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Simulations of long period strong ground motions during the 1990 Upland earthquake, California

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ABSTRACT: Long period ground motions in and around the Los Angeles basin during the Upland earthquake (M_L=5.2) of 28 February, 1990 are simulated using the 2-D boundary element method considering approximately a 3-D seismic source. 2-D underground velocity models based on the geological data and the kinematic source shown by Dreger and Helmberger[1991] are adopted in the simulation. Comparing synthetic seismograms with broadband seismograms recorded at CIT and USC, the following conclusions are obtained. 1) Phases and envelopes of the long period seismic waves at the two stations are simulated well, however, amplitudecs are not computed well at USC by the 2-D underground models and the kinematic source. 2) While long period waves at CIT are mainly surface waves propagating in the upper crustal layers, waves at USC are local surface waves excited in the soft sedimentary layers of the Los Angeles basin and the San Gabriel valley.

1. INTRODUCTION

Estimation of long period strong ground motions at an arbitrary site is one of the most important tasks for earthquake engineering. Since long period seismic waves are affected by many complex factors, such as a source, a path, and a site factor, it is very difficult to estimate these waves considering all those factors at once. In particular, effects of 3-D irregularities of an underground are hard to treat in analyses, because they require much computation memory and a large amount of underground information which is unknown now. Though 2-D calculations have been already applied to many analyses, they can not deal with a quantitative seismic source, on the other hand. In order to consider a 3-D seismic source in a 2-D wave-field, Helmberger and Vidale[1988] proposed a new method with a finite difference approach. Using the boundary element method, we proposed a simple technique to consider a 3-D kinematic source in a 2-D wave-field and simulated long period ground motion in the Kanto area, Japan [Yamamoto *et al.*, 1989; 1990]. In this paper, we applied the method to the 1990 Upland, California earthquake.

The Upland earthquake occurred at about 50*km* east of the Los Angeles city on February 28, 1990. The local magnitude of this earthquake is 5.2 and the focal depth is estimated to be 5*km* [Dreger and Helmberger, 1991]. During the earthquake, broadband seismograms are recorded at the Kresge Laboratory of California Institute of Technology (CIT) by Streckeisen seismometers and at Geology Department of University of Southern California (USC) by Guralp CMG-4 seismometers. In Figure 1, the locations of the epicenter and the stations are superposed on the geological map in and around the Los Angeles basin and the San Gabriel valley. CIT is located on Pre-Tertiary bedrocks in the northern edge of the Los Angeles basin, and USC is located on Quaternary sediments of the basin. The epicentral distance at each station is 45*km* and 55*km*, respectively. The transverse and radial components of the seismograms recorded at CIT and USC are shown in Figure 2. Although their epicentral distances are not largely different, seismograms recorded at two stations show a great difference; *i.e.* while CIT records predominate in the initial phases, USC records dominate in the later part and have longer duration. It is remarkable that main phases at USC last over 60*sec* at longer periods (about 2 ~ 10*sec*) and show clear dispersion.

To investigate these phenomena, simulations of long period ground motion are carried out by the technique mentioned above with 2-D underground models along the hypocenter-station profiles including soft sediments of the Los Angeles basin and the San Gabriel valley.

2. SIMULATION METHODS

Assuming a 2-D wave-field as elastic, formulation is done in frequency domain in this study. When a kinematic source is included in the domain Ω as an inner boundary, a boundary integral equation is expressed as follows.

