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SYNOPSIS

This paper is concerned with theoretical analyses and numerical evaluations based on the wave propagation theory to find dynamic characteristics of an alluvial basin locally situated on a half spatial bedrock due to concentrated loadings on the free surface. The method presented herein is derived from the Aki and Larner's method by releasing the assumption of the repeated irregularities, so that the wave field having localized irregularities can be evaluated. The numerical analyses show that the amplification effects are obvious on the free surface inside the alluvial sediment and the subsurface structure influences the seismic behavior observed on the surface.

INTRODUCTION

Aki and Larner(1970) presented a practical method to investigate seismic responses of a layer-over-half-space with an irregular interface subjected to incident plane SH waves. Bard and Bouchon(1980) applied the method to the problems concerning sediment -filled valleys due to incident plane waves and gave some results in time and frequency domain. The essential assumptions on which the method is based are the neglection of upward-going scattered waves near the interface in the half-space and the periodicity in the shape of the interface in horizontal directions. The former assumption induces incomplete description of the wave field. The latter induces effects of repeated irregularities, which will be shown later in the numerical examples carried out in the time domain.

Baba, Inoue and Nishigaki(1988) derived a method from the Aki and Larner's method(1970) by means of the analytical manipulation to release one of the assumptions involeved in it, or the periodicity in the shape of the interface, so that the seismic wave field with localized geologic irregularities and the radiating phenomina toward an infinitely far field can be evaluated.

In order to study the dynamic characteristics of the slightly alluvial basin locally situated on a half-spatial bed rock due to forced disturbances such as artificial explosions, the incident field due to concentrated loadings on the surface are prepared herein for the formulation of the problem in the following manner on the basis of the method presented by Baba et al. (1988), as mentioned below in brief.

In description of this problem having the complicated and irregular boundaries, the total displacement field is divided into the incident motion corresponding to the loadings and the scattered field due to the presence of irregular boundaries. The scattered field is further divided into the two sets of fields, producing the following subproblems (P0) and (P1);

(P0) the one related to a layered half space whose boundaries are extended flat in horizontal directions and

(P1) the other corresponding to the difference between the problem initialy given in the present study and the auxiliary subproblem(P0).

By applying Fourier transforms to the wave field (P1) in terms of spatial variables, the integral equations are derived without producing singular components in the infinite integrals. The response functions are expressed in combination with the coefficients given by the solution of the subproblems (P1) and (P0); the former can be solved numerically and the latter analytically.

Finally ,the numerical results in the domain of frequency and time are presented for some physical properties of the problem.

FORMULATION OF THE PROBLEM

The 2-dimensional wave field is composed of multiple layers overlying a half basis due to concentrated loadings on the free surface. Each layered medium is assumed to be linear biscoelastic and irregularly bounded by the surface Γ_0 and the interfaces Γ_j ($j=$ I , II , ... J). In consequence, the turbulent condition(1-1) of a concentrated force on the surface Γ_0 and the continuous conditions(1-2) of stress and displacement on the interface Γ_j are required to be satisfied as well as the radiation conditions in the infinitely far field;

$$\tau_{I} = P_0 \qquad \text{on } \Gamma_0 \quad (1\text{-}1)$$

$$u_j = u_{j+1}, \quad \tau_j = \tau_{j+1} \qquad \text{on } \Gamma_j \quad (1\text{-}2)$$

in which u_j and τ_j are the displacement and stress vector in the medium(j).The displacement field is represented as a combination of the incident field u^i and the scattered one u^s.

$$u = u^i + u^s \qquad (2)$$

where the incident field and the scattered one are presented in Fourier integral forms in respect of the wave number parameter in horizontal directions, by using the spatial Cartesian coordinate system(x,z) in frequency domain;

$$u^i = \int_{-\infty}^{\infty} dp\; e^{ipx} A^i(x,p) Y^i(p) \qquad (3\text{-}1)$$

$$u^s = \int_{-\infty}^{\infty} dp\; e^{ipx} A(x,p) Y(p) \qquad (3\text{-}2)$$

in which x is the position vector in the wave field, $Y^i(p)$ is determined under the turbulent conditions and the boundary ones in the far field and Y(p) are denoted as the unknown coefficients in wave number domain. When the wave field is completely described in the irregularly layered system, it should contain upward-going components together with downward ones. The scattered representation in the half 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 Γ_J is slight and the excitations have only low frequency components.

