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A STUDY ON GROUND MOTION FOR SEISMIC DESIGN BASED ON WAVEPROPAGATIONTHEORYAND SOURCE DYNAMICS

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ABSTRACT

It is reasonable to design a structural system on the seismic safety evaluation of an integrated system including source, wave propagation path, site, and a structural system. This paper presents the ground motion model on the basis of wave propagation theory and source dynamics. The numerical analysis denotes that the geometric relation between the observation points and the fault segment strongly affects the characteristics of the ground motion especially when the observation points are very near to the fault plane. It is also shown that the upper and lower bounds of seismic safety of a structural system could be predicted through the response sensitivity analysis to the variable parameters and the physical conditions describing the ground motion.

KEYWORDS

seismic design; response analysis; theoretical ground motion model; wave propagation theory; multi-layered half space

INTRODUCTION

Strong ground motion is the resultant process associated with uncertain source movement in a fault region and wave propagation in heterogeneous soil and geological structures. The engineering modeling of strong ground motion has been an important problem to the seismic design of a structural system. It is reasonable to design a structural system on the seismic safety evaluation of an integrated system including source, wave propagation path, site, and a structural system. In relation to this problem, this paper intends to present the ground motion model based on wave propagation theory and source dynamics to derive the key parameters and physical laws which can describe essentially the characteristics of the ground motion. The wave propagation path from source to site is presented the multi-layered half-space which consists of surface soil layers overlying a semi-infinite random medium (Kawano *et al.*, 1995; Kawano, 1993; Kawano and Kobori, 1983; Kobori *et al.*, 1977; Sato, 1984). The rupture process on the fault plane is reduced to the source function which is expressed by the dynamic behaviors of flexible membrane on the rough surface (Ben-Menahem, 1976; Kawano *et al.*, 1995). The ground motions are evaluated for the variable parameters

Table 1. geological properties of soil sediment model

Depth z (m)	S-wave velocity V_S (m/sec)	P-wave velocity V_P (m/sec)	Density ρ (g/cm^3)	Damping factor h
0 - 10	200	1020	1.50	0.010
10 - 30	222	1129	1.50	0.010
30 - 60	265	1349	1.50	0.010
60 - 100	329	109[illegible]	1.50	0.010
100 - 200	415	1376	1.50	0.010
200 - 500	630	1798	1.75	0.010
500 - 1000	1275	2654	2.00	0.005
1000 - 2000	2350	4070	2.50	0.005
2000 -	4500	7794	2.50	0.005

on the source and site characteristics, and physical conditions on wave propagation. The useful information and data for a reasonable estimate of damage potential and seismic design of a structural system have been obtained through the response sensitivity analysis to the selected key parameters describing the ground motion model.

GROUND MOTION MODEL

The wave propagation path from the source to the site is modeled as multi-layered half-space which consists of surface soil layers overlying semi-infinite random medium (Kawano *et al.*, 1995; Kawano, 1993; Kawano and Kobori, 1983; Kobori *et al.*, 1977; Sato, 1984). The geological properties of the soil sediment models used in this study are listed in Table 1. The rupture process on a fault plane is reduced to a source function as dynamic behaviors of a flexible membrane on a rough surface (Ben-Menahem, 1976; Kawano *et al.*, 1995). The source model of faulting is composed of this function as asperity source filter. Dividing the fault plane into some small segments, the theoretical ground motions are evaluated with superposition of the seismic waves radiated from the subevent on the fault segments. Shear wave velocity of this model varies from 200 m /sec to 4500 m /sec linearly as the depth. The predominant periods of soil sediment model are about 1.0 sec and 5.0 sec.

