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SIMPLIFIED SEPARATION TECHNIQUE OF BODY AND SURFACE WAVES IN STRONG MOTION ACCELEROGRAMS

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A simplified separation technique of body and surface waves in strong motion accelerograms have been proposed. To confirm the dispersion characteristics of surface waves the evolutionary power spectrum have been examined for Japane typical accelerograms. The parameters t_d, and f_d, in time and frequency domain, respectively, have been defined as the separation parameters. To make sure of importance of separation, ground strain caused by body and surface waves have been analyzed for original data and its separated body and surface waves. It has been pointed out that the separated surface waves should be used spcially for estimation of local ground strain.

1. INTRODUCTION

It is a significant subject in earthquake engineering to evaluate ground strain caused by earthquake motions. For estimation of ground strain the multi-reflection theory for shear waves has been often applied for ground motion records. Haskell's model[1] for surface wave analysis has been also used[2] for estimation of ground strain caused by surface wave propagation. The strong motion data used for calculation of ground strain should be confirmed whether it consists of body waves or of surface waves. Most of strong motion data, however, consist of body and surface waves, and it is impossible to separate exactly these two types of waves in the data recorded at a single independent site. Dense observation networks for strong ground motions have been recently set up by many research groups[3] to observe relative grond motions caused by surface and body waves. The array data from these network stations have been accumulated little by little, however the data from strong earthquake have been scarecely obtained.

In this view of the problem, this paper deals with a simplified separation technique of body and surface waves in strong motion accelerograms. The evolutionary power spectrum[4] of strong motion accelerograms have been obtained to specify dispersion characteristics of surface waves. Difference of strain level of surface waves calculated from original data and separated surface waves has been discussed with regard to a relative distance in which relative ground motions are considered. The present study is a generalization of the study by the authors[5],[6].

2. SEPARATION OF BODY AND SURFACE WAVES

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Surface waves which propagate in multilayerd media have dispersion characteristics. Evolutionary power spectrum[4] can make it possible to recognize dispersive wave energy of surface waves in strong motion time histories[7]. In this study Rayleigh waves are dealt with as an example of surface wave components. Therefore the evolutionary power spectra for the grond motions in the direction to the epicenter are examined in the following calculations. **Fig.1** shows an example of evolutionary power spectra of strong motion records at Hachinohe site during the 1968 Tokachi-oki Earthquake[8]. The filter damping β_0[4] has been fixed as $\beta_0=0.05$ in calculation of evolutionary spectra. In Fig.1, the acceleration time history, which has been corrected[9] for baseline and instrument, represents ground motions in the direction to the epicenter. Generally, surface waves can be recognized sometime after the principle motions in recorded accelerograms which contain surface wave components, and surface waves are dominant in relatively low frequency range. Therefore, the peak time $t_m(f)$, which gives a time when the evolutionary spectrum gets its maximum value, can be modeled as shown in **Fig.2**. The point A in **Fig.2** represents the resonant frequency of surface waves and the energy of waves are concentrated at around this frequency. From these characteristics of surface waves, the ground motions in the shadowed area in **Fig.2** can be regarded to consists mainly of surface wave components. As shown in **Fig.2**, the separation frequency f_d can be determined at the point B : the dispersion characteristics cannot be found. The separation time t_d can be also defined to separate body and surface waves in time domain. The parameter t_d is defined as the time when the evolutionary spectra of low frequency range, in which dispersive wave energy can be obseved, start to increase. **Fig.3** shows

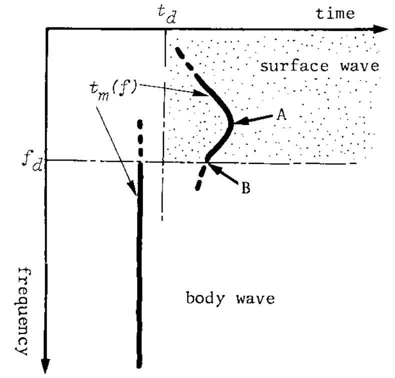


Fig.2 Schematic Description for Peak Time $t_m(f)$ of Evolutionary Power Spectra with Separation Parameters t_d and f_d.

