Broadband Ground Motion Simulation during the 1999 Kocaeli (Turkey) earthquake

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Abstract

Broadband ground motion simulation of the 1999 Kocaeli (Turkey) earthquake was performed in the region around the fault plane. The methodology applied is aimed to produce ground motions in the 0.1Hz – 1.0Hz frequency band. The simulation is performed in low frequency (0.1-1.0Hz) and high frequency (1.0-10Hz) bands separately and then added at each station. The low frequency part is based on an asperity model determined from the slip distribution result of a Kinematic inversion. One point source is used to represent the low-frequency ground motion at each asperity. The high frequency part is obtained from an extended area representing each asperity. The empirical Green's function summation technique is applied, using an element waveform calculated stochastically that follows an omega square source model and regional attenuation of Q.

Introduction

The 1999 Kocaeli earthquake that struck the western Turkey was a complex rupture characterized by a right lateral strike-slip fault with a moment magnitude of 7.4. The earthquake was produced by the western part of the North Anatolian fault east of the Marmara Sea. Approximately 130 km of surface rupture was observed (CNRS-INSU, IPGP, Istanbul Technical University). To understand the kinematic rupture process of the earthquake a kinematic inversion of the source was performed using the strong motion stations shown in figure 1 (Sekiguchi 2000). The fault model used for the inversion is also shown in that figure.

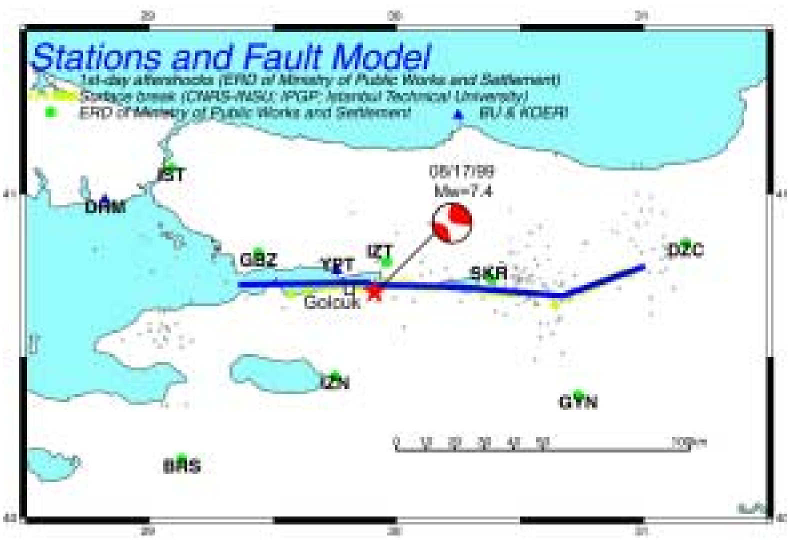

Figure 1 Surface break and fault model of the 1999 Kocaeli earthquake. The strong motion stations used for the kinematic source inversion are shown (Sekiguchi 2000) .

The final slip solution shows three patches of large slip, the first one localized in the bottom of the fault, 10 km west of the hypocenter. The second one 15 km to the east of the hypocenter at the bottom of the fault and the third one localized in the upper part of the fault 40 km to the east of the fault.

Ground Motion Estimation Methodology

The basic idea of the ground motion estimation methodology is to produce ground motions in a broadband frequency range (0.1Hz to 10 Hz) in order to be able to compare the simulated ground motions with the observed damage distribution. The procedure to be applied is a hybrid ground motion simulation technique, which consists in the generation of ground motions in a low frequency (<1Hz) and high frequency (>1Hz) bands (figure 3).