$$C(x)U(x) + \int \{P^*(x,y)U(y) - U^*(x,y)P(y)\} d\Gamma(y)$$

$$= P^*(x, y_f; n_f) S_{2D}(\omega) \quad (1)$$

where U is the displacement and P is the traction on the boundary Γ. U^* is the Green function of a 2-D medium and P^* is its traction. x, y express 2-D vectors representing an observation point and a source point on the boundary, respectively. n_f indicates the outward unit normal which defines a radiation pattern of a seismic source. C denotes a free term depending on the boundary shape. $S_{2D}(\omega)$ represents a 2-D seismic source function. Since the right-hand side of equation (1) is equivalent to the contribution at x from the seismic source, it is obvious that the contribution at the reference point x_{ref} from the same seismic source is represents as

$$U(x_{ref}) = P^*(x_{ref}, y_f; n_f)\, S_{2D}(\omega) \quad (2)$$

In the same manner, the contribution at X_{ref} from a 3-D seismic source in the 3-D full space is given by

$$U(X_{ref}) = P^*_{3D}(X_{ref}, Y_f; N_f) S_{3D}(\omega) \quad (3)$$

where P^*_{3D} is the traction of the Green function of the 3-D full-space, and $S_{3D}(\omega)$ indicates a 3-D seismic source function. X, Y, N_f represent 3-D vectors. If the contribution from the 3-D seismic source and the contribution from the 2-D seismic source is the same at the point $x_{ref}(=X_{ref})$, the next relation is obtained.

$$S_{2D}(\omega) = P^*_{3D}(X_{ref}, Y_f; N_f) S_{3D}(\omega) / P^*(x_{ref}, y_f; n_f)$$
$$\equiv \bar{S}(\omega) \quad (4)$$

When a seismic source is far enough from the reference point $x_{ref}(=X_{ref})$ on the boundary, $S_{2D}(\omega)$ in the right-hand side of the equation (1) can be approximately replaced by $\bar{S}(\omega)$ in expression (4). This can be written

$$C(x)U(x) + \int \{P^*(x,y)U(y) - U^*(x,y)P(y)\} d\Gamma(y)$$
$$= P^*(x, y_f; n_f)\bar{S}(\omega) \quad (5)$$

Equation (5) is the 2-D boundary integral equation approximately considering contributions from a far-field 3-D seismic source. In case of a near-field source, applicability of this approximation to long period wave propagation problems is shown by Yamamoto *et al.*[1990]. Once a boundary equation is obtained for each medium, displacements and tractions on boundaries in frequency domain can be computed by the usual BEM procedure. Time domain responses are obtained by means of the FFT algorithm.

3. GEOLOGICAL DATA AND SOURCE PARAMETERS

Underground geology of the Los Angeles basin and the San Gabriel valley has been investigated along several profiles[Yerkes *et al.*,1965; USGS, 1987; West *et al.*, 1988; Davis *et al.*, 1989]. Figure 3 shows geological sections between the hypocenter and the stations based on those studies. It is clear that the Los Angeles basin and the San Gabriel valley consist of Recent and Pleistocene sediments, and Pliocene and Miocene rocks, underlain by Cretaceous and older basements. Considering velocity structures in this area [Duke *et al.*, 1971; Hauksson *et al.*, 1987], 3-layered underground velocity models used in this study are determined. Figure 4 shows 3-layered models along two profiles; one is the hypocenter-CIT profile, and the other is the hypocenter-USC profile. S-wave velocity of each layer is 0.6*km/sec*, 1.5*km/sec*, and 3.2*km/sec*, respectively. The 0.6*km/sec* layer represents Recent and Pleistocene sediments, the 1.5*km/sec* layer represents Upper Pliocene rocks, and the 3.2*km/sec* layer stands for Lower Pliocene and older basement rocks.

The seismic source of this earthquake is investigated in detail by Hauksson and Jones[1991] and Dreger and Helmberger[1991]. According to those studies, there is a strong asperity zone on the fault plane which controls shorter period components of the seismic waves. But this asperity is negligible when we discuss long period waves [Dreger and Helmberger, 1991]. Thus, we treat long period source parameters determined by Dreger and Helmberger[1991] in this study, and they are shown in Table 1.