In this study, the magnitude of the ground motion model is set to be M=7.8. The causative fault is L=100 km by W=50 km, and the seismic moment is M_0=1.6×10^{27} dyne•cm. As shown in Fig.1, the depth at the center of the fault is 20 km, and the dip angle is 45 degrees. Therefore the depth of the fault plane varies from 3.8 km to 36.2 km. The fault plane is divided into N=5x3 small segments, and each segment is denoted by the cross point of two lines parallel with the X and Y axes. Three types of slip distribution on the fault plane are considered: (1) uniform slips on all segments; (2) large slips on deep segments, in the ratio of the slips on the segments lying along the line Y-1, Y-2 and Y-3 as 4:2:1; and (3) large slips on shallow segments in the ratio of 1:2:4. In this paper, these slip distributions are called type-1, type-2 and type-3, respectively. Each fault segment has an area of 20 km × 17 km, and the segment size seems too large to estimate the relatively short period ground motions with relation to structural response. Therefore the rupture process on each segment is represented by a source function with spatial and temporal slip fluctuations. The normalized spectrum of source function corresponding to subevent on a fault segment is expressed as

$$\hat{F}(\omega)=\sum_{j=1}^{N_1}\sum_{k=1}^{N_2}\frac{\delta_j\gamma_k}{\omega\sqrt{1+(\omega\Delta\tau_k)^2}}\frac{\sin(\omega\Delta T_j/2)}{\omega\Delta T_j/2}\exp\left[-i\left\{\omega\tilde{t}_j+\omega\tau_{k-1}+\tan^{-1}(\omega\Delta\tau_k)-\frac{\pi}{2}\right\}\right]$$
$$\sum_{j=1}^{N_1}\delta_j=\sum_{k=1}^{N_2}\gamma_k=1,\quad \sum_{j=1}^{N_1}\Delta T_j=T,\quad \sum_{k=1}^{N_2}\Delta\tau_k=\tau,\quad \tilde{t}_j=\sum_{l=}^{j-}\Delta T_l+\Delta T_j/2,\quad \tau_k=\sum_{l=1}^{k-1}\Delta\tau_l \tag{1}$$

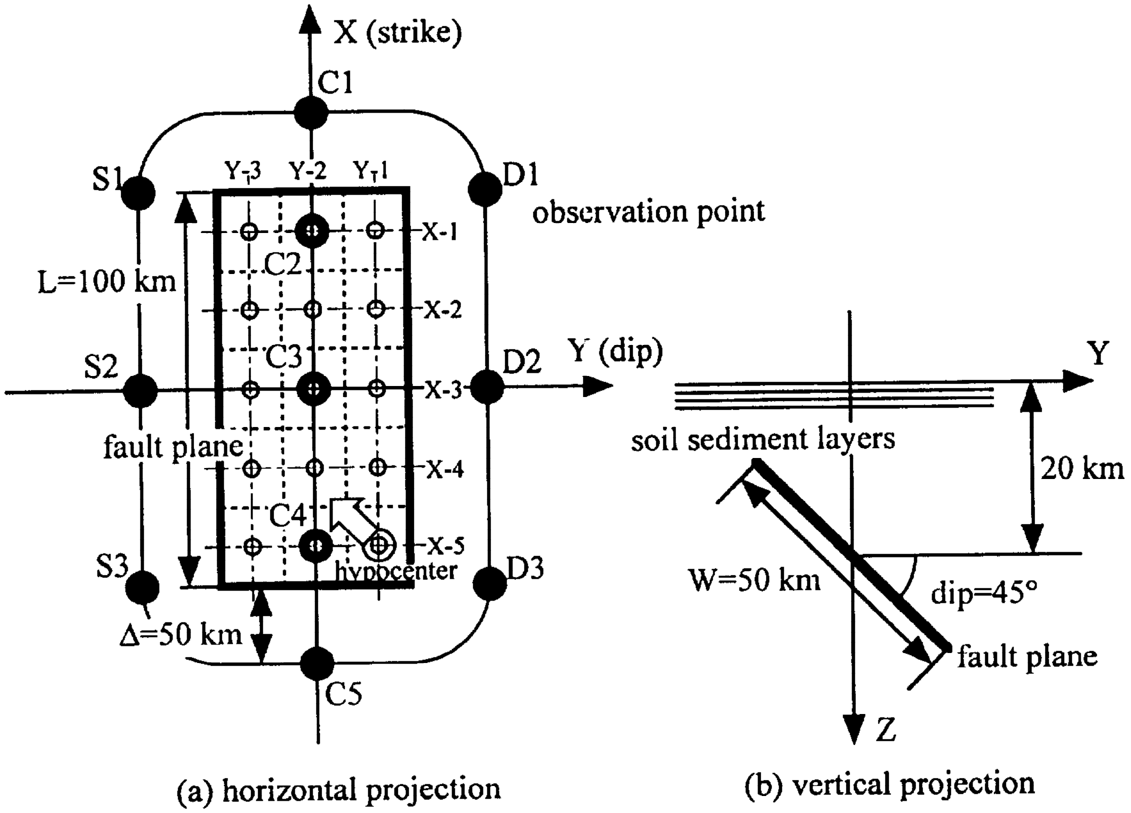
where ω is angular frequency, τ is rise time and T is rupture time of subevent on a fault segment. N_1 and N_2 are the numbers of the fluctuation in space and time within one segment. In this study, τ and T are 3.0 sec and 6.0 sec, and $N_1 = N_2 = 10$. $\{\delta_j\}$, $\{\gamma_k\}$, $\{\Delta T_j\}$ and $\{\Delta\tau_k\}$ are series of random numbers to satisfy the above relations. The moment tensor of the m-th subevent is given by

