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NEAR SOURCE STRONG GROUND MOTION SIMULATION FOR KOCAELI EARTHQUAKE (1999)

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ABSTRACT

A near field strong ground motion simulation was carried out due to fault rupturing in the Kocaeli Earthquake (1999). The ground motions are simulated by the convolution scheme in time for source function and in space along rupture direction with the layered soil Green's function method based on the kinematic dislocation model. The effects of the asperities in the fault rupturing are focused considering inhomogeneous rupture mechanism in terms of a multiple asperities. The synthetic motions based on the inversion information from the observed data are compared well with the YPT (Yarimca Petrochemical Complex) record of the Kocaeli Earthquake. The response spectrum results also show good agreement between observed and simulated motions. The wavelet transform analysis is applied to observe the variation of frequency contents with the time for recorded and simulated motions.

INTRODUCTION

On August 17, 1999, Turkey has experienced a devastating earthquake called Kocaeli Earthquake (Ms.7.4). The earthquake struck along the North Anatolian Fault Zone (NAFZ) in the northwestern region of Turkey which is Turkey's most densely populated and industrialized region. The earthquake lasted 45 seconds, and was felt almost in all Western Turkey. As it was seen in the past earthquakes in (NAFZ), following the above Kocaeli earthquake another big event on November 12, 1999 which is called Duzce Earthquake occurred. This latter event completed the rupture on the Duzce fault that was initiated by the Kocaeli Earthquake (JSCE, 1999).

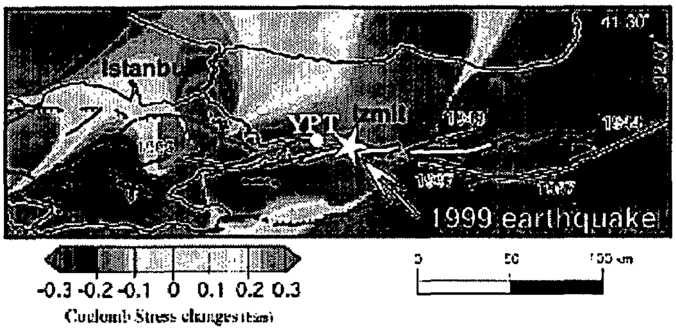
The NAFZ is one of the most active strike-slip faults in the world. It has a length of 1500 km and constitutes the northern boundary of Anatolian block, which is between the North and East Anatolian faults. The Anatolian block, which is between the Arabian and Black Sea blocks, has a westward escape because of the collision of these two blocks. The geological studies indicate that a slip rate of the North Anatolian Fault is 2.5 cm/per year (MCEER, 2000).

The studies on recent earthquakes, the 1994 Northridge earthquake and the 1995 Hyogo-ken Nanbu earthquake, showed that the characterization of the fault surface and the modeling of the wavefield are important factors for near source strong ground motion predictions (Kamae & Irikura, 1997), (Takemiya *et al.*, 2000). Especially, in case of the shallow source earthquakes, the near surface geology apparently comes into view. To get the information about near surface geology, source parameters are extracted inversely from observed strong ground motions depending on the source model, and later it is attempted to the forward analysis for predicting the ground motions. The causality condition governs the transient response for a multiple rupture segments, in particular. A simulation method of near-source motions by taking into account the above factors is developed by Takemiya and Goda (1997a,b). The kinematic model that incorporates fault asperities in specific ways is taken. The solution method for the related moving Green function is to apply the Laplace-Fourier transform method respectively to time and space.

In this study, it is aimed to simulate near field strong ground motions in view of inhomogeneous rupture mechanism in terms of a multiple asperities due to fault rupturing in the 1999 Kocaeli earthquake case by taking into account the and the succeeding wave propagation path.

