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DYNAMICAL BEHAVIOR OF A SLIGHTLY ALLUVIAL BASIN DUE TO PLANE WAVE TURBULENCES

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SUMMARY

In order to evaluate the seismic response of an alluvial basin, the practical method of representing the scattered wave field with irregular boundaries and the radiating wave phenomina for an infinitely far-field may be necessary. This paper is concerned with a theoretical analysis and numerical evaluation based on the wave propagation theory to find dynamical characteristics of a slightly sedimental basin standing alone on a half-spatial bed rock, subjected to obliquely incident plane waves. Numerical examples of this system are shown in frequency and time domain.

INTRODUCTION

Some recent experimental results such as the ones in Mexico city area (1985) corresponding to local site amplification and very strong variations in great earthquake damage, have led us to think that geometrical surface configulations may induce a local disparity in seismic motions. Investigations of the response of bidimensional and laterally heterogeneous media to incident plane waves have been carried out by Aki and Larner (1970), Bard and Bouchon (1980) whose works, however, are limited to study of a few configurations.
The present study is concerned with the dynamic analysis of a slightly alluvial bidimensional basin standing alone on a half-spatial basis. In describing this problem with the complicated boundaries, the total displacement field is separated into the incident motion and the scattered field due to the presence of irregular boundaries. And, the latter field is further separated into the two sets of fields, corresponding to the following subproblems;
(0) the one related to a half flat-stratum expanded infinitely in horizontal direction, and
(1) the other corresponding to the difference field between the given scattered field with laterally irregular boundaries and the auxiliary one (0).
By applying the Fourier transforms to this separated wave fields with respect to time and spatial variables, the integral equations are derived in the domain of frequency and wave numbers. In solving this equations, the response functions are expressed in terms of the unknown functions of the scattered field (1). Finally, numerical results are presented for some physical properties of the problem in frequency and time domain.

FORMULATION OF THE PROBLEM

The bidimensional wave field is composed of multiple layers overlying a half-space, and subjected to plane wave turbulences from the lower far-field. Each medium is assumed to be perfectly elastic, and to be bounded by the irregularly shaped surface S_0 and interface S_j (j=I,II,...J). So that, the following boundary conditions are required to be satisfied;

$$\tilde{\tau}_I = 0 \qquad \text{on } S_0 \tag{1-i}$$

$$\begin{pmatrix}\tilde{u}\\ \tilde{\tau}\end{pmatrix}_j = \begin{pmatrix}\tilde{u}\\ \tilde{\tau}\end{pmatrix}_{j+1} \qquad \text{on } S_j \quad (j=I,II,..J) \tag{1-ii}$$

in which $\tilde{u}_j$ and $\tilde{\tau}_j$ are the displacement and stress vector in the medium (j) and

(i) the stress free condition at the surface S_0,

(ii) the continuous conditions of stress and displacement at the interface S_j.

In addition, the radiation condition in the infinitely far field is required to be satisfied. For the brevity of this analysis, it is convenient to write the displacement field as a combination of the incident field $\tilde{u}^i$ and the scattered one $\tilde{u}^s$ as follows;

$$\tilde{u} = \tilde{u}^i + \tilde{u}^s \tag{2}$$

where the incident field is obtained in the closed form in frequency domain and the scattered one may be presented in Fourier integral forms for the horizontal direction by using the Cartesian coordinate system (x,z) in this spatial field,

$$\tilde{u}^s = \int_{-\infty}^{\infty} dp e^{ipx} \tilde{A}(\tilde{x},p)\tilde{z}(p) \tag{3}$$

in which $\tilde{x}$ is the position vector in the wave field and $\tilde{z}(p)$ is denoted as the unknown functions expanded in wave number domain. When the wave field composed of the layered system with irregularly shaped boundaries is completely described, it should contain upward-going waves together with downward ones. The scattered representation in the half-spatial basis, however, has only downward components which provides the approximate description in this field and introduces an aberration, named Rayleigh ansatz error, which is practically small when the geometrical irregularity in the lowest interface is slight and the incident waves have only low frequency components. By instituting eqs.(2), (3) into the boundary conditions (1), the following dominant equation associated with the unknown functions $\tilde{z}(p)$ is obtained,

$$\int_{-\infty}^{\infty} dp e^{ipx} \tilde{G}(\tilde{x}_c,p)\tilde{z}(p) = e^{-ikx}\,\tilde{h}(\tilde{x}_c) \tag{4}$$