$$\hat{M}_{(m)pq}(\omega)=M_{0(m)}R_{pq}\hat{F}(\omega) \tag{2}$$

where R_{pq} is radiation pattern and $M_{0(m)}$ is seismic moment released at the m-th segment. The summation of $M_{0(m)}$ over all the fault segments equals to the total seismic moment M_0. The Fourier spectrum of seismic wave radiated from the m-th fault segment is

$$\hat{u}_{(m)n}(x,\omega)=\hat{M}_{(m)pq}(\omega)\partial\hat{G}_{np}(x,\xi_{(m)};\omega)/\partial\xi_q \tag{3}$$

where $\hat{G}_{np}(x,\xi_{(m)};\omega)$ is Green's function which is the n-th component of displacement at position x caused



(a) horizontal projection

(b) vertical projection

Fig. 1. Geometric relation between fault plane and location of observation points

by an unit force in the p direction at $\xi_{(m)}$, the position of the reference point of the m-th fault segment. Green's function is calculated numerically using the wave number integral method (Luco and Apsel, 1983). The subevent occurs when the rupture front reaches the fault segment with appropriate delay time. The ground motion is expressed by the sums of the elementary waves radiated from subevents on all fault segments (Joyner and Boore, 1986).

$$u_n(x,t)=\sum_{m=1}^{N} u_{(m)n}(x,t-t_m) \tag{4}$$

where $u_{(m)n}(x,t)$ is the inverse Fourier transform of $\hat{u}_{(m)n}(x,\omega)$, and t_m is the occurrence time of the subevent on the m-th fault segment. It is assumed that the rupture propagates radially on the fault plane from the hypocenter located at the point shown in Fig.1. The rupture velocity is assumed to be 3 km/sec, and the occurrence time of subevent on each segment is determined from the arrival time of the rupture front to the reference point.

Eleven observation points are just over and around the fault plane as shown in Fig.1. The points D1, D2 and D3 are at the 50 km distance from deep side of the fault plane on the horizontal projection in Fig. 1. And the points S1, S2 and S3 are on the opposite side. The points C1 to C5 lie on the X-axis. C1 and C5 are at the 50 km distance from the short side of the fault plane, and C2, C3 and C4 are just over the fault plane.

