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ANALYSIS OF STRONG GROUND MOTION OF PLAIN AND BASIN BEING COMPOSED OF SOFT SOIL BY FAULT MODEL AND BOUNDARY ELEMENT METHOD

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SUMMARY

SH and Love waves in Kanto sedimentary basin are investigated by 2-D BEM including seismic source fault. Near sources are treated, and following conclusions are obtained: 1) Waveforms in the basin strongly depend on source location to the basin; 2) In particular, when a source is located shallowly and laterally away from the basin, large Love waves are generated at the basin edge; 3) The Love waves predominate only in comparatively long period. Thus, they probably influence long-period structures on the basin, if the natural period of the structures is nearly equal to the dominant period of the Love waves.

INTRODUCTION

Recently, earthquake damage of long-period structures on alluvial plain or sedimentary basin is on the increase. For example, 1) oil overflow of storage tanks in Niigata city, Japan during 1983 Nihonkai-chubu earthquake, 2) severance of elevator tail cords of high-rise buildings in Shinjuku, Tokyo during 1984 Naganoken-seibu earthquake (Ref.1), 3) collapse of multistory buildings in Mexico city during 1985 Michoacan earthquake. Many large cities are situated on soft sediment basins, and a lot of long-period structures are located on them. Thus, to investigate seismic waves of longer period in sediment basin is very important for earthquake engineering.

In order to simulate longer period (1-10 sec) seismic waves in Kanto sedimentary basin (in and around Tokyo, Japan), it is necessary to deal with a huge-scale basin model including a source fault. Because, seismic waves observed on the basin indicate that the longer period waves strongly depend on following three factors : 1) physical property of both bedrock and thick sediments (2-3 km depth), 2) three dimensional irregular shape of the basin, 3) source mechanism and its location to the basin (e.g. Refs.2,3).

Various types of methods including a source have been proposed to simulate seismic waves in a basin (e.g. Refs.4,5,6). Recently, boundary element method (BEM) is widely used to compute wave propagation and scattering in a basin (e.g. Refs.7,8). Because it naturally contains the radiation condition of waves in a infinite domain, and it needs much fewer discrete elements than domain element methods, such as finite difference method (FDM) and finite element method (FEM). Therefore, we proposed 2-D BEM including a source fault in 1987 (Ref.9).

The purpose of this paper is to study longer period SH and Love waves in

Kanto sedimentary basin with the BEM including a source, and to discuss influence of the waves on long-period structures in the sedimentary basin.

BOUNDARY ELEMENT METHOD INCLUDING SEISMIC SOURCE FAULT

Fundamental Equation of BEM Including Source Fault (Ref.9) Anti-plane waves in 2-D medium are treated. The medium consists of a bedrock and a basin sediment, as illustrated in Fig.1. The bedrock is assumed to be elastic, isotropic and homogeneous material. Its boundaries are composed of free surface, infinite boundary, internal boundary and irregular shaped boundary between bedrock and basin sediment. The free surface and infinite boundary are not treated, when we formulate the integral equation of this model with the fundamental solution of semi-infinite medium. The internal boundary is formulated as the dislocation model of the crack theory or seismology. In this study, the dislocation is modeled after Haskell's source model (Ref.10) as illustrated in Fig.2. Under the foregoing assumptions, the boundary integral equation of the bedrock in frequency domain is given by

$$V(X)/2 + \int_{\Gamma B} \{ P'(X,Y)*V(X) - V'(X,Y)*P(X) \} \, d\Gamma(X) = Vf(Xf,Y) \quad \text{--- (1)}$$

$$X = (x,z),\ Y = (xs,zs),\ Xf = (xf,zf) \quad \text{--- (2)}$$

$$\left.\begin{array}{l} V'(X,Y) = -i*\{ H0(K*R1) + H0(K*R2) \}/4, \quad P'(Xf,Y) = \mu*V',n \\ R1 = \sqrt{Rx^2 + R1z^2},\quad R2 = \sqrt{Rx^2 + R2z^2} \\ Rx = x - xs,\ R1z = z - zs,\ R2z = z + zs \end{array}\right\} \quad \text{--- (3)}$$