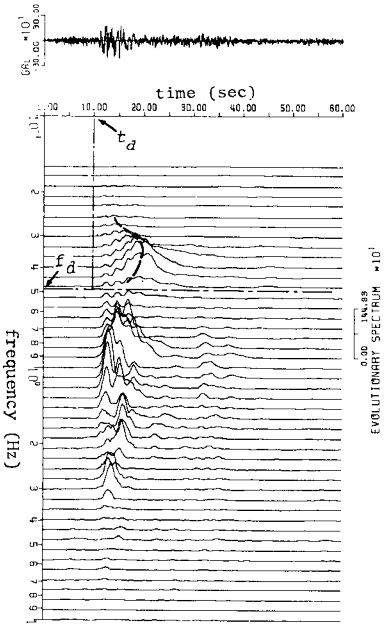
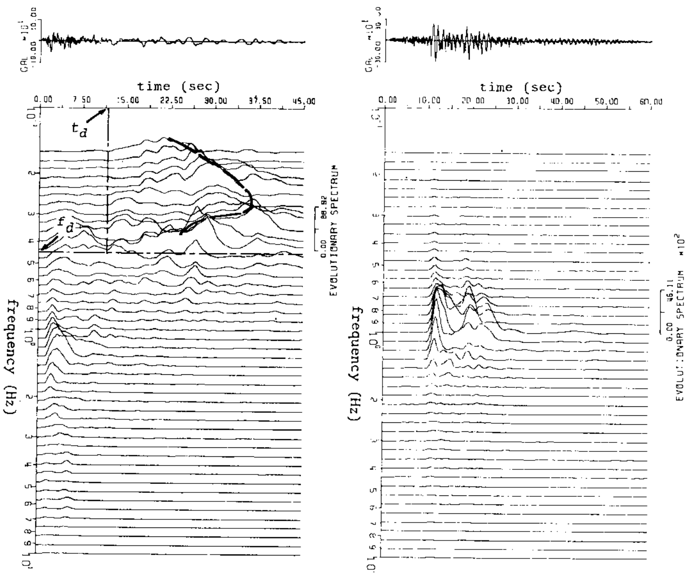


Fig.1 Evolutionary Power Spectra with Acceleration Time History (S-252 Hachinohe, Direction ot Epicenter, 1968 Tokachi-oki Earthq.).



(a) S-1066 Shimizumiho, Direction to Epicenter, Izu-Ōshima Kinkai Earthq., $M=7$, $\Delta=71.4$ km $d_p<$ 10 km.

(b) S-1202 Shiogama Kojyo, Direction to Epicenter, 1978 Miyagiken-oki Earthq., $M=7.4$, $\Delta=100$ km, $d_p=$ 40 km.

Fig.3 Typical Examples of Evolutionary Spectra.

other two typical examples of evolutionary spectra. Fig.3(a) shows the example where a depth of fault d_p is quite shallow (less than 10 km), and the dispersive wave energy are recognized clearly. The separation parameters can be determined as $f_d=0.45$ Hz, and $t_d=11.6$ second. On the other hand, the dispersive wave energy cannot be found in case of Fig.3(b), a depth of fault d_p of which is 40 km.

After obtaining the separation parameters f_d and t_d from the evoutionary power spectra of the accelerograms, the separated body wave $x_b(t)$ and surface wave $x_s(t)$ can be represented as follows.