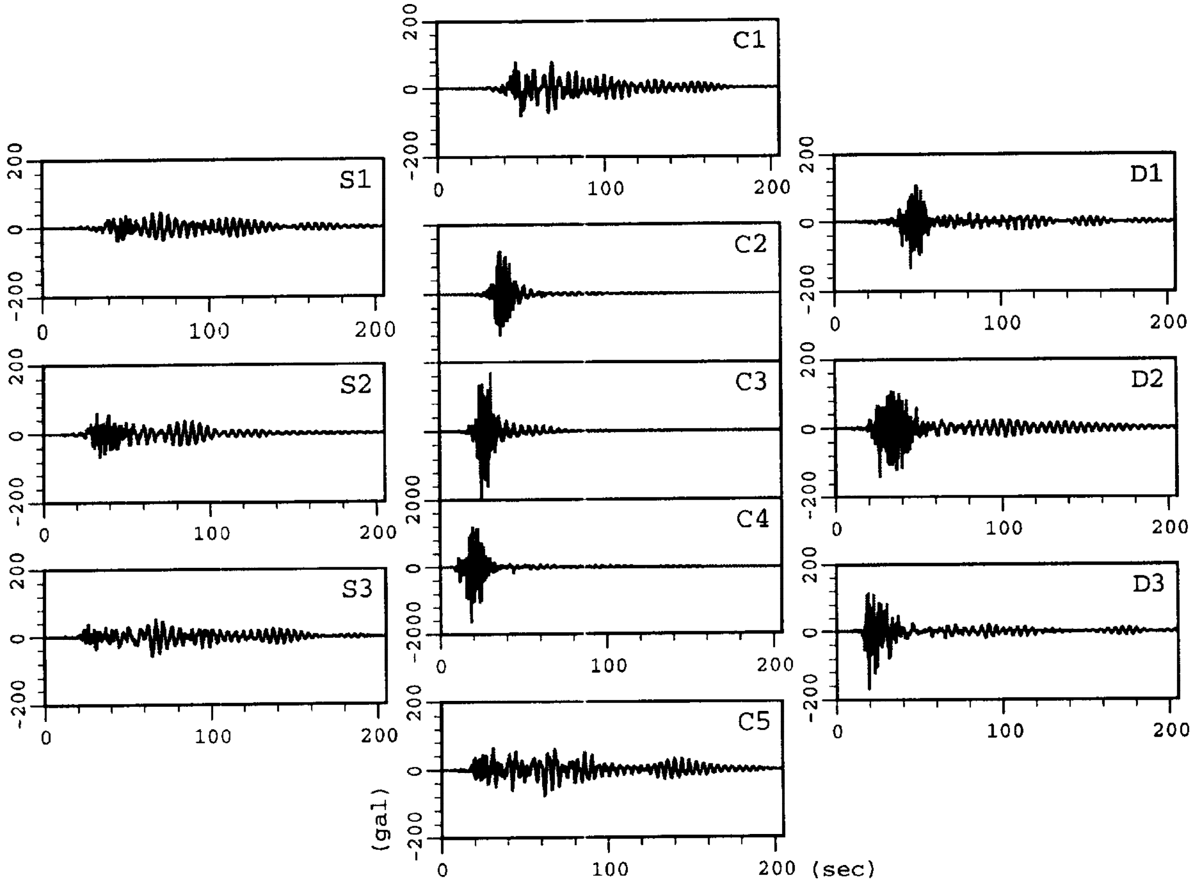


Fig. 2. Acceleration time history of ground motion (type-1, X component)

NUMERICAL RESULTS AND DISCUSSION

Figure 2 shows acceleration time histories of the ground motions at all observation points for the slip distribution type-1. The accelerations at the points C2, C3 and C4 just over the fault plane are about ten times as large as the ones around the fault plane. This is because the large direct body waves are superposed within very short arrival times. The large surface waves with long duration appear at the points S1 to S3, D1 to D3 and C1 and C5.