The position vector of the irregular boundaries is denoted by $\tilde{x}_c$ in the unique expression of the horizontal coordinate x, and k is the lateral component of wave number when incident turbulences are propagating obliquely. In order to derive the boundary equation in the domain of wave numbers, the Fourier transform with respect to the horizontal coordinate is to be applied to eq.(4), whose infinite integrals are not convergent. Then, the proposed technique is associated with the following restriction of the boundary configulation in horizontal direction,

(a) the irregular zone $|x|\leq L$ which includes the irregularly shaped boundaries of multiple layers, and

(b) the regular zone $|x|>L$ which is composed of the flat-layered stratum.

And, the auxiliary subproblem which corresponds to the flat-layered half-space having the boundaries in consistence with the objective ones inside the regular zone is considered, and its solution expanded in wave number domain is given by using the Dirac's delta function,

$$\tilde{z}_0(p) = \delta(p+k)\tilde{G}_0^{-1}(p)\tilde{h}_0 \tag{5}$$

the coefficients of which hold the following relationships,

$$\begin{pmatrix} \tilde{G}(\tilde{x}_c,p) \\ \tilde{h}(\tilde{x}_c) \end{pmatrix} = \begin{pmatrix} \tilde{G}_0(p) \\ \tilde{h}_0 \end{pmatrix} \qquad :|x|>L \tag{6}$$

By using the solution (5) of the auxiliary problem, the dominant equation (4) is reconstructed with respect to the functions $\tilde{z}_1(p)$, which are the differences between the functions $\tilde{Z}(p)$ and $\tilde{Z}_0(p)$.

$$\tilde{z}_1(p) = \tilde{z}(p) - \tilde{z}_0(p) \tag{7}$$

After Fourier transformed along the horizontal direction and changed in the order of integrals, the equation (4) associated with the unknown functions $\tilde{z}_1(p)$ may yield the following integral equations,

$$\tilde{G}_0(q)\tilde{z}_1(q) + \int_{-\infty}^{\infty} dp\{\tilde{K}_1(p,q)-\tilde{K}_2(p,q)\}\tilde{z}_1(p) = \tilde{f}_1(q) - \tilde{f}_2(q) \tag{8}$$

in which the coefficients are obtained in the finite integral forms,

$$\begin{pmatrix} \tilde{K}_1(p,q) \\ \tilde{K}_2(p,q) \end{pmatrix} = \frac{1}{2\pi}\int_{-L}^{L} dx e^{-i(q-p)x} \begin{pmatrix} \tilde{G}(x_c,p) \\ \tilde{G}_0(p) \end{pmatrix} \tag{8-1}$$

$$\begin{pmatrix} \tilde{f}_1(q) \\ \tilde{f}_2(q) \end{pmatrix} = \frac{1}{2\pi}\int_{-L}^{L} dx e^{-i(q+k)x} \begin{pmatrix} \tilde{h}(\tilde{x}_c) \\ \tilde{G}(\tilde{x}_c,-k)\tilde{G}_0^{-1}(-k)\tilde{h}_0 \end{pmatrix} \tag{8-2}$$