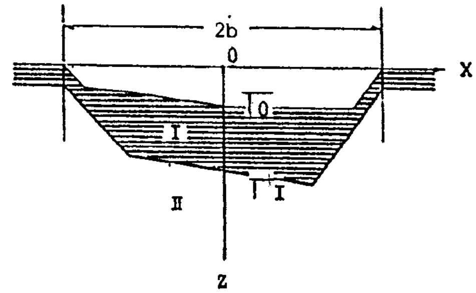

Fig.1 Configuration of ground having irregular boundaries

By instituting Eqs.(2),(3) into the boundary conditions(1), the following equations associated with the unknown coefficients Y(p) are obtained.

$$\int_{-\infty}^{\infty} dp\; e^{ipx} G(x_c,p) Y(p) = \int_{-\infty}^{\infty} dp\; e^{ipx} H(x_c,p) \qquad (4)$$

in which x_c is the position vector of the irregular boundaries uniquely defined by the horizontal coordinate x. The Fourier transform applied to the Eq.(4) in terms of the horizontal coordinate x, may lead to the boundary equations in the wave number domain, however the infinite integrals in the equations are not always convergent. So as to assure the convergence of those infinite integrals, a subproblem(P0), which is related to the flatly layered half space, is introduced with the restrictions imposing on the boundary configuration;

(Z0) the irregular zone which includes the heterogeneous boundaries of multiple layers bounded finite in $|x|<b$ and

(Z1)the regular zone composed of the flatly layered half space in $|x|>b$.

The boundary equations for the subproblem (P0) are given in the similar manner to the Eq.(4) ;

$$\int_{-\infty}^{\infty} dp\; e^{ipx} G_0(p) Y_0(p) = \int_{-\infty}^{\infty} dp\; e^{ipx} H_0(p)$$

or

$$Y_0(p) = G_0^{-1}(p) H_0(p) \qquad (5)$$

The coefficients of Eqs.(4), (5) hold the following relationships ,

$$\begin{bmatrix} G(x_c,p) \\ H(x_c,p) \end{bmatrix} = \begin{bmatrix} G_0(p) \\ H_0(p) \end{bmatrix} \quad : \quad |x| > b \qquad (6)$$

The boundary equations(4) are reconstructed by using the coefficients $Y_1(p)$, which are defined as the difference between Y(p)and Y_0 (p);

$$Y_1(p) = Y(p) - Y_0(p) \qquad (7)$$

After Fourier transormed along the horizontal direction and changed in the order of integrals in terms of the parameter p and x, the equation (4) yields the following integral equations in the domain of wave number and frequency;

$$2\pi G_0(p)Y_1(p)+\int_{-\infty}^{\infty}dp\{K(p,q)-K_0(p,q)\}Y_1(p)$$
$$=\int_{-\infty}^{\infty}dp\{F(p,q)-F_0(p,q)\} \quad (8)$$

in which the kernel matrices and the inhomogeneous vectors are obtained in the finite integral forms;

$$\begin{bmatrix} K(p,q) \\ K_0(p,q) \end{bmatrix} = \int_{-b}^{b}dx\ e^{i(p-q)x}\begin{bmatrix} G(x_c,p) \\ G_0(p) \end{bmatrix} \quad (8\text{-}i)$$

$$\begin{bmatrix} F(p,q) \\ F_0(p,q) \end{bmatrix} = \int_{-b}^{b}dx\ e^{i(p-q)x}\begin{bmatrix} H(x_c,p) \\ G(x_c,p)Y_0(p) \end{bmatrix} \quad (8\text{-}2)$$

Furthermore ,the finite integrals can be expressed analytically when the irregular boundaries are composed of piecewise linear planes .

The displacement responses of this irregularly layered medium due to unit exciting forces concentrated on the free surface are expressed in terms of the coefficients $Y_1(p)$;

$$u(x)=u^i(x)+\int_{-\infty}^{\infty}dp\ e^{ipx}A(x,p)\{Y_0(p)+Y_1(p)\} \quad (9)$$

Consequently, by making use of the spectrum $s(\omega)$ of exciting forces and the impulsive response functions (9) of the systems, the transient displacement responses are presented through the Fourier inversion transforms in respect of frequency parameter ω;

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

REMARKS ON AKI AND LARNER'S METHOD

In the Aki and Larner's method(1970), the upward - propagating scattered waves near the interface in the lower medium are assumedsmall enough to be neglected for practical purposes and the function $\zeta(x)$, which defines the interface shape, is set periodic along the horizontal axis;

$$\zeta(x+mL)=\zeta(x), \quad : m = \pm 1, \pm 2 \ldots$$

The former assumption results in incomplete description of the wave field. The latter induces effects of repeated irregularities in evaluating the problems with localized geologic irregularities.

On the other hand, Baba,Inoue and Nishigaki (1988) presented a method which is successful in evaluating the seismic wave field with local irregularities and the radiating phenomina toward an infinitely far field.

Numerical examples

In order to examine the validity of these assumptions imposed on the Aki and Larner's method, numerical analyses are executed in comparison with the one presented by Wong and Trifunac(1974) or Baba,Inoue and Nishigaki(1988).