FAULT RUPTURE MODEL

For the near field ground motion simulation, a slip rupturing over a certain area of a fault is considered. According to waveform inversion results of [Yagi & Kikuchi, 1999] the fault rupture model was formed. In the Kocaeli Earthquake (1999), the surface ruptures occurred close to known geological active faults. The traced fault length on the ground surface was about 105 km. The focal depth was determined as 17 km. The maximum dislocation was 7 m. The location of the epicenter, ruptured and unruptured faults, and YPT record station are shown in Fig. 1. Following the



☆:*Epicenter of Kocaeli Earthquake(1999)*

O:*Location of YPT station*

Fig.1 Location of the ruptured and unruptured faults (from Homepage of the Paris Globe Physics Institute)

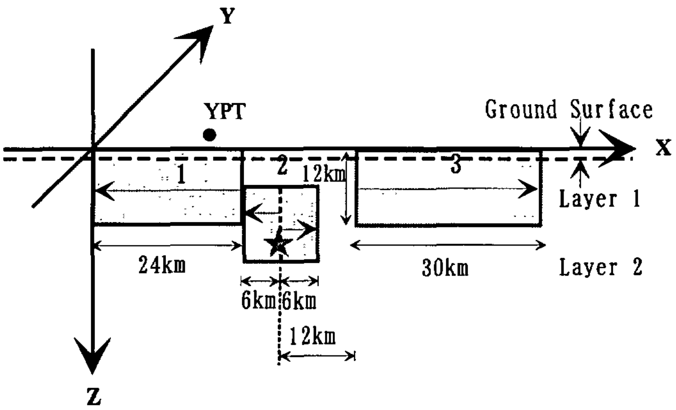


Fig.2 Asperity representation and fault rupture model of Kocaeli Earthquake (1999)

waveform inversion results, a source model consisting of 3 asperities was used in this study as shown in Fig. 2. The model is located in a two layered soil whose parameters are assumed as in Table 1, 2, 3. The target for the simulation is the ground motions at YPT record station.

Source mechanism studies have shown that the fault has right-lateral strike-slip faulting. Among the proposed rupture models, a unilateral rupture propagation or the so-called Haskell model is most simple and extensively used. The Haskell model is a shear dislocation propagating with constant velocity over a whole rectangular fault. The dislocation can be a dip slip, a strike slip or a combination of these. The further explanation about the Haskell model can be found in [Theoharis & Deodatis, 1994]. The Haskell model is assumed for the fault rupture process. A unilateral rupture process is employed from the bottom end where the epicenter was located toward the upper end of the faults. Therefore, discretization is counted only by sub-layering of thin layers.

For the numerical computation, a fictitious rigid base is assumed at the depth of 115 km in order to approximate a half space. The thin layer subdivision of the soil layers is made for the bottom layer so as to accommodate the wave propagation of the shortest wavelength corresponding to the maximum frequency considered.

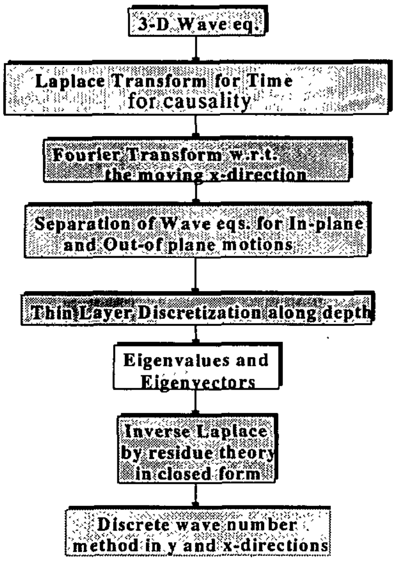


Fig. 3 Simulation flow

Table 1- Seismic Parameters

Asperity No.	Time (sec)	Strike, dip, rake (degree)	Area (km^2)
1	2.4~12.0	90,90,180	24*12
2.1	0~2.4	90,90,180	6*12
2.2	0~2.4	90,90,0	6*12
3	4.8~16.8	90,90,0	30* 12
Rupture Velocity (V_r)= 2.5 (km/sec) Rise Time (T_r) = 2.4(sec)			

Table 2- Soil Parameters

Layers No.	Thickness (km)	S Wave Velocity (km/sec)	Poisson's Ratio ν	Density $\rho(x10^9 t/km^3)$
1	1.0	1.0	0.280	2.1
2	Infinite	3.5	0.250	2.8

