{V}_s = (\overline{\mu} / \rho)^{1/2} = V_s(1+i/Q_2)^{1/2} \tag{7}$$

where Q_1 *and* Q_2 *are quality factors.*

The boundary integral equations (2) and (5) are discretized by means of boundary element method. A various shape function can be used.

For a structure under harmonic excitation $\{F\}\exp(i\omega t)$, the response displacement $\{U\}\exp(i\omega t)$ can be easily formulated by means of finite element approach.

$$[K(\omega)]\{U\} = \{F\} \tag{8}$$

.or

$$\begin{bmatrix} K_{11}(\omega) & K_{10}(\omega) \\ K_{01}(\omega) & K_{00}(\omega) \end{bmatrix} \begin{bmatrix} U_1 \\ U_0 \end{bmatrix} = \begin{bmatrix} F_1 \\ F_0 \end{bmatrix} \tag{9}$$

where $\{U_0\}$ and $\{F_0\}$ are the displacement and force of the foundation base of the structure. The effect of damping has been included in the stiffness matrix. It is easy to obtain

$$[K_0(\omega)]\{U_0\} = \{F_0\} \tag{10}$$

where

$$[K_0(\omega)] = [K_{00}] - [K_{01}][K_{11}]^{-1}[K_{10}] \tag{11}$$

If the foundations are rigid the displacement field of the medium can be easily linked with the displacement vector $\{U_0\}$. If the foundations are too flexible to be considered as rigid the foundations can be treated as a medium and the base of column as the foundation base. It is not difficult to formulate the relationship between the traction and $\{F_0\}$. These relationships together with the traction free condition on the free boundary and the equation of continuity on the interior boundaries of the media enable us to solve $\{U_0\}$, $\{F_0\}$, U_i and T_i simultaneously.

SOME RESULTS

A certain structure located on the surface of rock is modeled for simplicity as a cantilever beam with mass concentrated at fifteen positions (Fig.1). The cross sectional area of the equivalent beam is $116m^2$ and the moment of inertia $I_1 = I_2 = 1.99\times10^4 m^4$. $J = 3.98\times10^4 m^4$. The material constants are $E = 2.74\times10^4 MN/m^2$, $\nu \approx 0.17$, $\rho = 2.45g/cm^3$. The first four natural frequencies are 3.27Hz, 3.27Hz, 6.90Hz and 10.57Hz. The wave *velocities of the rock medium are* $V_p = 4260m/sec$, $V_s = 2710m/sec$.

The layout of the element is shown in Fig.2. For simplicity constant boundary element is used. The results for vertically incident SH, SV and P waves in elastic medium are depicted in Fig.3 to Fig.5. The results for waves with incident angle $\theta=30^\circ$ in viscoelastic medium are also depicted. As can be seen from these figures the ground motion is reduced slightly by the existence of the structure under most frequencies of excitation except under the natural frequencies of the structure. Under the natural frequencies the ground motion near the structure could be amplified while under the structure is reduced notably.

CONCLUSIVE REMARK

The method presented in this paper can be used to analyse soil structure interaction with consideration of the effect of structure on the wave field at site with complicated topography and substrata. The advantage of this approach is that no assumption that at a certain depth the ground motion is not affected by the existence of the structure and the site condition is needed.

The energy dissipation in the medium is rather small in the local site effect problem and is accounted for by the use of viscoelastic model. The use of more sophisticated model, say elastoplastic model seems unjustifiable for much uncertainties involved in the source and propagation path as well as the formidable computer time needed.

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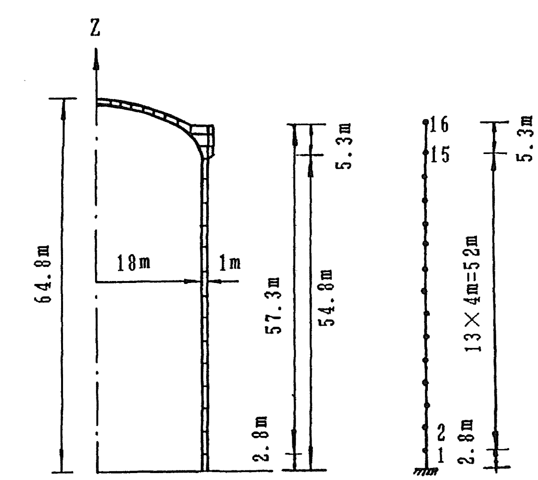