For the convinience of the study, the following dimensionless parameters and dimensionless components are introduced with subscript($^-$).

$$\begin{bmatrix} \bar{x} \\ \bar{z} \end{bmatrix} = \frac{1}{b}\begin{bmatrix} x \\ z \end{bmatrix} \qquad \begin{bmatrix} \bar{p} \\ \bar{q} \end{bmatrix} = b\begin{bmatrix} p \\ q \end{bmatrix}$$

$$\bar{\omega} = \omega b/C_0 \qquad \bar{t}=tC_0/b$$

$$\bar{C}_j=C_j/C_0 = \bar{C}_{j0}(1+iD_j) \quad (j = \mathrm{I}, \mathrm{II})$$

$$\bar{\zeta}(\bar{x}) = \zeta(x)/b \qquad \bar{u}=u\mu_0 b/P_0$$

in which ω,t are the angular frequency and the time factor, P_0 is the amplitude of a concentrated external force ,C_0, μ_0 are the standard shearing velocity and the standard shearing constant. D_j,v_j,C_j are damping factor, Poisson's ratio and generalized shearing velocity of medium (j).

Example 1

The model(A) consists of double layered medium having an interface linearly interpolating 31 nodes fixed on a semi -elliptical outline with the ratio of the major to minor axis,R = 0.3, as shown in the Fig. 2, and the definition of the interface position;

$$\bar{\zeta}(x) = a_n x + b_n \quad : -\cos\theta_n < x < -\cos\theta_{n+1}$$
$$= 0 \quad : |x| > 1$$

where

$$a_n = \frac{0.3(\sin\theta_{n+1} - \sin\theta_n)}{(-\cos\theta_{n+1}+\cos\theta_n)}$$

$$b_n = 0.3 \sin\theta_n + a_n \cos\theta_n$$

$$\theta_n = 2\pi n / 30 \quad (n = 0,1,2, \ldots ,30)$$

The model(B) consists of a layered medium with a semi-elliptical interface, R = 0.3. In both models (A)and (B), the soil is composed of the linear hysteric type biscoelastic medium whose generalized Lame's constants are expressed in complex forms with the numerical values chosen as;

$$\bar{C}_{I0} = 0.5 \ , \ \bar{C}_{II0} = 1 \ , \ D_I = 0 \ , \ D_{II} = 0$$

Each cross section of the basin in the model (A) and (B), is equally set in area. The excitation consists of infinite train of SH waves propagating from below with the incident angle $\gamma = 0, \pi/3$, amplitude 1 and angular frequency $\omega = \pi C_{II}/b_1$, which leads to the dimensionless angular frequency $\bar{\omega} = \pi b_0 / b_1 = 1.00091\pi$ for the model (A) and $\bar{\omega} = \pi$ for the model (B), where b_0, b_1 are the half width of the basin in the model (A),(B) ,respectively.

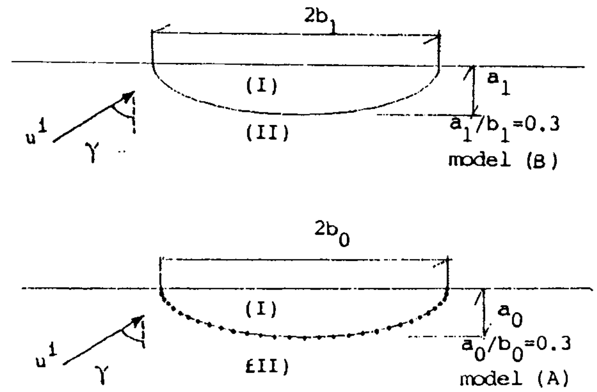

Fig. 2 Configuration of ground model (A),(B)

In numerical calculations, the Aki and Larner's method(1970) is applied to the model(A), adopting two sets of parameters, $\bar{L}=4$,(2N+1)=31 and $\bar{L}=20$,(2N+1)=121, where $\bar{L} = L / b$ is the period of interface shape and (2N+1) is the total of truncated and descretized wave numbers. The same problem is analysed on the basis of the method presented by Baba et al.(1988), chosing