Furthermore, the coefficients can be expressed analytically when the boundaries are composed of partially linearized planes in the irregular zone.
The displacement responses of this layered system are expressed in terms of the *solutions* $\tilde{z}_1(p)$ *which are obtained in the integral equations* (8),

$$\tilde{u}(\tilde{x}) = \tilde{u}^i(\tilde{x}) + e^{-ikx}\tilde{A}(\tilde{x},-k)\tilde{G}_0^{-1}(-k)\tilde{h}_0 + \int_{-\infty}^{\infty} dp e^{ipx}\tilde{A}(\tilde{x},p)\tilde{z}_1(p) \tag{9}$$

When subjected to unit disturbances, the response functions (9) in frequency domain are considered as the transfer functions $\tilde{g}(\tilde{x},\omega)$ of the system. Consequently, by making use of the spectrum $s(\omega)$ of the incident field, the response functions in time domain are presented through the Fourier inversion transforms with respect to frequency parameter ω, as follows;

$$\tilde{U}(\tilde{x},t) = \frac{1}{2\pi}\int_{-\infty}^{\infty} d\omega e^{i\omega t}\tilde{g}(\tilde{x},\omega)s(\omega) \tag{10}$$

NUMERICAL ANALYSIS AND CONCLUDING REMARKS

In evaluating the basic dynamic characteristics of a slightly alluvial basin standing alone on a half-space, it is assumed that the bidimensional wave field is constructed on a double layered half-space with partially linearized irregular boundaries in the irregular zone $|x|\leqq L$ and a negligibly slight surface layer in the regular zone $|x|>L$ where the bedrock appears nakedly, as shown in Fig. 1, and the soil is composed of the linear hysteretic type viscoelastic medium whose generalized Lame's constant are expressed in complex forms. In this numerical analysis, the integral equations (8) are converted into the simultaneous equations by means of the discretization and truncation technique in wave number domain as well as the response functions (9) are into the finite summation forms. For the culculation carried out in brief, the dimensionless parameters and dimensionless components with superscript ($\bar{\ }$) are introduced,

$$\begin{pmatrix} \bar{x} \\ \bar{z} \end{pmatrix} = \frac{1}{L}\begin{pmatrix} x \\ z \end{pmatrix}, \quad \begin{pmatrix} \bar{p} \\ \bar{q} \end{pmatrix} = L\begin{pmatrix} p \\ q \end{pmatrix}, \quad \begin{matrix} \bar{\omega} = \omega L/c_0, & \bar{k} = kL, \\ \bar{t} = tc_0/L, & \bar{c}_j = c_j/c_0 \ :j=I,II \end{matrix} \tag{11}$$

$$|\bar{u}| = u/|\tilde{u}^i|, \quad \bar{h}(\bar{x}) = h(x)/L \quad : |\bar{x}| \leq 1$$

in which ω, t are angular frequency and time factor, c_0, $c_j = c_{j0}(1+iD_j)$ are the standard shearing velocity and the generalized shearing velocity of medium (j), and h(x) is the depth function of irregularly shaped alluvial basin. In addition, the following dimensionless parameters are necessary to describe this ground system adequately, such as ν_j: Poisson's ratio, γ: incident angle measured from the vertical direction. The numerical values of dimensionless system parameters for the alluvial basin are chosen as;

$$\bar{c}_{I0}=0.177,\ \bar{c}_{II0}=1,\ \nu_I=\nu_{II}=0.333,\ D_I=0.025,\ D_{II}=0.01,\ \hat{h}_0=0.05,\ \alpha=\pi/6$$

In the numerical integration and summation to obtain the responses in frequency and time domain according to eqs. (9), (10), there are no singular points because of the application of an auxiliary flat-layered problem and the presence of dissipative damping in the soil layer. Therefore ordinary methods of computation can be applied while an appropriate interpolation technique is necessary in evaluating discretized and truncated functions. The following remarks can be made on the results of numerical analysis;

(1) As shown in Fig. 2, the phase velocities of scattered waves to incident SH or P waves are presented condensable around the Love or Rayleigh surface wave modes of the corresponding flat-layered systems.

(2) In Fig. 3, the absolute-valued transfer functions of slightly alluvial basins show the considerable growth around the dominant frequencies of the flat-layered systems inside the basin, whereas a little outside the basin.