Fig.1 The Structure and Its Mathematical Model

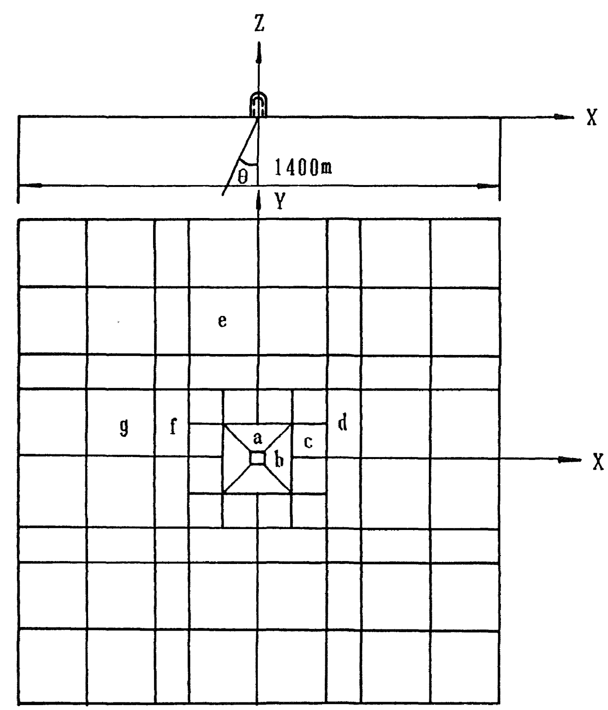

Fig.2 The Division of The Boundary Element

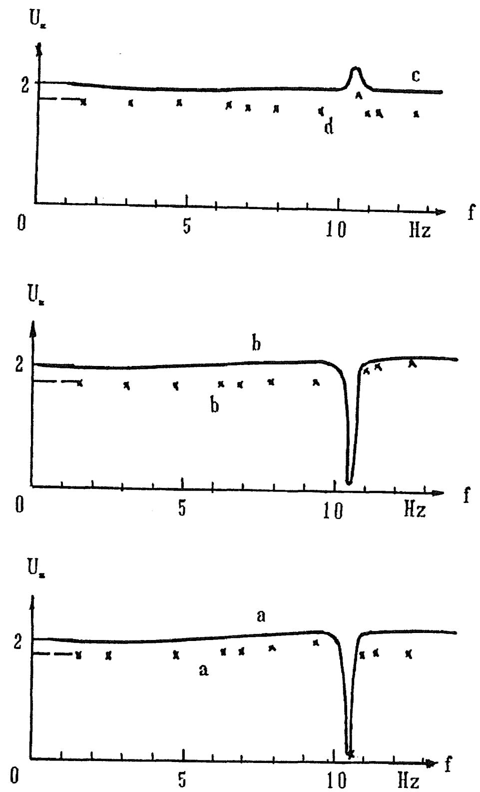

Fig.3 Response for Incident P Wave

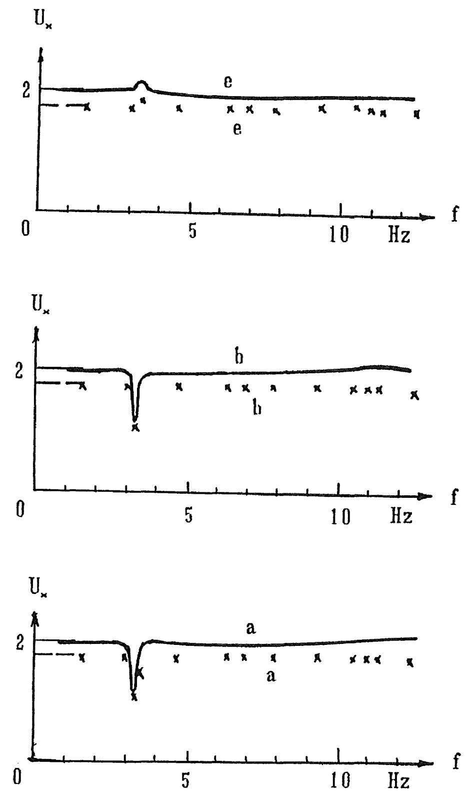

Fig.4 Response for Incident SV Wave

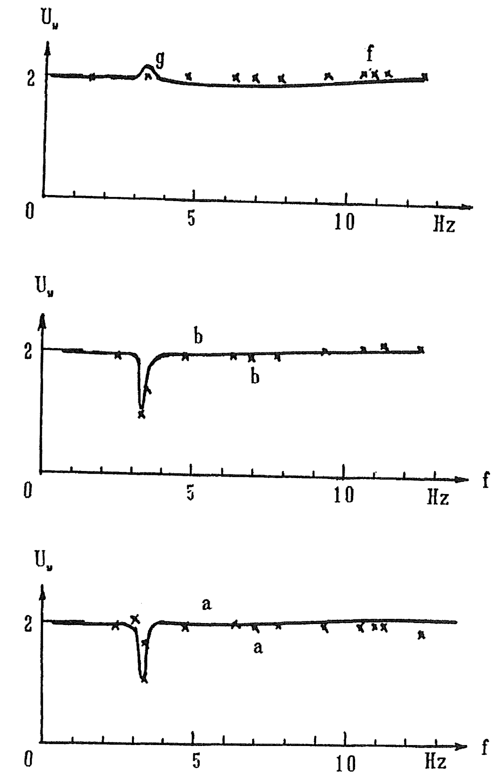

Fig.5 Response for Incident SH Wave

— incident angle = 0° × incident angle = 30° Q=1000

critical damping ratio=0.02