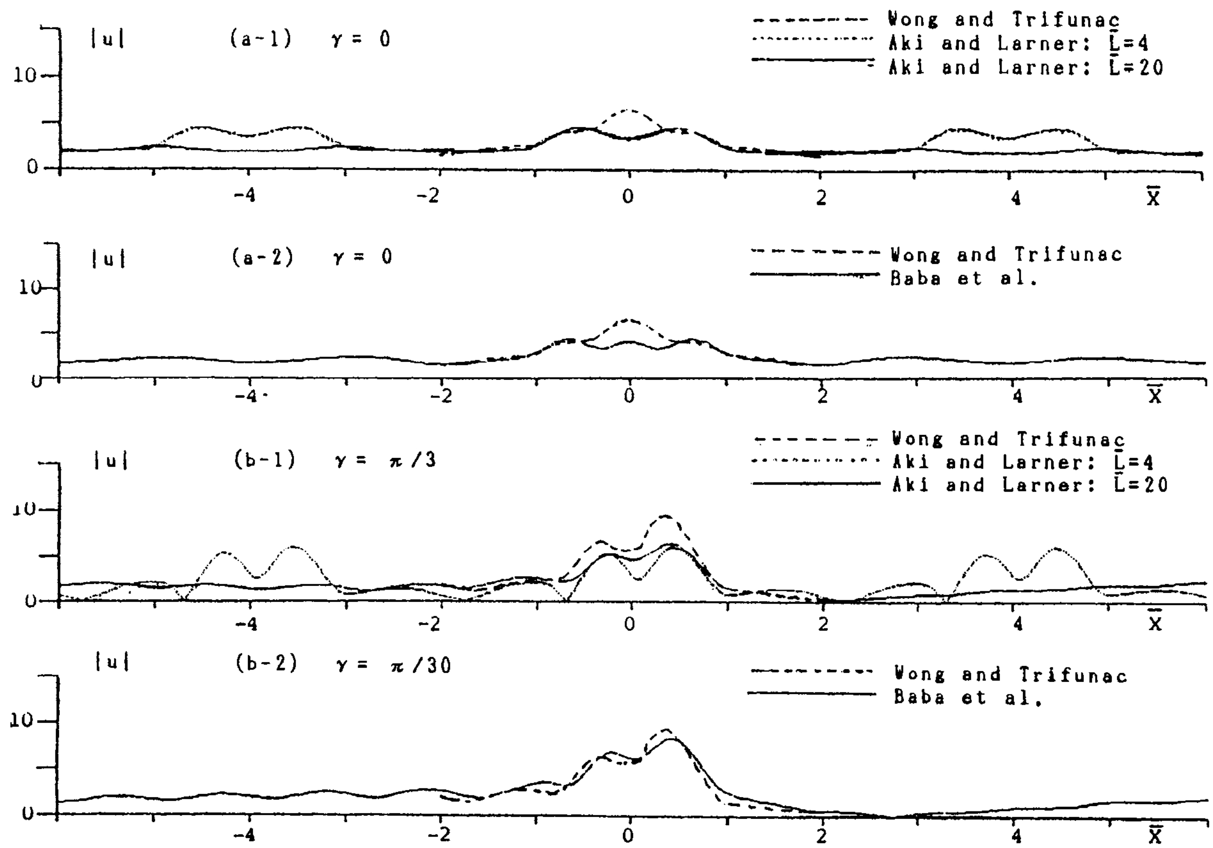

Fig.3 Displacement amplitude on Γ_0;model(A),(B)

the parameters, $\Delta \bar{p} = 0.2$ and $(2N+1)=121$, where $\bar{\Delta} p$ is the increment of the discrete wave number. On the other hand, Wong and Trifunac (1974) gave exact solutions to the problems concerned with the model(B).

Fig. 3 shows the displacement amplitude on the free surface in the model (A) and (B), due to incident plane SH waves. The results given by the Aki and Larner's method(1970) exhibit a dipendence on the period of the interface shape, especially when the incident angle is large, as well as a tendancy to come close to the exact values for the model(B) in association with the larger periodicity of the interface shape. The method derived by Baba et al.(1988) also shows good agreement with the exact values for the model(B).

Example 2

The transient behavior is calculated in the case that the geologic model(C) with a flat bottomed interface is subjected to vertically incident plane SH waves, as shown in Fig.4.

In the analysis, the Aki and Larner's method is applied to the problem setting the parameters, $\bar{L}=2\pi$, $N=60$ and $\bar{\omega}=n\Delta\bar{\omega}$, whereas the method of Baba et al.(1988) is applied to the same problem with the parameters,

$\Delta\bar{p}=1$, $N=60$ and, $\bar{\omega}=n\Delta\bar{\omega}$, in which $\Delta\bar{\omega}=0.1$, $n=1,2,\ldots,100$. The incident waves are provided with the Ricker wavlet with the peak frequency $\bar{\omega}_p=5$. Fig.5 shows the time histories of the displacement on the free surface. The effects of repeated irregularities observed at $\bar{t}>450\Delta\bar{t}$ in Fig.5(a); the scatterd waves induced by the imaginarily repeated irreegularities are observed. As shown in Fig.5(b), the method given by Baba et al. (1988) can avoid such effects and works efficiently within longer time intervals.

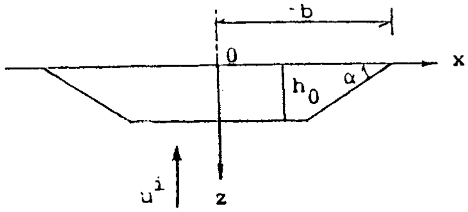

Fig. 4 Configuration of ground model(C)