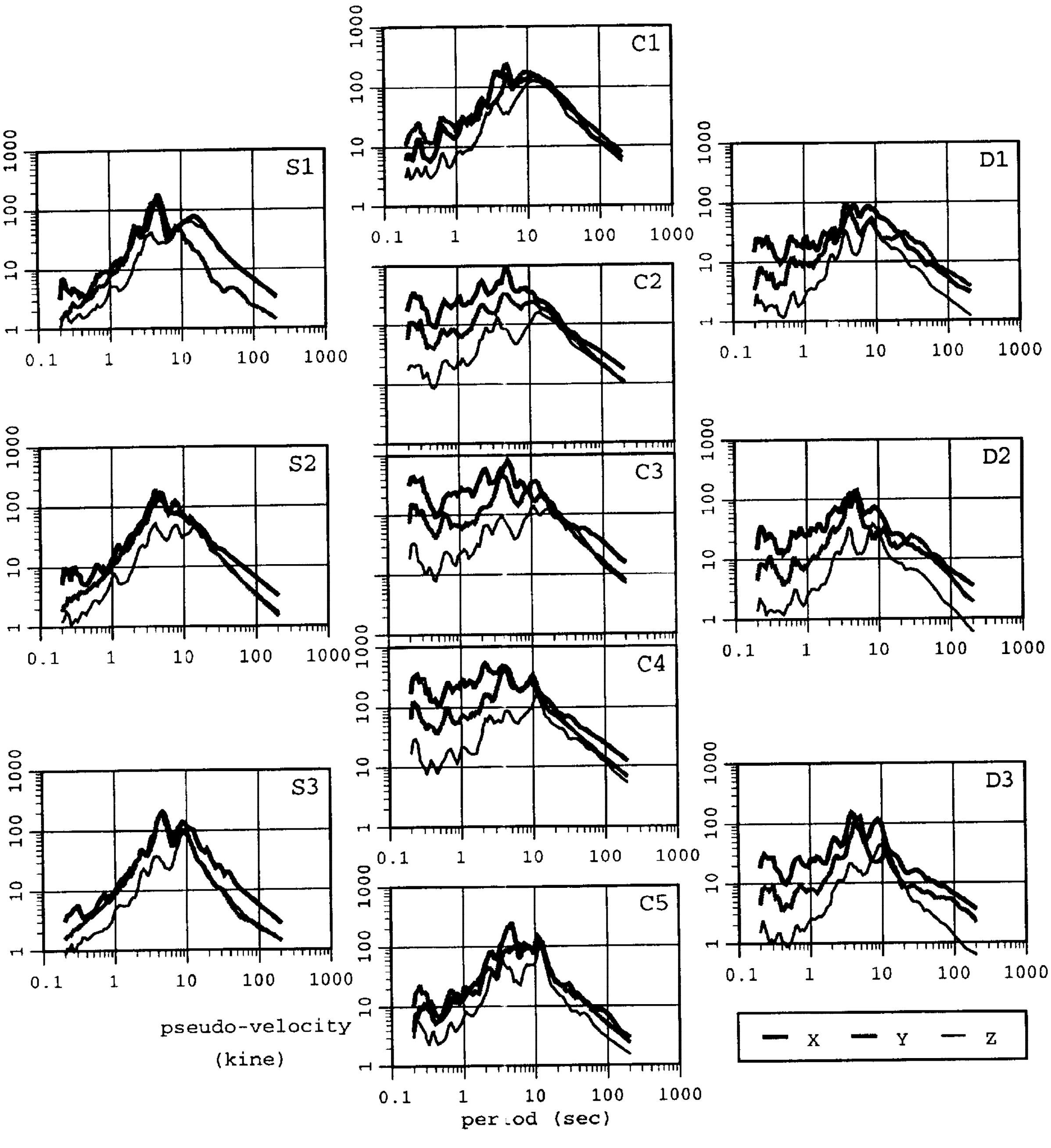


Fig. 3. Response spectra of ground motion (type-1)

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