Table 3- Parameters for numerical computation

Base Depth(km)	115
Numbers of Sub-division	157
Fundamental Wave Length(km)	204.8
Time Step Numbers	300
Time Increment(s)	0.1

SIMULATION METHOD

The simulation procedure is briefed in Fig. 3.: The kinematic

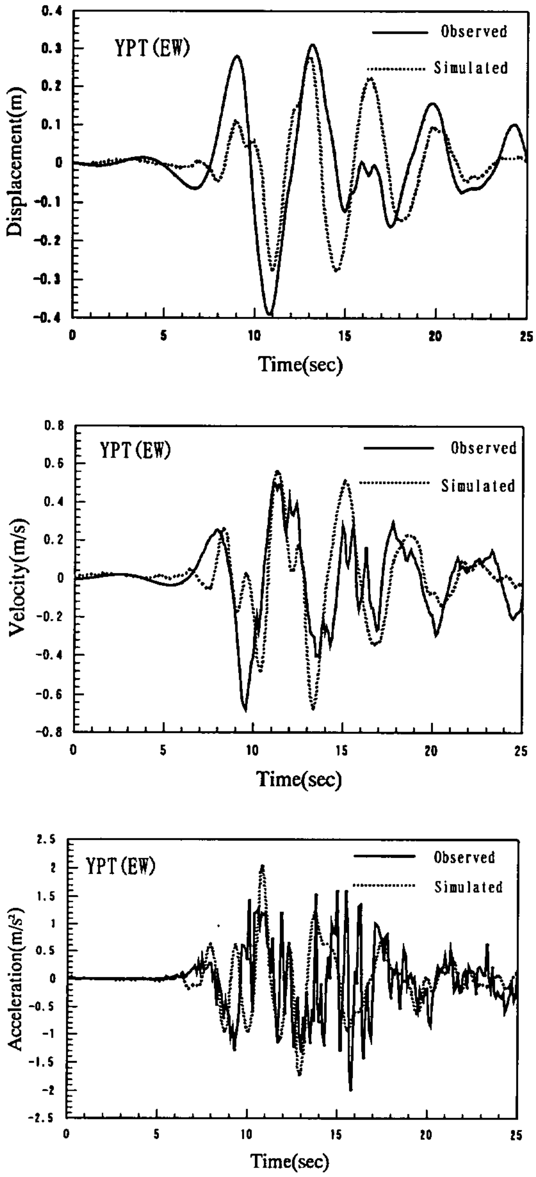


Fig.4 Comparison of observed YPT record with simulated record for EW direction

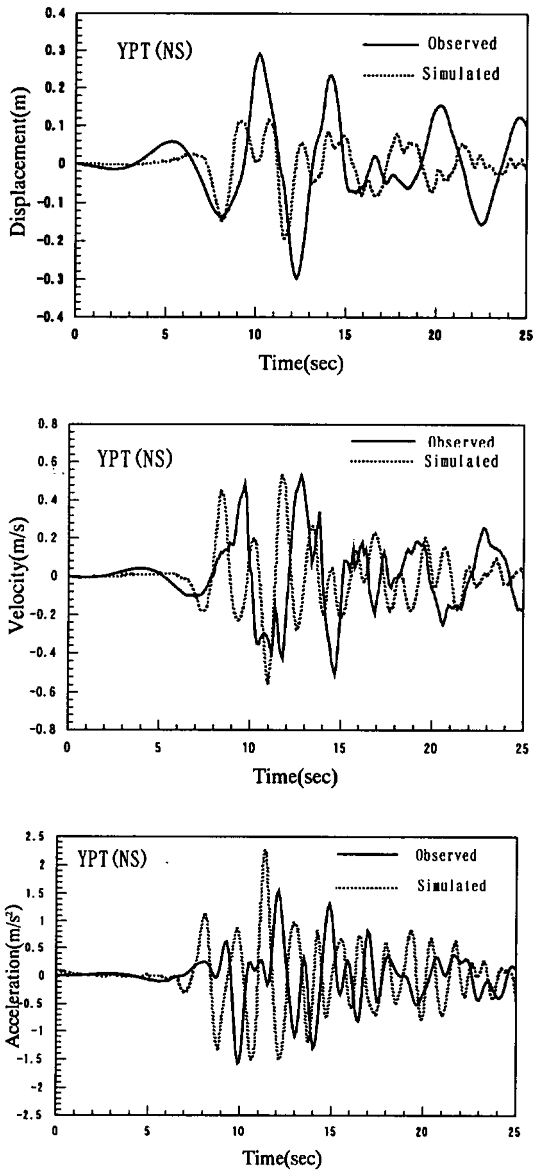


Fig.5. Comparison of observed YPT record with simulated record for NS direction

fault rupture mechanism (dislocation theory), replaced by the equivalent force action on fault area, is solved for the near-source strong ground motion simulation. The 3-dimensional wave analysis is formulated for an elastic media that includes the fault rupturing. The Laplace transform with respect to time and the Fourier transforms with respect to space on the horizontal plane are used for the moving Green Function computation. For the rupture process, the double time convolution integral was implemented by the slip function and space propagation. The inverse Laplace transform is performed analytically and the inverse Fourier transform is carried out numerically when replaced by the discrete wave number method. The detail explanation can be found in Takemiya, *et al.* (1998) Takemiya and Goda (1999).