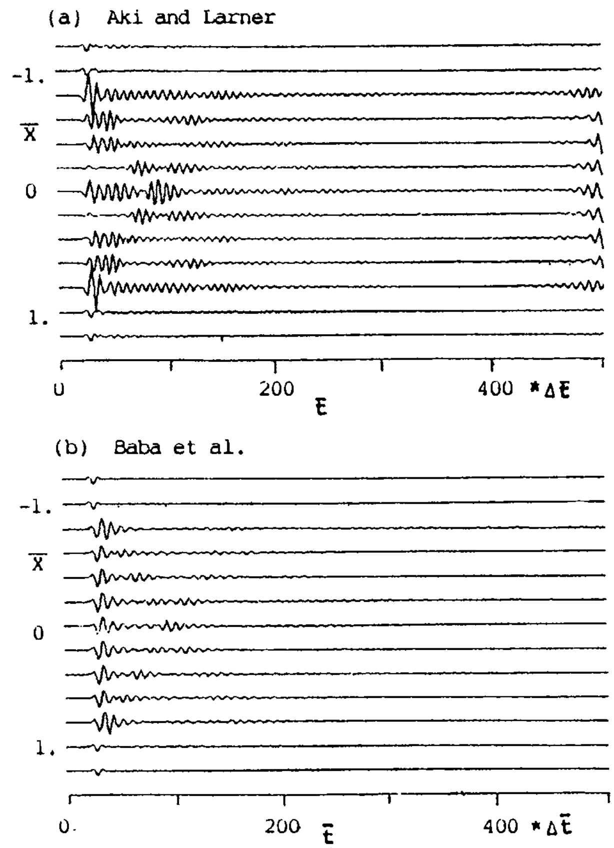

Fig.5 Time histories of displacement on Γ_0 ; $\bar{\omega}_p=5$, $\Delta\bar{t}=0.1227$

SEISMIC BEHAVIOR OF AN ALLUVIAL BASIN DUE TO CONCENTRATED LOADINGS ON SURFACE

The geologic structure models (D),(E),(F) and (G) are employed to analyse the dynamic characteristics of an alluvial basin due to concentrated loadings on the free surface, setting the identical numerical values in these models as;

$$\bar{C}_{I0}=0.177,\ \bar{C}_{B0}=1,\ D_I=0.025,\ D_B=0.01$$

$$\bar{h}_0=0.05,\ \alpha=\pi/6\quad \nu_I=\nu_B=0.333$$

(1)As shown in Fig. 6, the displacement responses distributed over the ground surface present the considerable growth inside the alluvial sediment when it is subjected to concentrated loadings on the basin, whereas a little in the case of loadings situated on the bedrock outside the basin.

(2)In Fig. 7, the frequency response functions on the surface show remarkable ampification in the domain $5<\omega<10$ inside the basin, in contrast, a little prominence outside the basin.

(3)With regard to the transient behavior of the wave field due to the concentrated loadings of the Ricker wavelet with a peak frequency $\bar{\omega}_p=5$. As shown in Fig. 8, the wave front is translated linearly in the horizontal direction in the case of the flat bottomed basin (model D), and the wave mode is extremely crushed when the wave front encounters the projection of a half basis(model E). When the bottom of the basin is inclined as shown in Fig. 9, the wave front vanishes as its depth of the bottom is increased in proportion to the distance from the point source(model G), while the wave front grows larger with its depth decreased(model F).

CONCLUSIONS

In evaluating the seismec wave field, the Aki and Larner's method involves the assumption which requires the periodic subsurface structure in horizontal directions, which may induce undesirable effects of scattered waves resulted from repetition of the irregularities. On the other hand, Baba et al.(1988) succeeded in releasing the assumption to evaluate the wave field with local geologic irregularities. In this paper , the incident field due to concentrated loadings on the free surface is prepared for the formulation and dynamic characteristics of an alluvial basin locally situated on a half spatial bedrock is analysed to be concluded as;

(1)The site effects are obvious, showing greater amplification effects on the free surface inside the alluvial sediment.

(2)The subsurface structure affets the seismic behavior of the wave field.