$$Vf(Xf,Y) = Ff(Xf,Y)*Mo(\omega)/4\rho Vs \quad \text{--- (4)}$$

$$\left.\begin{array}{l} Ff(Xf,Y) = R1*H1(K*Rf1) + R2*H1(K*Rf2) \\ R1 = (Rfx*\sin\delta - Rf1z*\cos\delta)/Rf1 \\ R2 = (Rfx*\sin\delta - Rf2z*\cos\delta)/Rf2 \\ Rf1 = \sqrt{Rfx^2 + Rf1z^2},\ Rf2 = \sqrt{Rfx^2 + Rf2z^2} \\ Rfx = xf - xs,\ Rf1z = zf - zs,\ Rf2z = zf + zs \end{array}\right\} \quad \text{--- (5)}$$

$$\left.\begin{array}{l} Mo(\omega) = Mo*\{\sin\chi/\chi\}*\{\sin\chi w/\chi w\}*\exp\{-i*(\chi + \chi w)\} \\ Mo = \mu*D*W,\ \chi = \omega*\tau/2,\ \chi w = \omega*\tau w/2,\ \tau w = W/Vr \end{array}\right\} \quad \text{--- (6)}$$

where, V : displacement, P : stress on boundary, X,Y : point on smooth boundary, Xf : point on source fault, V' : the fundamental solution (assuming $\exp(i*\omega*t)$), P' : stress of V' on boundary, i : imaginary number, $K(=\omega/Vs)$: wave number, HN : Hankell function of the Nth order of the second kind, and W, δ, D, τ, Vr : fault parameters (width, dip angle, fault displacement, rise time of ramp function, rupture velocity).

The irregular shaped boundary between the bedrock and the basin sediment is treated by the BEM. In this study, the basin sediment is also formulated by the BEM.

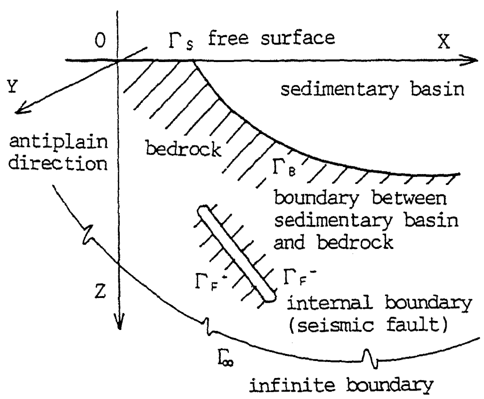


Fig.-1 Domain and boundaries

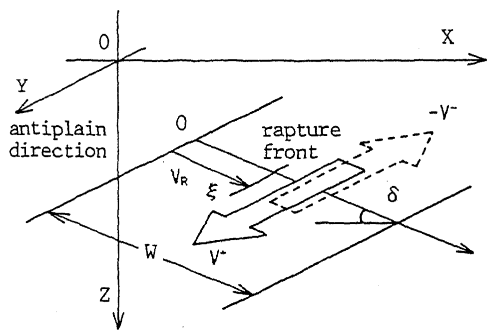


Fig.-2 Two-dimensional Haskell's fault model

Quality Factor (Internal Damping) The quality factor (Q) is introduced into the model by multiplying R1 and R2 of the fundamental solation (eq.(3)) by the following term.

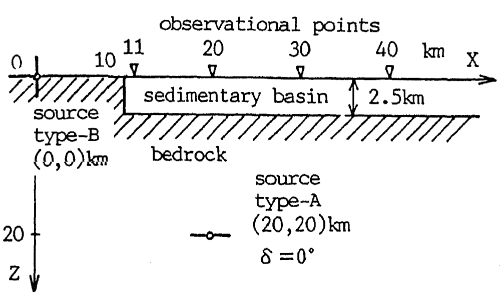
$$Aq(\omega, Ri) = exp\{-\omega * Ri/(2Q * Vs)\}, \qquad Ri = R1 \text{ or } R2 \qquad \text{--- (7)}$$