4. COMPUTED RESULTS AND DISCUSSION

Synthetic ground motions along the two profiles are computed by the above-mentioned BEM technique. A cut-off period for the calculations is defined as 2.0*sec*, since long period (2~ 10*sec*) components of the recorded seismograms are our focus in these simulations. Figure 5 shows spatial variations of the synthetic waves along two profiles (the hypocenter-CIT line and the hypocenter-USC line), and Figure 6 shows transverse components of the synthetic waves compared with seismograms recorded at CIT and USC.

At CIT, an envelope of the synthetic waves is well computed except initial phases which predominate in longer periods in the recorded seismograms. The later arrivals appeared after 20~ 40*sec* from the direct S-wave at CIT are identified as a kind of local surface waves which are excited in soft sediments of the San Gabriel valley, however, wave energy of them is smaller than that of the initial phases. In contrast to the later phases, the initial phases in the CIT records are probably affected by deeper structure along the hypocenter-CIT profile, judging from their arrival time and the dominant periods. An additional simulation is carried out to confirm this explanation. Figure 7 shows a new underground model along the hypocenter-CIT line considering the upper crustal structures proposed by Dreger and Helmberger[1990], and Figure 8 shows computed results by the new model. The initial phases are simulated better by this model than the former model, which demontrates these initial phases at CIT are mainly surface waves excited by the upper crustal layers rather than the soft sedimentary layers.

At USC, two wave groups are identified in the synthetic seismograms in Figure 6 b); the first group appears after 0～ 30*sec* from the direct S and the second group appears after 30～60*sec* from the direct S. Phases, dispersions and durations of both groups are almost corresponding to those of recorded seismograms, however, amplitudes are not computed well. The reasons for this misfit are considered as follows; 1) the 2-D underground model is too simple and does not represent the actual structures. 2) Q values used in this study are not appropriate. In spite of this misfit concerning with amplitudes, it is obvious from Figure 5 b) that the long period wave groups at USC are mainly the local surface waves excited in the soft surface sediments; the first wave group is excited mainly in the Los Angeles basin, and the second group is generated first in the San Gabriel valley, then excited again in the Los Angeles basin after transmitted from the valley. These two kinds of local surface waves make the duration at USC unusually longer. The similar phenomenon, during the 1971 San Fernando earthquake, was indicated by Vidale and Helmberger[1988].

5. CONCLUSIONS

Simulations of long period ground motions in and around the Los Angeles basin during the Upland earthquake of 28 February, 1990 are carried out by the 2-D boundary element method considering approximately a 3-D seismic source. In the simulations, 2-D underground velocity models based on the geological data and the kinematic source shown by Dreger and Helmberger[1991] are adopted. Comparing the synthetic seismograms with the broadband seismograms recorded at CIT and USC, the following conclusions are obtained.

1) Phases and envelopes of the long period seismic waves at the two stations are simulated well, however, amplitudecs are not computed well at USC by the 2-D underground models and the kinematic source.

2) While long period waves at CIT are mainly surface waves propagating in the upper crustal layers, waves at USC are mainly local surface waves generated in the soft sedimentary layers of the Los Angeles basin and the San Gabriel valley.