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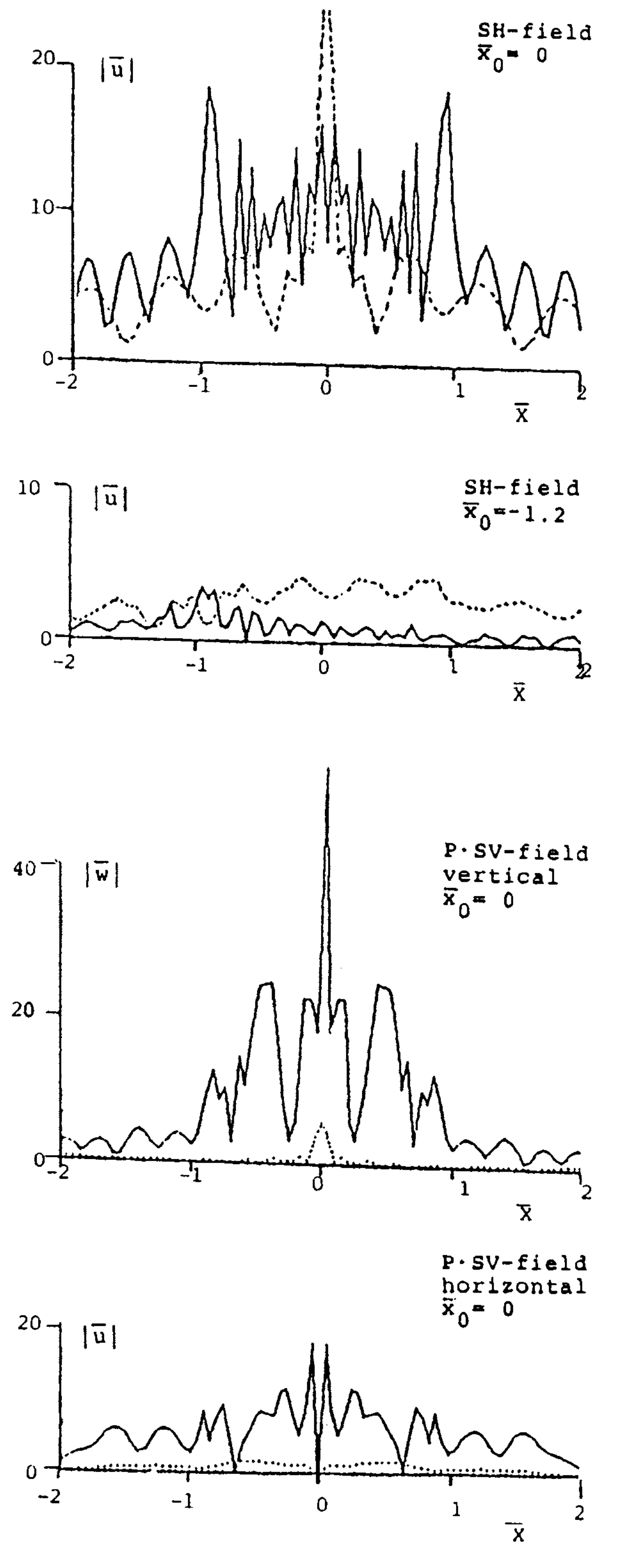

Fig. 6 Displacement amplitude on T_0 in model (D)