SH AND LOVE WAVES ANALYSIS IN KANTO SEDIMENTARY BASIN

SH and Love Wave Analysis in the Basin by the BEM According to observation of seismic waves on Kanto basin, it is certain that the seismic waves in the basin are greatly effected by source location to the basin, as mentioned in INTRODUCTION. In particular, when the sources are located under the basin (source type A), the waves seem to consist of only body waves and the duration is short. On the contrary, when the sources are located shallowly and laterally away from the basin (type B), large surface waves are observed inside the basin and the duration becomes much longer than the one of the type A (e.g. Refs.2,3).

We simulate SH and Love waves in Kanto basin by the BEM and explain the foregoing phenomena. Kanto basin model and two type sources A and B are illustrated in Fig.3. The model consist of a bedrock and a basin sediment. The right edge of the sediment is not discretised in order to transmit almost all waves in right direction. In the basin, dominant period of SH wave is 10 sec. Type A source locates under the basin, and type B locates shallowly and laterally away from the basin. A simple pulse wave is generated at those sources by using fault parameters listed in Fig.3. Fourier amplitude spectrum of the source becomes zero at circular frequency (ω) = π , and $\omega < \pi$ (period > 2 sec.) is treated. However, static term ($\omega = 0$) is neglected, because displacement amplitude diverges due to the 2-D source. Thus, amplitude of calculated displacement waves does not start from 0.

Fig.4 shows displacement waves and Fourier amplitude spectra of velocity; they are simulated on the basin. Dotted lines are computed by the BEM, and solid lines are by 1-D multiple reflection method (only vertical SH waves in the sediment are dealt with). The waves simulated at every 10 km are vertically arranged. The top waves are obtained at the nearest point to the basin edge. The four left waves are obtained by type A source. The waves almost consist of SH waves vertically traveling from bedrock, and the duration of the strong part is not long. Waves and spectra of the BEM are almost equal to ones of the 1-D method. The four right waves are obtained by the type B source. In this case, the duration becomes longer, as the observational points are located away from the basin edge. This is because large waves are generated at the edge and they are slowly propagated through the sediment. In this case, the 1-D method is only applicable to SH wave part, and it underestimates Fourier amplitude spectra of the BEM waves. These results agree with the ones of the foregoing observation on Kanto basin.



Constants

sedimentary basin: $V_S = 1.0$km/s $\rho = 2.0$t/m³
bedrock : $V_S = 3.0$km/s $\rho = 2.5$t/m³
fault parameters: $W = 5.0$km $V_R = 2.5$km/s
$\tau = 1.0$s $D = 1.0$m