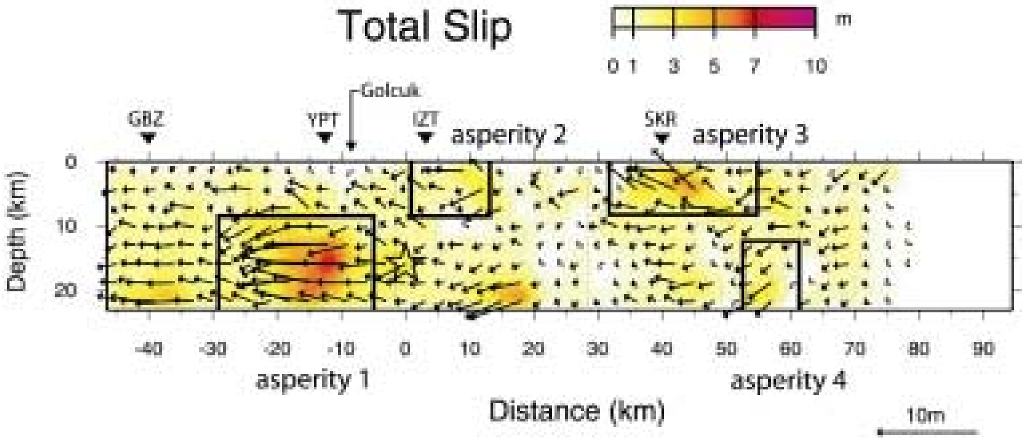

Figure 2. Kinematic Model of the 1999 Kocaeli earthquake. Final Slip distribution (Sekiguchi 2000). The hypocenter is shown by a star. Horizontal distance is measured from the hypocenter. Arrows denote final slip vector. The preferred asperity model is shown.

The low frequency part of the ground motion is calculated from the radiation of a simplified asperity model (figure 2) propagating in a 1D velocity structure. For this purpose a Discrete Wave Number method for a 3D elastic wave propagation in a layered media is applied (Bouchon 1981). One point source is used to calculate the ground motion from each asperity.
The high frequency motion generation uses the idea of the empiricals Green's function technique (Irikura 1983), which consists in using recordings from small events (aftershocks) in order to reproduce the ground motion from a large event (mainshock). For that purpose the scaling relation of the source spectra and the source parameters together with an appropriate selection of the small event is considered. For regions like the Goluck city, where no appropriate recording of aftershocks is available, the seismograms of the small event are generated stochastically in such a way that they follow an omega square model and a regional attenuation relationship (Boore 1983). Then the empirical Green's function method is applied using the synthetic aftershock waveform obtained previously.
Finally the amplification of the seismic waves and the nonlinearity effect of surficial layers should be included to get the ground motion at a specific site. This step is not performed in our simulation. The final motion is obtained from the summation of the low and high frequency parts obtained before.

Simulation Results

The ground motion methodology was applied to all the near and intermediate field stations recorded during the Kocaeli earthquake, showing in general a good agreement between the simulated and observed waveforms. From the kinematic source model of the Kocaeli earthquake (Sekiguchi 2000) and initial asperity model was determined for the regions of large slip. After studying the contribution of each asperity to the ground motion at all the stations, a final model consisting of 4 patches of large slip (asperities) that optimised the fitting of the waveforms was determined (figure 2).
The rise time of the shallow asperities was found to be larger than the deeper ones. The stress drop was smaller for the shallow asperities like No. 3, where a slight increase in this parameter produces a large increase in the acceleration amplitude. The final parameters of asperities are summarized in table 1. In figures 4(a) and (b) we can see a good agreement between the simulations and observations at the SKR and GBZ stations. The response velocity spectra and acceleration response spectra also show a good agreement in the low and high frequency content.
We obtained that the best fitting of the waveforms was obtained for a model that includes a large rupture velocity inside the asperities in the eastern part (No3 and No4) compared with a smaller rupture velocity for the asperities in the western part (No1 and No2). These results are constrained by the stations SKR and GBZ, which are, located in a forward directivity direction and whose ground motion is determined mainly by asperities No3 and No1 respectively. We obtained in general that the amplitude of the acceleration waveforms are mainly controlled by the stress drop and rise time inside asperities while the size and rupture duration of asperities controls the velocity waveforms (rupture velocity inside asperity).