:---- $\bar{\omega}=5$, —— $\bar{\omega}=10$

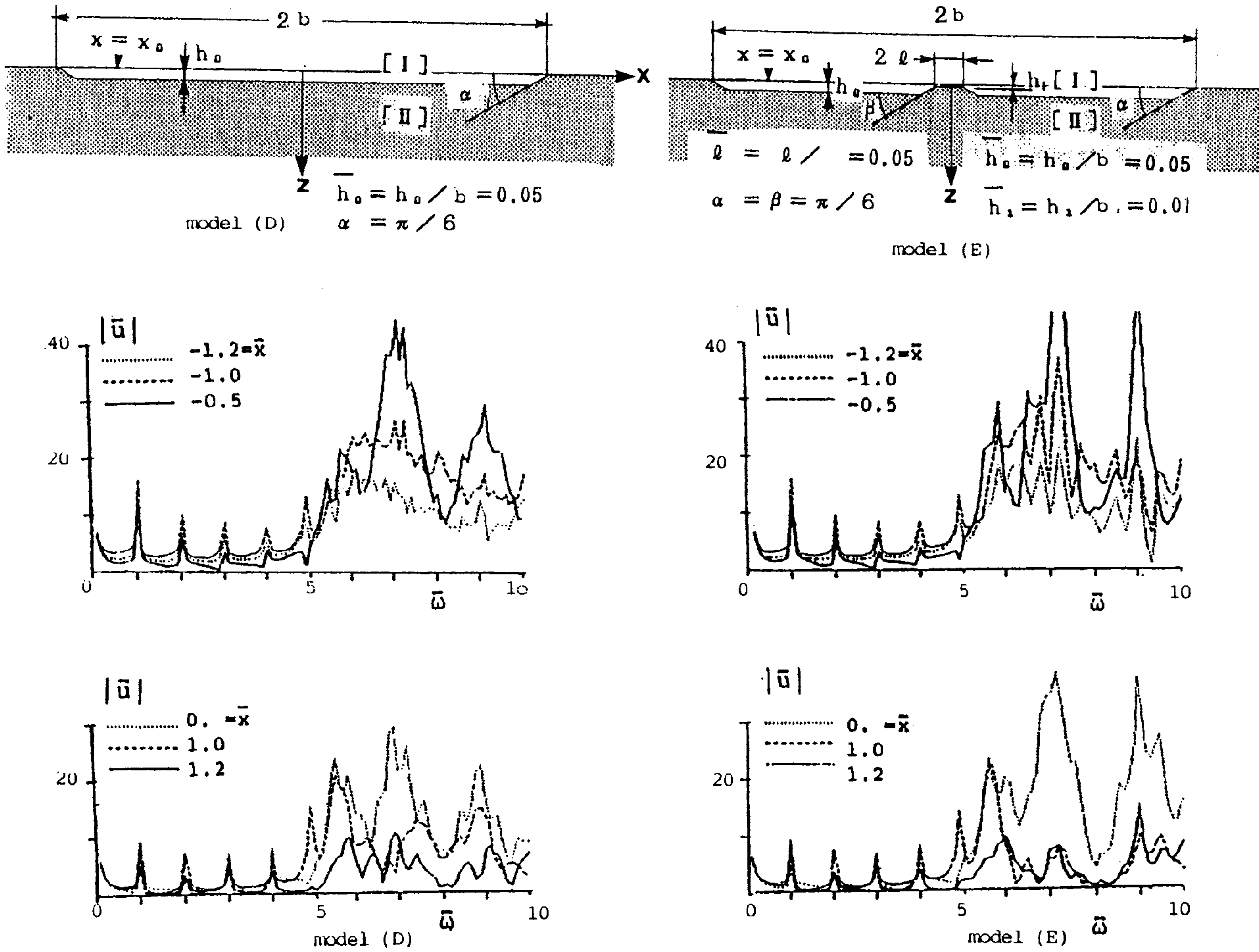

Fig. 7 Frequency amplification functions on Γ_0 in SH-field

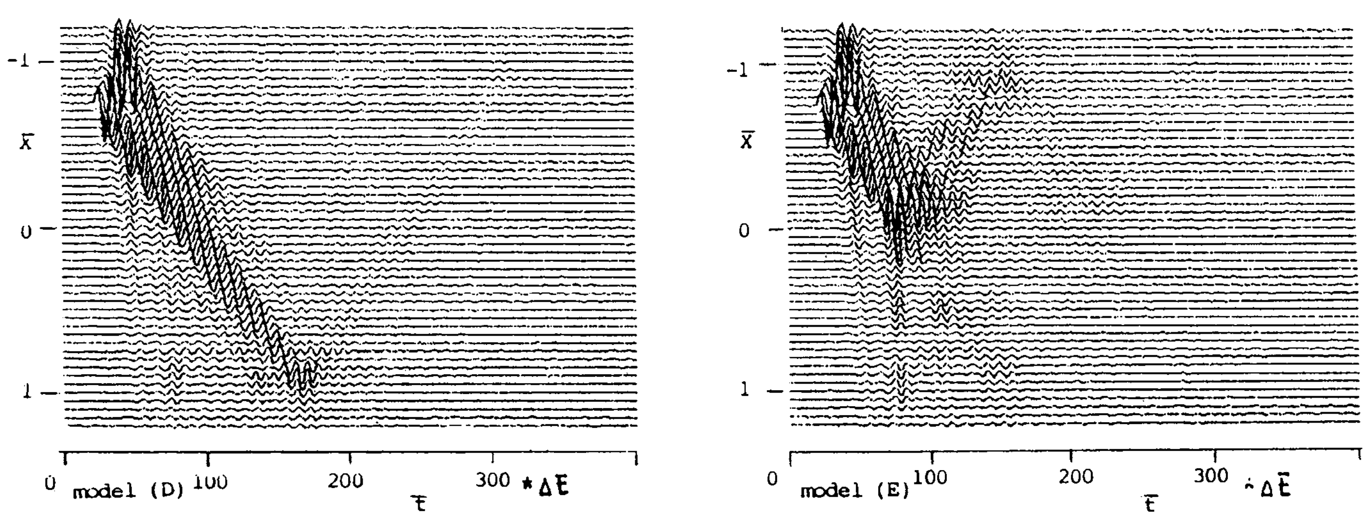

Fig. 8 Time histories of displacement on Γ_0 in SH-field
:$\bar{\omega}_p$=5, $\Delta\bar{t}$=0.1227