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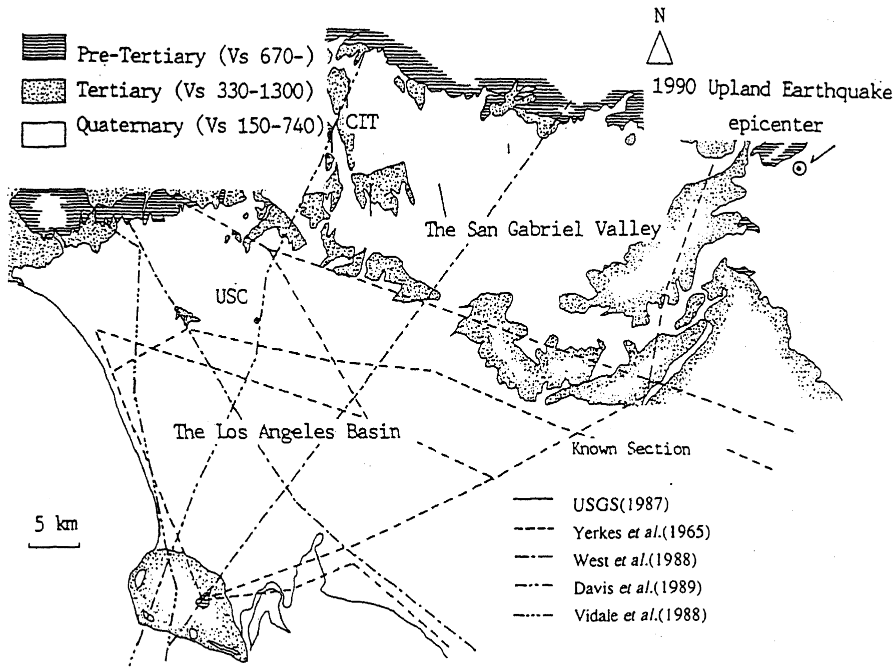


Figure 1. Locations of the 1990 Upland even epicenter and the CIT and the USC stations

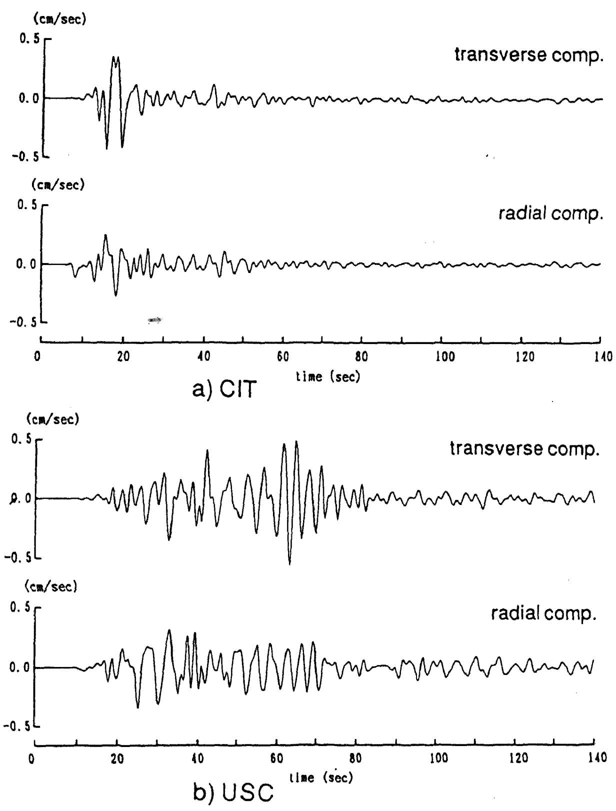


Figure 2. Transverse components and radial componenets of the seismograms recorded at CIT and USC

Table 1. Source parameters of the 1990 Upland earthquake after Dreger and Helmberger [1991]

source parameters	
L (km)	5.0
W (km)	3.0
θ (deg)	N216E
δ (deg)	77
λ (deg)	5
M_0 (dyne · cm)	2.5×10^{24}
τ (sec)	0.4
Vr (km/sec)	2.5