(a) $0 \leqq t \leqq t_d$

$$\left.\begin{aligned} x_b(t)&=\frac{1}{2\pi}\int_{-\infty}^{\infty}F(\omega)e^{i\omega t}d\omega,\\ x_s(t)&=0 \end{aligned}\right\} \quad \cdots\cdots\cdots (1)$$

(b) $t_d<t$

$$\left.\begin{aligned} x_b(t)&=\frac{1}{2\pi}\int_{-\infty}^{\infty}F_s(\omega)e^{i\omega t}d\omega,\\ x_s(t)&=\frac{1}{2\pi}\int_{-\infty}^{\infty}F_b(\omega)e^{i\omega t}d\omega \end{aligned}\right\} \quad \cdots\cdots\cdots (2)$$

in which, $\omega=2\pi f$ and,

$$F_b(\omega)=0, \qquad F_s(\omega)=F(\omega), \qquad (f_l \leqq f < f_d)$$

$$F_b(\omega)=F(\omega), \qquad F_s(\omega)=0, \qquad (f_d \leqq f < f_u)$$

where $F(\omega)=F(2\pi f)$=Fourier Transform for accelerogram $x(t)$, and f_l, f_u=lower and upper cut-off frequency, respectively. These limit frequencies are fixed as $f_l=0.15$ Hz and $f_u=10.0$ Hz, according to the correction filter[9] for the accelerograms used in this study.

Fig.4 shows examples of separated body and surface waves with its original data. The separation parameters for this accelerograms have been given as $t_d=10.0$ sec and $f_d=0.48$ Hz as shown in Fig.1. It can be obseved that body wave mainly contributes to acceleration of original data and surface wave mainly contributes to displacement in these cases. It may be concluded that the separation procedure described above can be used for separation of body and surface waves as an apporoximate estimation.

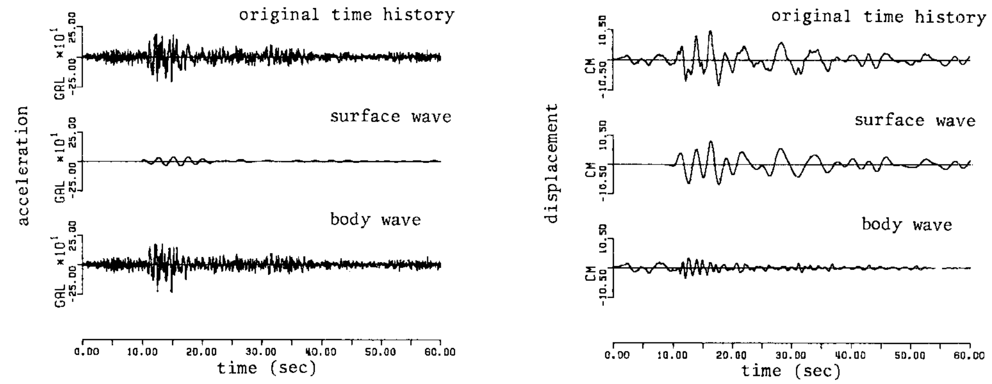


Fig.4 Separated Body and Surface Waves with Its Original Time Histories ($t_d=10$ sec, $f_d=0.48$ Hz, S-252 Hachinohe, Direction to Epicenter, 1968 Tokachi-oki Earthq.).

3. GROUND STRAIN CUASED BY BODY AND SURFACE WAVES

Ground strain cuased by body and surface waves have been discussed using the separated waves and its original data. As a typical example the soil profile data[10] shown in Table 1 and the corrected accelerograms dealt in the previous chapter have been used. The P-wave velocity v_p in Table 1 is given by use of ;

Table 1 Velocity Model for Hachinohe Site.

No. of layer	thickness (m)	v_s (m/sec)	v_p (m/sec)	density (gr./cm^3)
1	2.0	100.0	332.0	1.8
2	2.0	160.0	531.0	1.8
3	5.0	200.0	664.0	1.9
4	21.0	275.0	912.0	1.7
5	30.0	320.0	1061.0	1.7
6	15.0	340.0	1128.0	1.8
7	105.0	379.0	1257.0	1.9
8	180.0	690.0	2284.0	2.0
9	20.0	1100.0	3641.0	2.1
10	——	2800.0	5240.0	2.5

Table 2 Maximum Shear Strain on Top of Layers obtained from Separated Body Wave and Original Time History (S-252 Hachinohe, 1968 Tokachi-oki Earthq.).