Fig.-3 Kanto-basin model and fault models

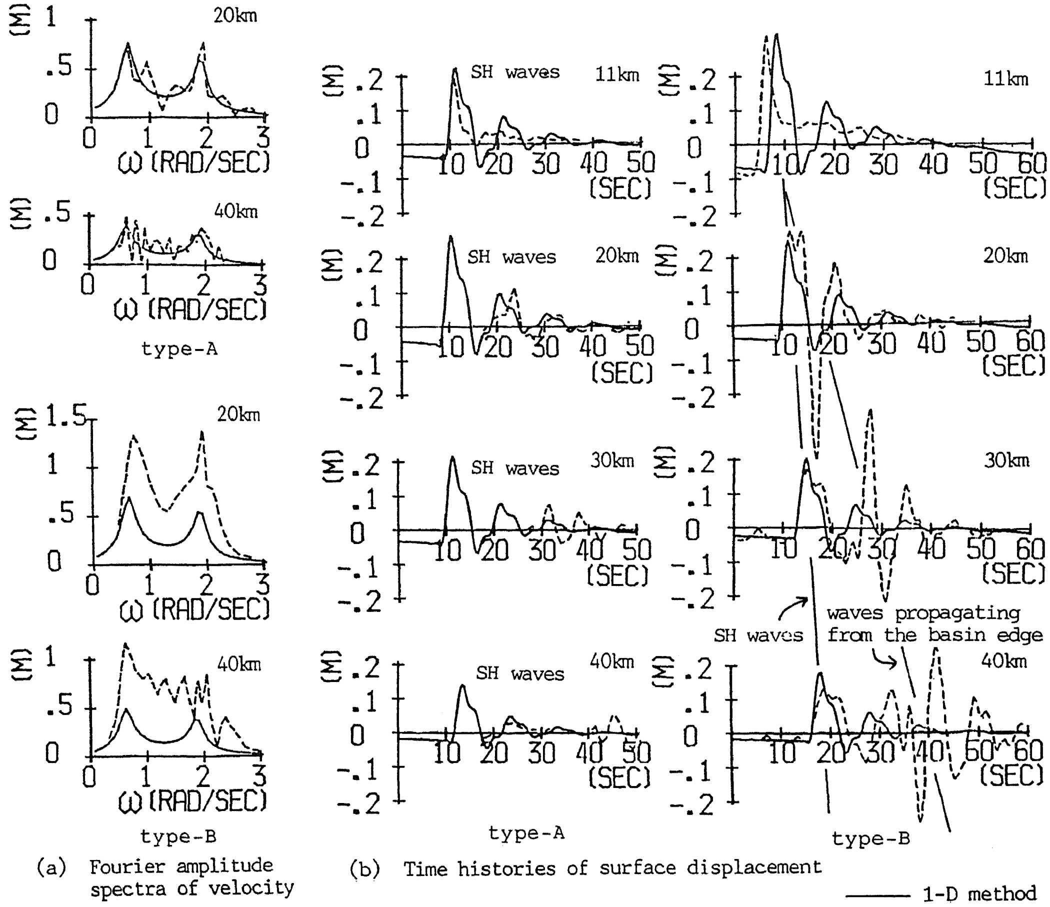


Fig.-4 Fourier spectra and seismic waves for source type A and B

Identification of Love Wave On the analogy of several researchers' studies (e.g. Refs.11,12), the large waves following SH waves are expected to be Love waves; they are generated at the basin edge. In this study, the waves are identified as mainly fundamental Love mode by a theoretical method. In the method, infinitely lateral sediment is assumed and a point force is given on free surface to generate Love waves. The force point corresponds to the basin edge point on free surface. Fourier spectrum of the point force is obtained by multiplying the source spectrum by a correction factor of amplitude. The equation is given by,

$$V1(X,\omega)= Vf(Rf,\omega)*T*A1(\omega)*C1*\exp(-i*\omega*X/C)/K, \quad K=\omega/C \qquad \text{--- (8)}$$

where, X : lateral length from the force point (basin edge point) to observational point, V1 : the theoretical Love wave displacement, Vf : the source spectrum of displacement, Rf : length from the source to the basin edge, T : transmission coefficient from the bedrock to the sediment, A1 : Harkrider's Love wave amplitude response (Ref.13), C1 : the amplitude correction factor ($4*\mu$ is used in this study, where μ is shear modules of the sediment), C : phase velocity of Love wave.

Fig.5 shows comparison of the BEM waves and the theoretical Love waves, in case of the source type B. The large BEM waves following SH waves nearly equal to the theoretical Love waves. Thus, it is confirmed that the latter waves are mainly the Love waves of fundamental mode and they are generated at basin edge.

Influence of Internal Damping (Q) on the Waves Fig.6 shows comparisons of Fourier spectrum and wave with and without Q in case of the source type B. Solid line is calculated with Q and doted line is without Q. The Q is assumed as 50 in sediment and 100 in bedrock. The wave comparison indicates that SH waves are little attenuated, because they shortly travel in low-Q sediment. On the contrary, the Love waves, especially short period components, are largely attenuated, because they travel long through the sediment. However, it is confirmed by the spectrum that long-period components are little attenuated. The similar result was obtained by Horike using the Aki-Larner method in 1987 (Ref.14).