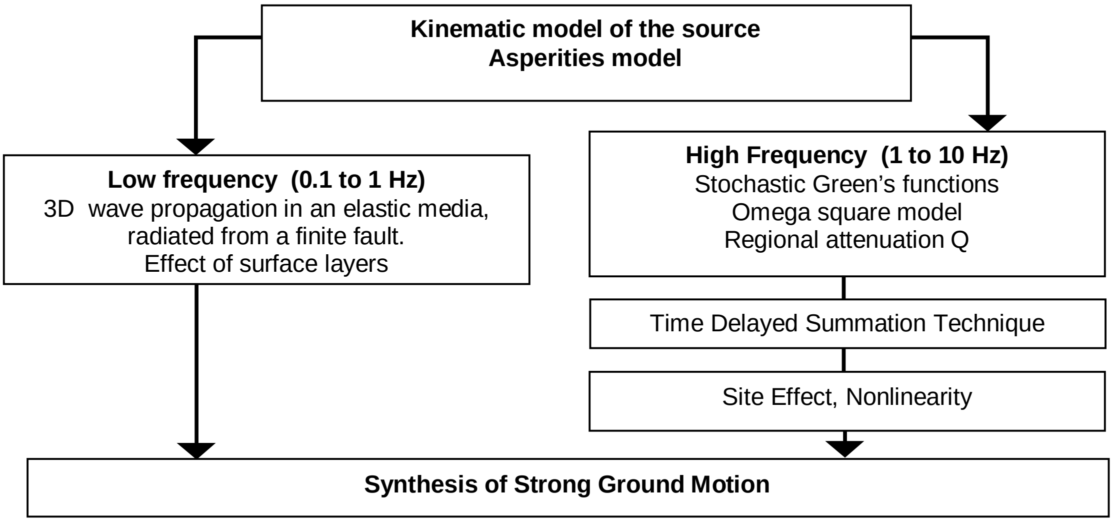

Figure 3. Flowchart for the Broadband estimation of ground motion (Hybrid Technique)

Asperity	**Area (km^2)**	**Seismic Moment $M_0 \times 10^{18}$ (Nm)**	**Rise time (sec)**	**Rupture Velocity (km/s)**	**Stress Drop (bar)**
1	14.5 x 24	44.10	0.4	2.5	100
2	8.7 x 12	4.62	1.5	2.9	100
3	8.7 x 24	7.68	1.5	3.6	50
4	11.6 x 9	5.89	0.3	3.5	200

Table 1 List of Parameters asperities

Conclusions

We estimated the ground motion at several stations during the 1999 Kocaeli earthquake. The good agreement of the waveforms supports the effectiveness of the hybrid ground motion simulation procedure, in estimating the ground motion in a broadband frequency.
The amplitude and frequency content of the acceleration waveforms are mainly controlled by the stress drop and rise time inside asperities, whereas the velocity waveforms are controlled by the rupture duration and size of asperities.
The estimated rupture velocity of asperities in the eastern part of the fault was larger than the rupture velocity in the western part. The hybrid ground motion simulation could be improved with the inclusion of a frequency dependent site effect at each station. For that purpose knowledge of the structure beneath the stations should be investigated.
The final target of the simulation is to obtain the ground motion at locations were no ground motion were recorded like the heavily damaged region of Golcuk in order to give an interpretation of the damage distribution.