(unit x10^{-4})

No. of layer	original wave	separated body wave
1	0.	0.
2	3.73	3.70
3	3.31	3.34
4	3.21	2.98
5	4.43	4.01
6	6.27	5.70
7	4.62	4.30
8	1.24	0.63
9	1.01	0.64
10	0.15	0.10

$$v_p = v_s \cdot \sqrt{\frac{2(1-\nu)}{1-2\nu}} \qquad (3)$$

where v_s=shear wave velocity and Poinsson's ratio ν is given as $\nu=0.45$ for sand and gravel, $\nu=0.46$ for clay and silt[11], and $\nu=0.3$ for rock.

(1) Ground Strain Caused by Body Waves

Ground strain cuased by body waves have been examined for separated body waves and its original data using the multi-reflection theory for shear waves. The equi-linearized method for shear rigidity and damping has been used for numerical calculations. Table 2 shows peak ground strain for each layer of Hachinohe site.

In Table 2 peak ground strains for original data and separated body waves do not differ very much specially in the layers near surface ground. This result supports the idea that original data can be used for approximate estimation of ground strain for body waves.

(2) Ground Strain Caused by Surface Waves

Ground strain cuased by surface waves have been examined for original data and separated surface waves. Relative ground motions at two points of relative distance D[12] along the ground surface have been dealt with for evaluation of surface wave-ground strain.

Mean ground strain $\varepsilon(D,\ t)$ between two points of relative distance D can be represented as

$$\varepsilon(D,\ t)=\frac{1}{2\pi}\int_{-\infty}^{\infty} F_d(\omega) ik \sin(kD/2)/(kD/2) e^{i\omega t} d\omega \qquad (4)$$

where $F_d(\omega)$=Fourier Transform for displacement $d(t)$, k=wave number given as $k=\omega/c$, and c= phase velocity of surface waves. Ground strain $\varepsilon(t)$ for $D=0$ is given as

$$\varepsilon(t)=\frac{1}{2\pi}\int_{-\infty}^{\infty} F_d(\omega) ik e^{i\omega t} d\omega \qquad (5)$$

Fig.5 shows phase and group velocities of Rayleigh wave for Hachinohe site. The frequency range where dispersive characteristics are predominant is approximately 0.25~0.45 Hz, and the resonant frequency is around 0.35~0.4 Hz. These values coincide with those in Fig.1.

Assuming that the Rayleigh waves are eminent in the direction to the epicenter, mean ground strain caused by Rayleigh waves have been examined. Fig.6 shows examples of mean ground strain obtained from separated surface wave and original data. In case of original data shown in Fig.6(b), ground strain strongly depends on relative distance D. The reason for the large value of ground strain for a case of small relative distance is that high frequency