Characteristics of Love Waves in a Sediment Basin and Influence of the Waves on Structures on the Basin As Drake had already pointed out with a FEM alluvial valley model(Ref.12) and we also confirmed in this study, the Love waves mainly propagate longer period components. Because they consist of principally fundamental mode (its dominant period is about 9 sec in this model) and their short period components are largely attenuated in the low-Q sediment. Therefore, short-period structures on the basin are not probably influenced by the waves. However, long-period structures are likely influenced, if the natural period of the structures is nearly equal to the dominant period of the Love waves. Although we investigate only one case in this study, it is analogized that the long-period structures' damage, as mentioned in INTRODUCTION, is partially caused by the local surface waves in the basins.

CONCLUSIONS

SH and Love waves in Kanto sedimentary basin are studied by the 2-D BEM including source fault. The basin is modeled as a single layer (dominant period of SH wave is 10 second). Near sources are treated and the waves of 2 sec and over period are simulated. With the BEM simulation and the theoretical Love wave analysis, following conclusions are obtained ;

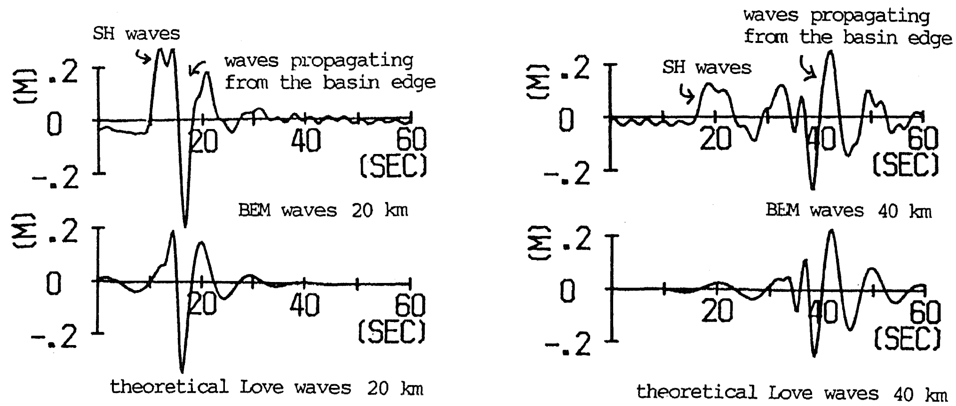


Fig.-5 Comparison of BEM waves and theoretical fundamental mode Love waves

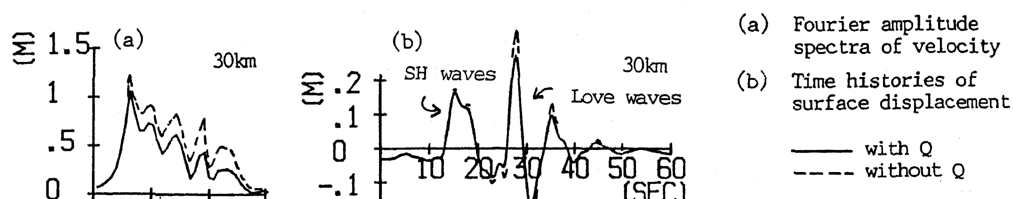


Fig.-6 Comparison of Fourier spectrum and seismic wave with and without Q

1) Waveforms in the basin are strongly effected by source location. When a source is located under the basin, the waves in the basin consist of mainly SH waves; the waves are vertically traveling from the underlying bedrock. In this case, it is reasonable to use the 1-D multiple reflection method of SH waves. On the contrary, when a source is located shallowly and laterally away from the basin, the waves consist of not only the SH waves, but also Love waves. The Love waves are generated at basin edge and slowly propagated through the basin sediment. In this case, the 1-D method is possible to simulate only SH waves part.
2) The Love waves in the sediment basin predominant only in comparatively long period, because they consist of mainly fundamental mode and their short period components are largely attenuated in the low-Q (high-damped) sediment. Consequently, the Love waves probably influence long-period structures on the basin, if the natural period of the structures is nearly equal to the dominant period of the Love waves.

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