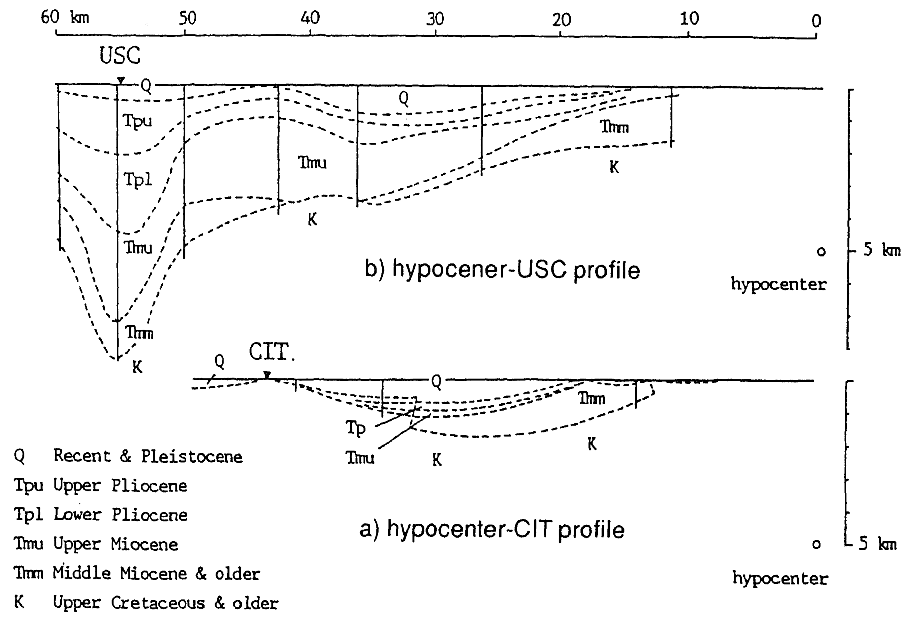


Figure 3. Geological profiles of the hypocenter-CIT and the hypocenter-USC lines

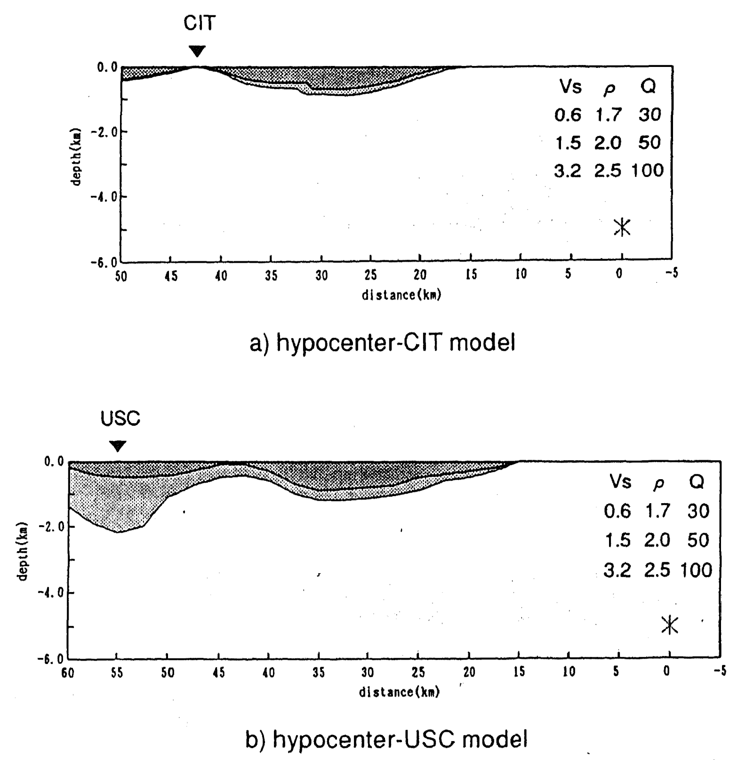
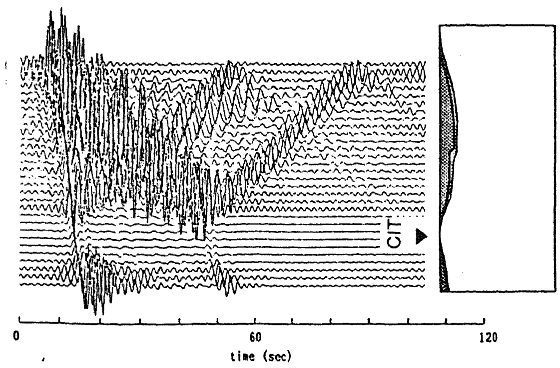
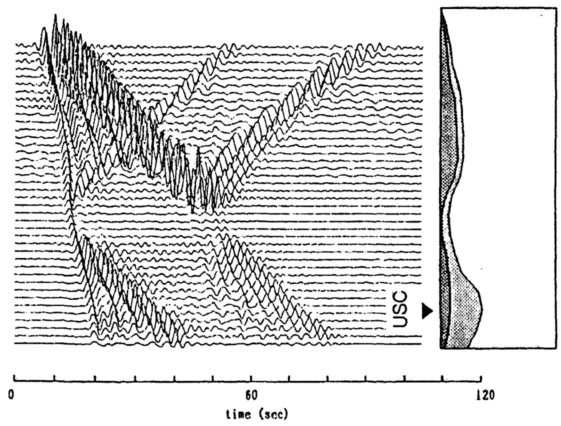