The present numerical computation are interpreted as follows:

1. The vertical discretization follows the thin layer procedure and the horizontal discretization is determined by in view of the rupture speed and the time increment for analysis.
2. The rupture progress is controlled by a unilateral Haskell model (Haskell, 1964).
3. Since the solution method depends on the step-by-step integration of the convolution integral of the moving Green function for the equivalent dislocation force action, the time increment should be chosen in view of the frequency contents in generated motions.
4. In adopting discrete wave number method the fundamental wavelength should therefore be predetermined according to the frequency contents considered.
5. The seismic parameters are listed in Table 1, the soil properties are in Table 2 and some specific parameters are in Table 3.

SIMULATION RESULTS

It is focused in this study to simulate the YPT record. Following the available source information from the inversion analysis, 3 fault asperities are used with the associated seismic parameters as shown in Table 1, 2, 3.

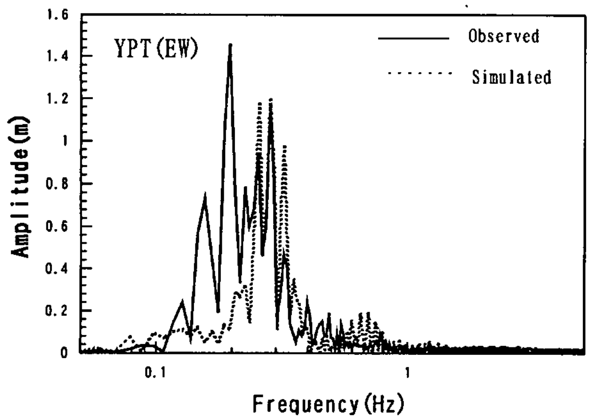


Fig.6 Fourier spectrum of observed and simulated displacement records for EW direction

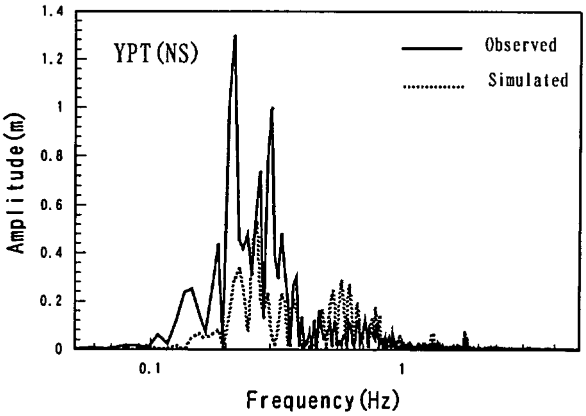


Fig.7 Fourier spectrum of observed and simulated displacement records for NS direction