Acknowledgments

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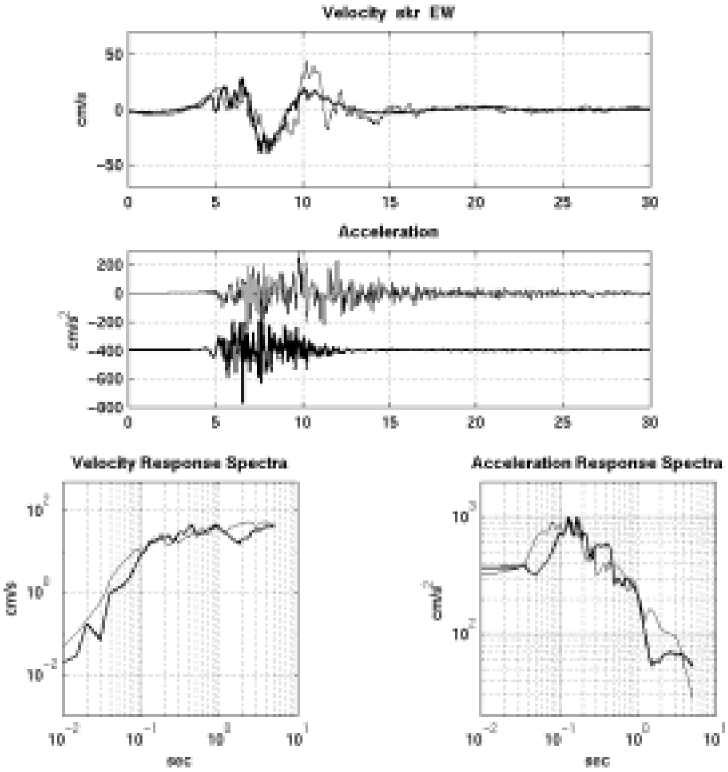
(a)



(b)

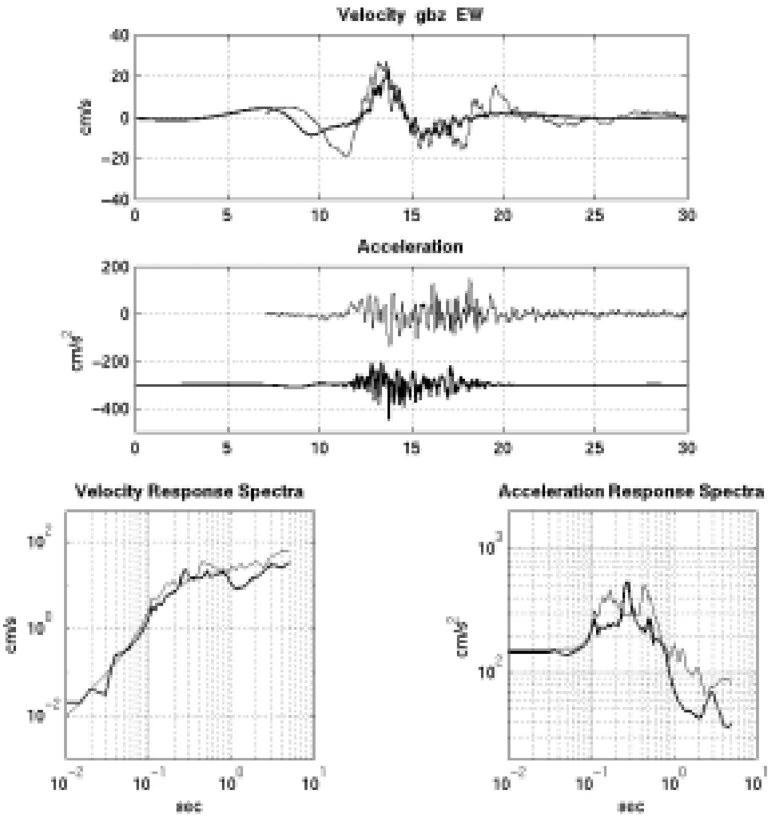


Figure 4 Comparison between Observed and Simulated ground motions (thicker line) at (a) GBZ station and (b) SKR station, (EW component). Velocity and Acceleration waveforms (upper figures). Velocity and Acceleration Response Spectra (lower figures).