(3) As found from Figs. 4 and 5, local site amplification on a sediment and interacted phenomena between the components outside a basin and the inside ones of distributed displacement amplitudes on the ground surface show the rather dependence on incident wavelengths and the proportions of a basin.

(4) With regard to the transient bahavior of wave field, the remarkable prolongation of wave propagating duration inside a basin to an incident Ricker wavelet with a peak frequency ω_p and few components in high frequency range, and the rotating particle orbit due to the presence of Rayleigh surface waves under incident P wave turbulences are shown in Figs. 6, 7 and 8.

It is noted, however, that the boundary condition associated with the wave field representation in a half-spatial basis are not yet completely satisfied in these figures, and its aberration is small because of the slight irregularity in the lowest interface and the incident field with low frequency components.

In conclusion, it can be mentioned that the present superposing description of the scattered wave field is useful for the construction of geophysical models, such as a sediment standing alone on a half-space with irregular boundaries.

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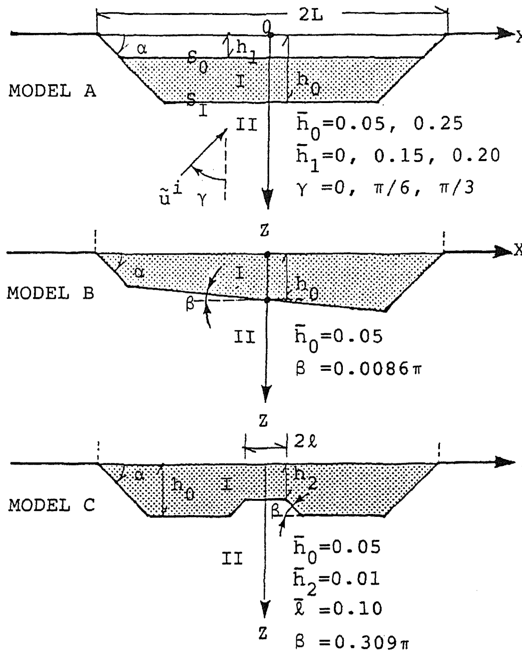


Fig. 1 Configuration of ground system

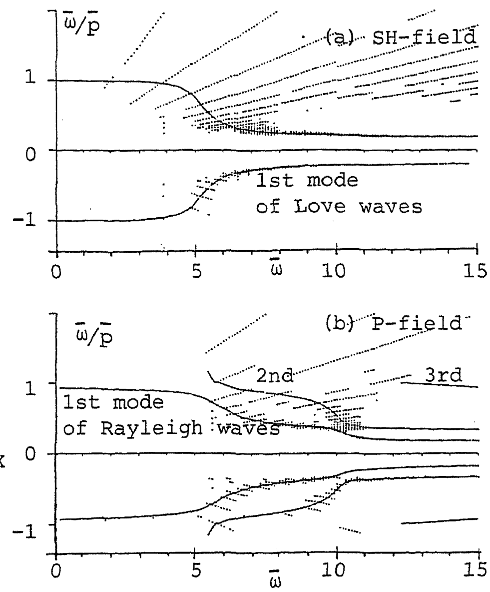
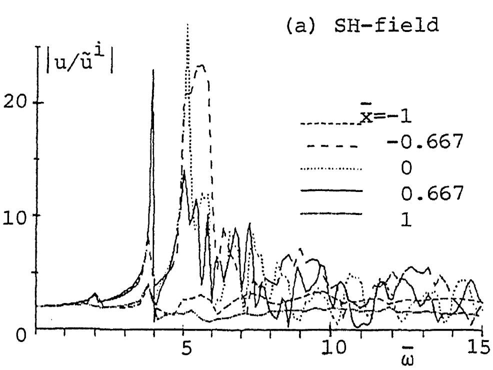


Fig. 2 Phase velocities: Model A and flat layer, $\bar{h}_0=0.05$, $\bar{h}_1=0$, $\gamma=\pi/3$.