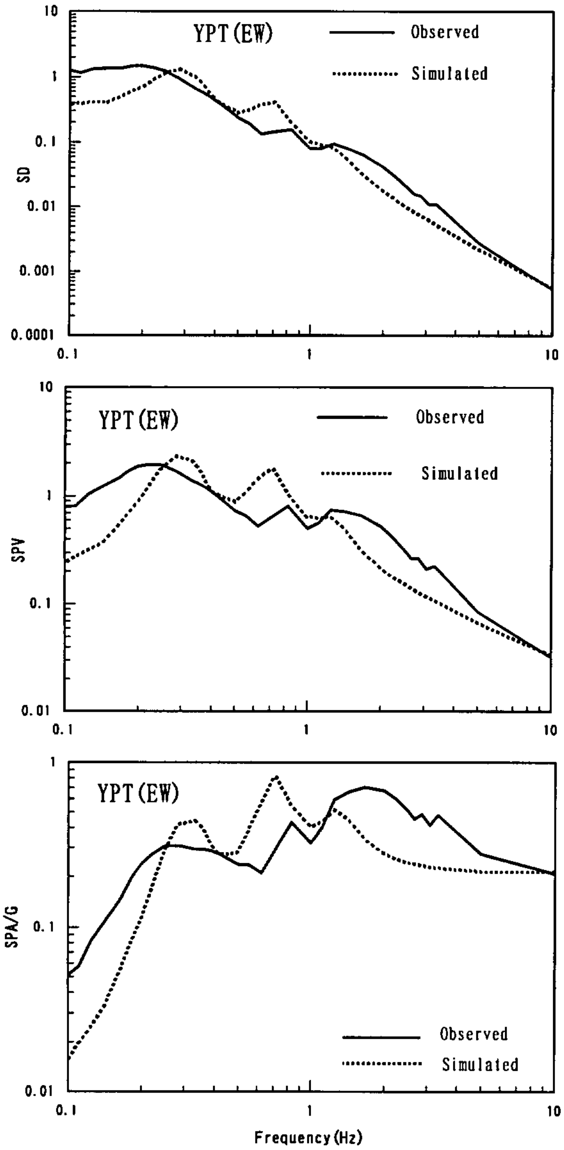


Fig.8 Response spectrums of observed and simulated motions for EW direction

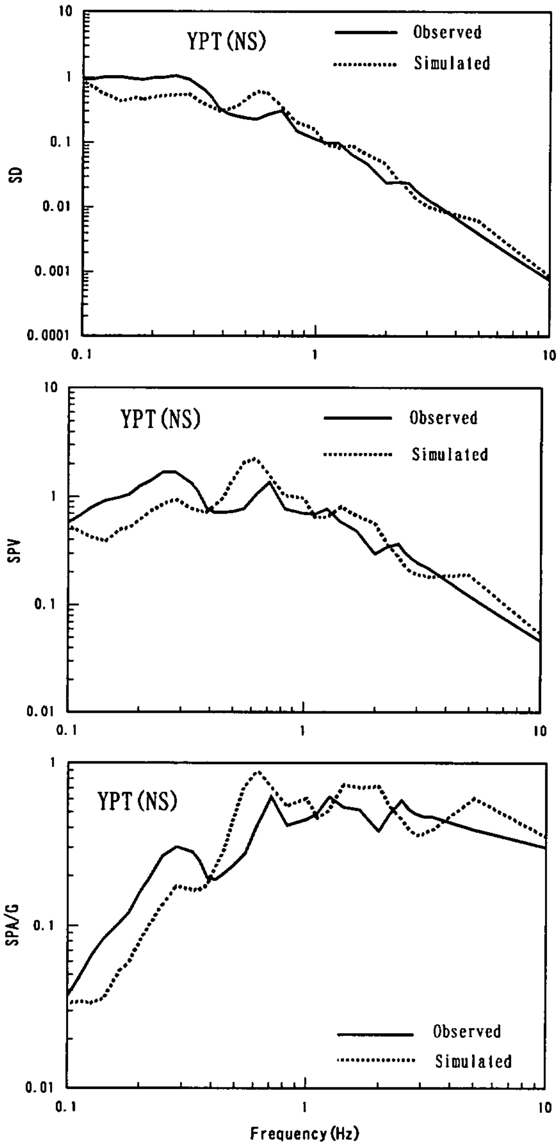


Fig.9 Response spectrums of observed and simulated motions for NS direction

The computation results are filtered in order to extract only the essential response features. The trapezoidal filtering window is used for the final evaluation of displacement, velocity and acceleration responses, which specifies as (0.05-0.1 Hz) for high-pass and (4.0-5.0 Hz) for low-pass cutoff frequencies.