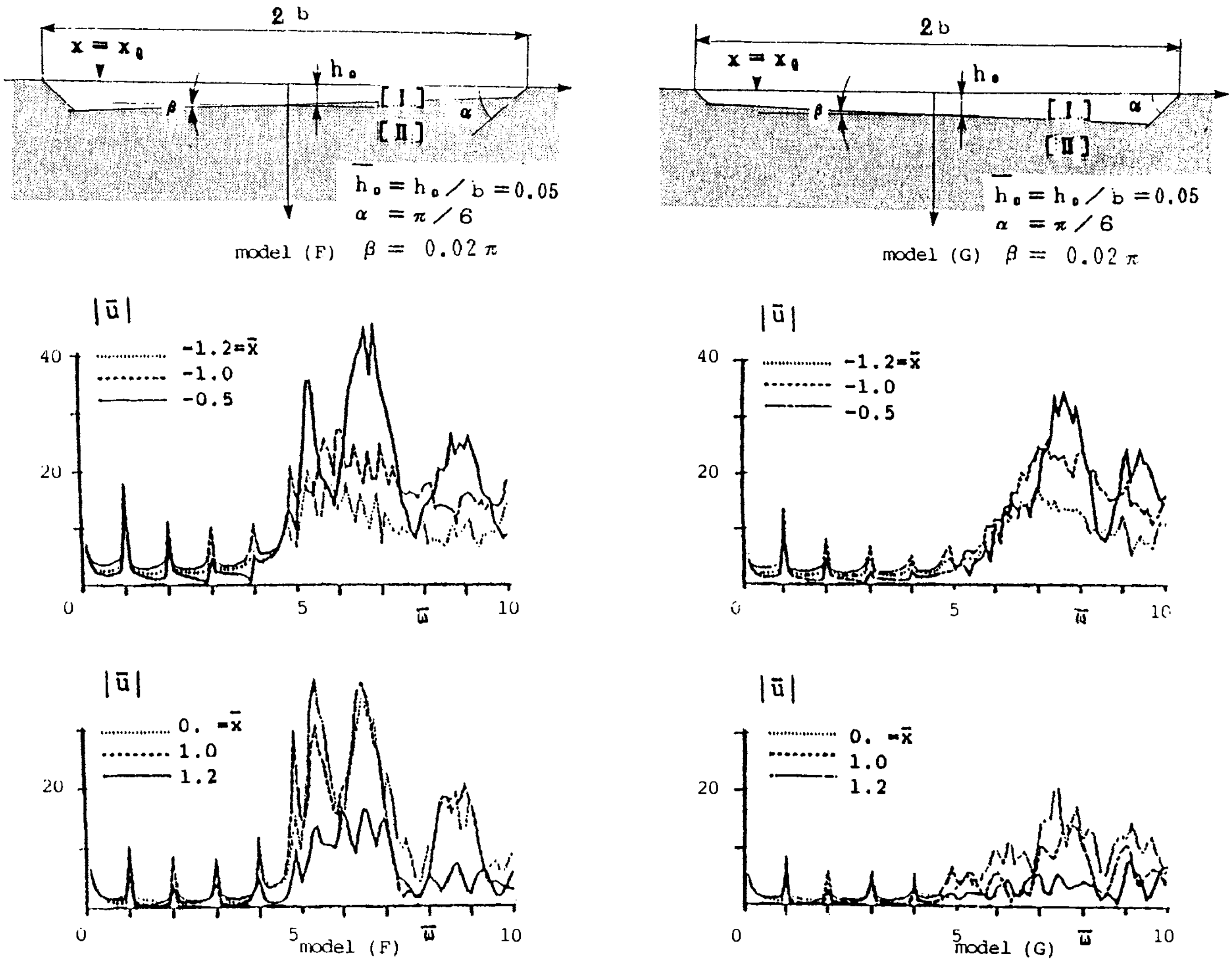

Fig. 9 Frequency amplification functions on Γ_0 in SH-field

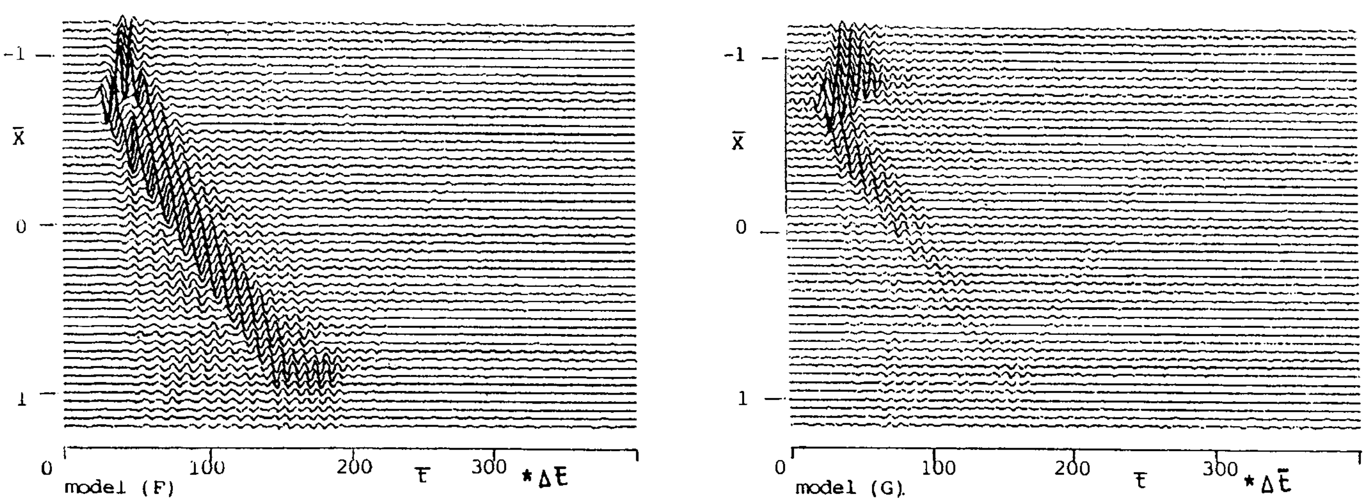

Fig. 10 Time histories of displacement on Γ_0 in SH-field
: $\bar{\omega}_p=5$, $\Delta\bar{t}=0.1227$