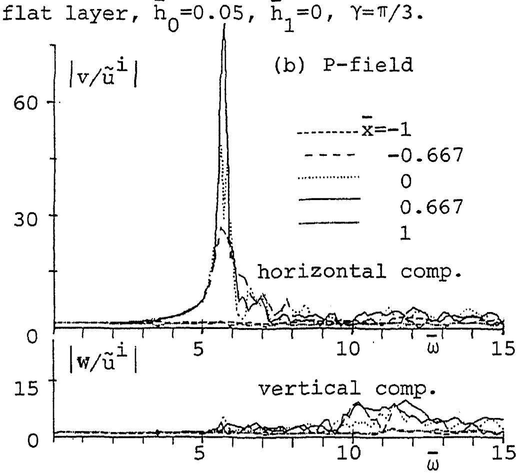


Fig. 3 Transfer functions on S_0: Model A, $\bar{h}_0=0.05$, $\bar{h}_1=0$, $\gamma=\pi/3$.

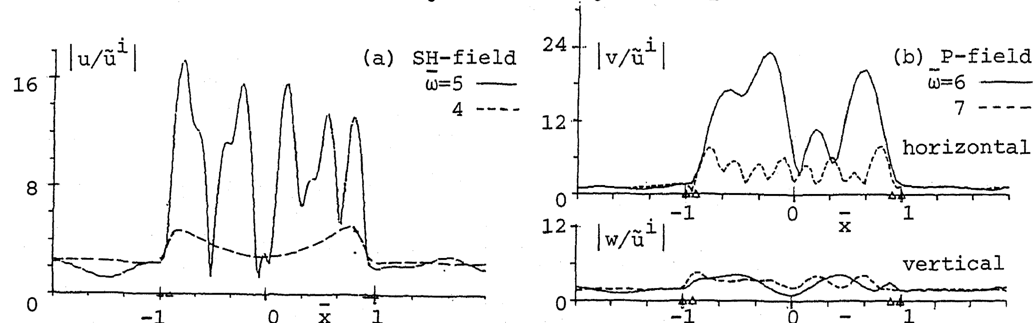


Fig. 4 Displacement amplitudes on S_0: Model A, $\bar{h}_0=0.05$, $\bar{h}_1=0$, $\gamma=\pi/6$.

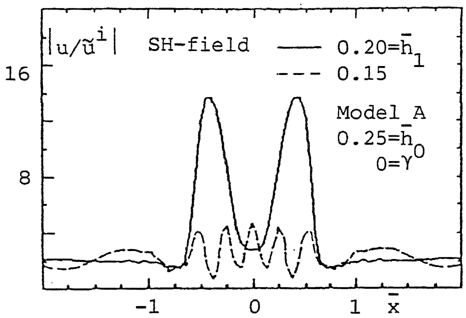
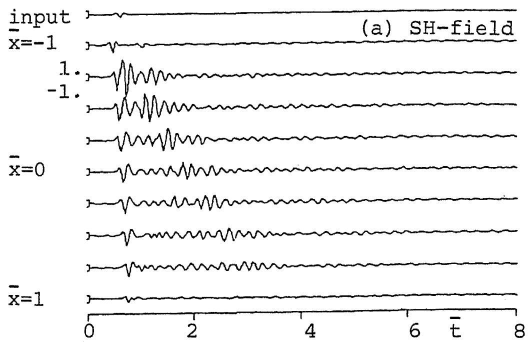


Fig. 5 Displacement amplitudes on S_0.