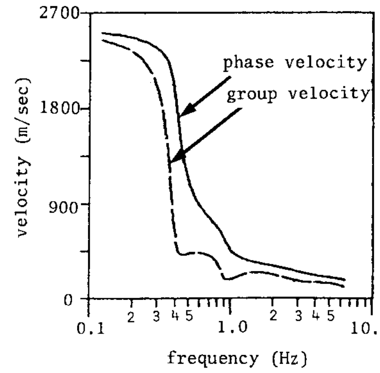
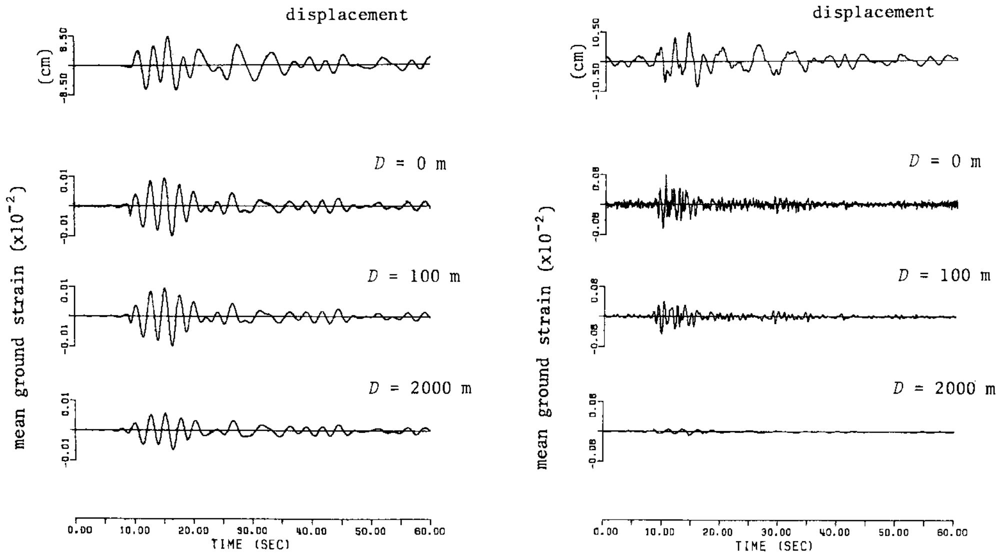


Fig.5 Phase and Group Velocity of Rayleigh Wave for Hachinohe Site.



(a) separated surface wave

(b) original time history

Fig.6 Mean Ground Strain Obtained from Separated Surface Wave and Its Original Data with Displacement Time Histories (t_d=10 sec, f_d=0.48 Hz, S-252 Hachinohe, Direction to Epicenter, 1968 Tokachi-oki Earthq.).

components of body waves have been regarded as surface waves ; these high frequency components, which are regarded to have short wave length, amplify the surface wave strain strongly. Fig.7 shows relation between peak values of mean ground strain and relative distance. It can be seen that the peak value of mean ground strain obtained from original data approach that from separated surface waves with increase of relative distance.

From the above numerical results it can be concluded that the separation of surface waves from original data is important specially for a case of estimation of local ground strain.

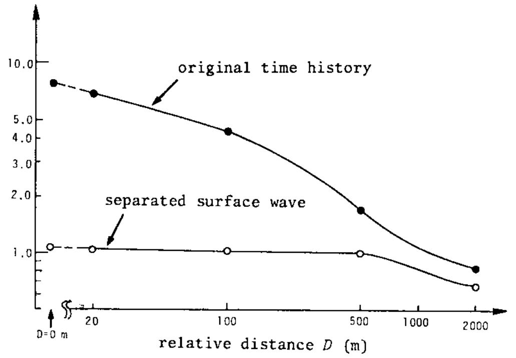


Fig.7 Maximum Ground Strain obtained from Separated Surface Wave and Its Original Data Against Relative Distance D.

4. CONCLUSIONS

Major results derived from this study may be summarized as follows.

(1) A simplified separation technique of body and surface waves in strong motion accelerograms has been proposed. In this technique the evolutionary power spectrum has been used to confirm the dispersion characteristics of surface waves contained in strong motion data. The separation parameters t_d and f_d, in time and frequency domain, respectively, have been proposed.

(2) Ground strains caused by body and surface waves have been analyzed for original data and its separated body and surface waves. It has been pointed out that separation of body and surface waves is important for estimation of local ground strain caused by surface wave propagation.

It is an essential subject for earthquake resistant design for buried pipes to evaluate earthquake surface motions rationally. The separation procedure which has been dealt here is anyhow a simplified technique, however, this method can be effective for evaluation of surface ground motions contained in recorded accelerograms, specially under the circumstances that surface ground motions from strong earthquakes have been scarecely obtained independently.

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