Fig. 4 and Fig. 5 compare the resulting time histories of observed and simulated motions of displacements, velocities and accelerations for horizontal directional components.

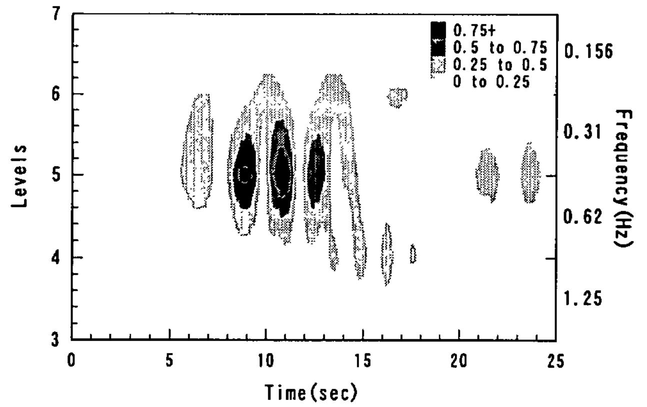


Fig.10 Wavelet Transform of Observed Displacement motion in the EW direction, YPT location

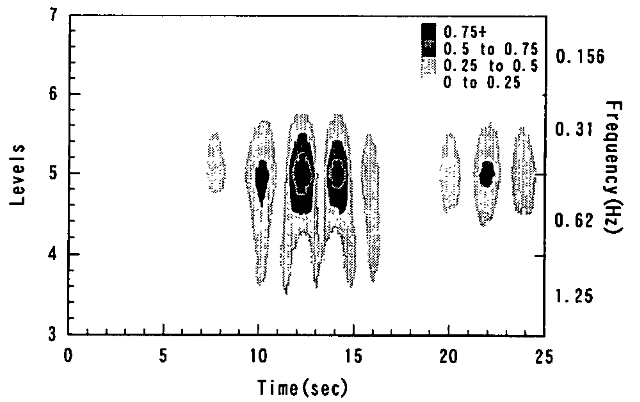


Fig.12 Wavelet Transform of Observed Displacement motion in the NS direction, YPT location

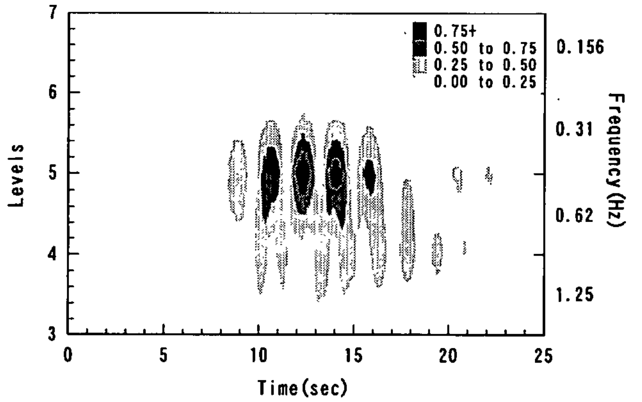


Fig.11 Wavelet Transform of Simulated Displacement motion in the EW direction, YPT location