Figure 4. Underground velocity models used in the simulations

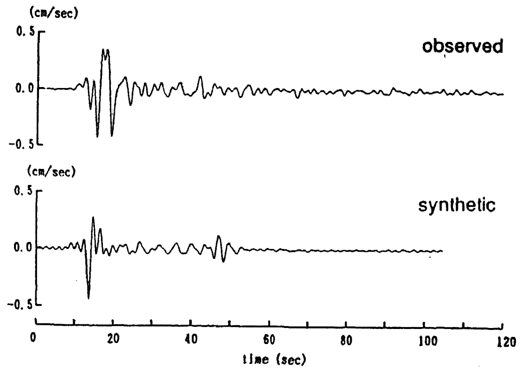


a) hypocenter-CIT profile

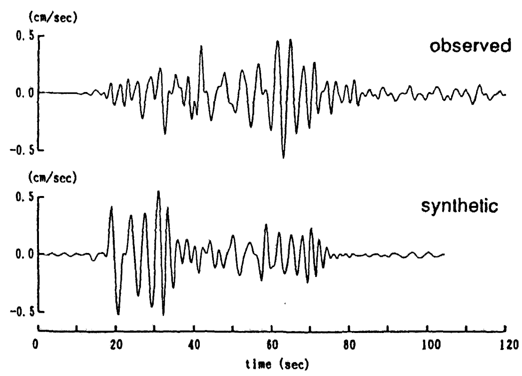


b) hypocener-USC profile

Figure 5. Spatial variations of the synthetic seismograms along the two profiles



a) CIT



b) USC

Figure 6. Synthetic seismograms comparing with observed seismograms at CIT and USC

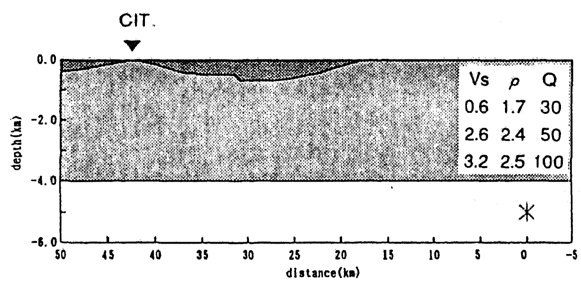
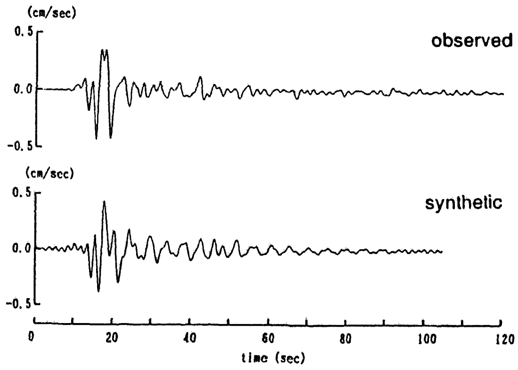


Figure 7. Underground velocity model considering the upper crustal structures along the hypocenter-CIT line



CIT

Figure 8. Synthetic seismograms at CIT considering the upper crustal structures