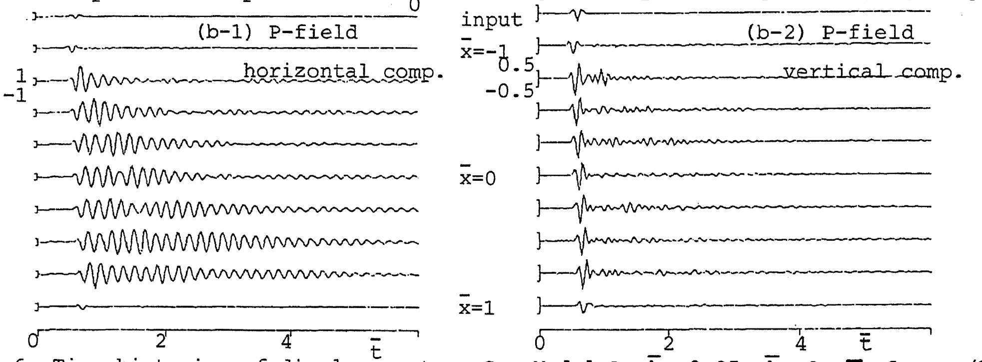


Fig. 6 Time histories of displacement on S_0: Model A, $\bar{h}_0$=0,05, $\bar{h}_1$=0, $\bar{\omega}_p$=6, $\gamma=\pi/3$

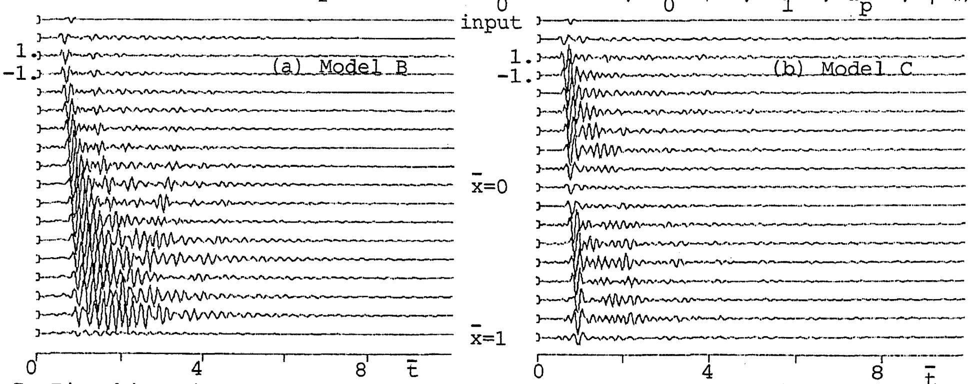


Fig. 7 Time histories of displacement on S_0 in SH-field: $\gamma=\pi/3$, $\bar{\omega}_p$=6.

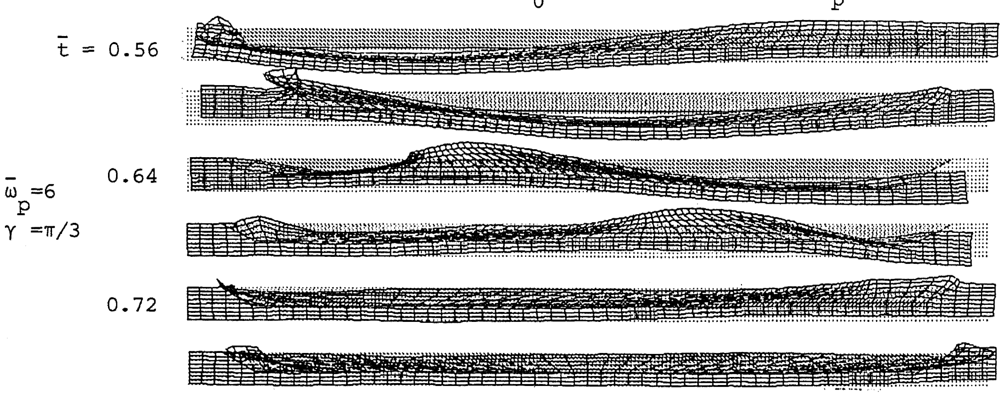


Fig. 8 Time histories of displacement in P-field: Model A, $\bar{h}_0$=0.05, $\bar{h}_1$=0.