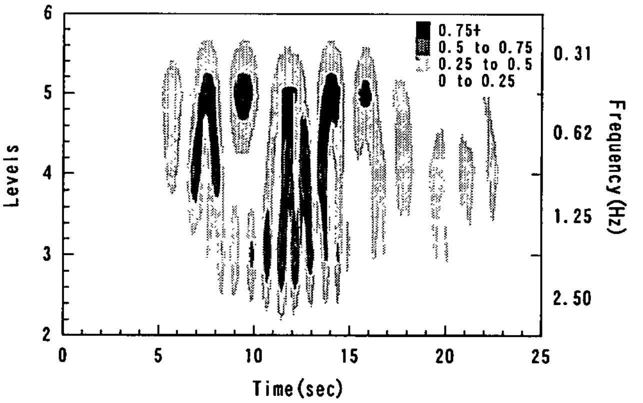


Fig.13 Wavelet Transform of Simulated Displacement motion in the NS direction, YPT location

It can be said that observed and simulated motions have a good matching especially in the displacement-time history for both directions. The differences between the amplitudes of the simulated and observed ground motions can be interpreted as the reason of lack of the sedimentary structure data. However, as it is seen from Fig. 4 and Fig. 5 the major characteristics of the observed records can be almost caught from simulated ones in the displacement, velocity and acceleration-time histories for both directions. The discrepancies between observed and simulated records may be corrected in the further studies by taking into account the site effects through seismic wave propagation.

The displacement-time histories of 2 horizontal motions in Fig. 4 and Fig. 5 indicate that the peak values occur at the same time for both observed and simulated motions. The Fourier Spectrum of the observed and simulated displacement records shown in Fig. 6 and Fig. 7 has a good agreement in each direction. Although the 1st frequency component in observed motion around 0.2 Hz can not be clearly viewed in the simulated motion, the frequencies from 0.25 Hz. to 1 Hz. are in a good agreement.

In Fig. 8 and Fig. 9, the response spectrums of observed and simulated displacement, velocity and acceleration records for 5% damping are presented. The conformity between the observed and simulated motions can be seen especially in the medium and high frequency regions in the spectral displacement (SD) and spectral pseudo velocity (SPV) response spectrums. However this conformity can be observed only in the medium frequency regions in the response spectrum of pseudo acceleration which is divided by gravity (SPA/G). Underestimation is observed in the very low frequency regions for spectra in both directions. These above comparisons can prove successful simulation for observed motions.

WAVELET TRANSFORM ANALYSIS

The comparison of the acceleration time histories in Fig. 4 and Fig. 5 showed the simulation is out of phase in time with the observed data. The acceleration, including high frequencies, indicates the sensitivity to the phase effect due to some uncertainty factors. The wavelet analysis provides us of the information to characterize the ground motions in both frequency and time domain. It decomposes the original signal into a set of level signals. The further explanations about Wavelet Transform analysis can be found in [Newland, 1993] and [Zulfikar & Takemiya. 2000].

In the wavelet transform analysis Daubechies' 10 coefficient mother wavelet function was used for wavelet analysis of the ground motions. The Wavelet transformed values were normalized with respect to peak values of each motion to have a good judgement for comparison.

It is seen from Fig. 10 and Fig. 11 that the main frequencies of both observed and simulated displacement records for EW direction are between 0.31 Hz. and 0.62 Hz. and around 10 sec. to 15 sec. This is in a good agreement with Fourier transform analysis results shown in Fig. 6.

Fig. 12 and Fig. 13 show the wavelet transform analysis of observed and simulated displacement motions for NS direction. It is seen that main frequencies again occur between 0.31 Hz. and 0.62 Hz. However, the simulated motion has rather high frequency components. This is also in a good agreement with Fourier transform analysis as shown in Fig. 7.

CONCLUSION

1. The ear field strong ground motions were simulated for Kocaeli Earthquake (1999). The convolution scheme in time for source function and in space along rupture direction with the layered soil Green's function method based on the kinematic fault rupture mechanism (dislocation theory) was solved in the discretetized form.
2. Regarding the simulation of YPT record, a Haskell model was used as a rupture model. Simulated and observed ground motions showed a good agreement on displacement, velocity and acceleration components in -EW- and -NS- directions.
3. The response spectrum calculations showed that observed and simulated motions have a good matching especially in the major part of the motions.
4. Wavelet analysis was applied to observe the detailed time-frequency information of the recorded and simulated motions. The results were in conformity with the Fourier Transform results.

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