

4 STRONG GROUND MOTION AND FAULT RUPTURE

During September 5 to 12, the members of the JSCE team for the survey on the strong ground motion and the fault ruptures visited the strong motion observation stations in the earthquake-affected region and measured the shear wave velocities using a portable elastic wave exploration device. Strong motion simulations have been done according to a fault rupture model. The estimated waveforms by using the fault rupture model show a good agreement with observed records.

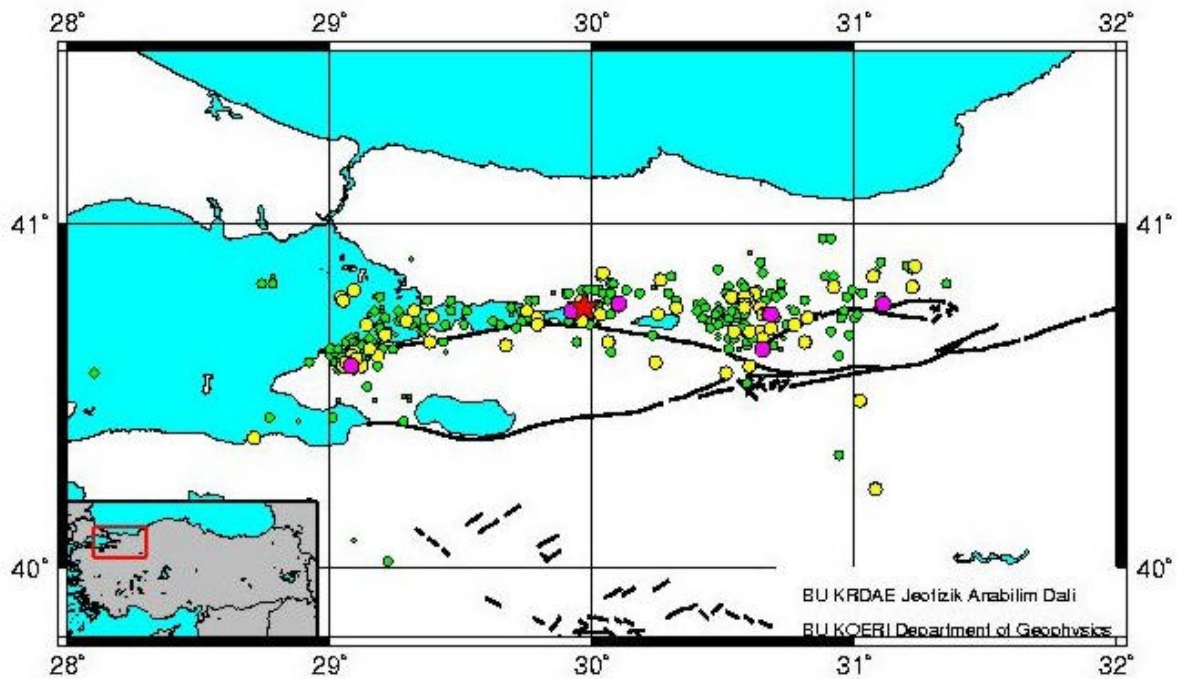


Figure 4.1 Aftershock distributions (after KOERI)

4.1 Mainshock and Aftershocks

At 3:01 a.m. local time on Tuesday, August 17, 1999, the main shock with a magnitude of 7.4 occurred in Kocaeli Province of Turkey. The epicenter of the earthquake was at 40.77 degrees latitude and 29.97 degrees longitude. The depth of hypocenter was about 17 km. The earthquake fault was observed between Hersek delta and Gökaya and it has two segments; one extends between Hersek delta and Akyaz , striking in almost EW direction and the second one spans between Akyaz and Gökaya striking in NE-SW direction. The traced fault length on the ground surface is about 100 km. Source mechanisms by USGS, HARVARD and DAD-ERD and ERI all indicate right-lateral strike-slip faulting. This agrees with field investigation results of the JSCE survey

team. The fault displacement ranges between 2-4 meters. The western portion of the fault is considered to be in the sea of Marmara. The total length of the fault is estimated as 150km (see section 4.4). The spatial distribution of aftershocks for three weeks after the main shock is shown in Figure 4.1. The aftershocks concentrate especially around the epicenter, and at the ends of two segments, namely, Yalova, Akyaz and Gökaya from west to east, respectively.

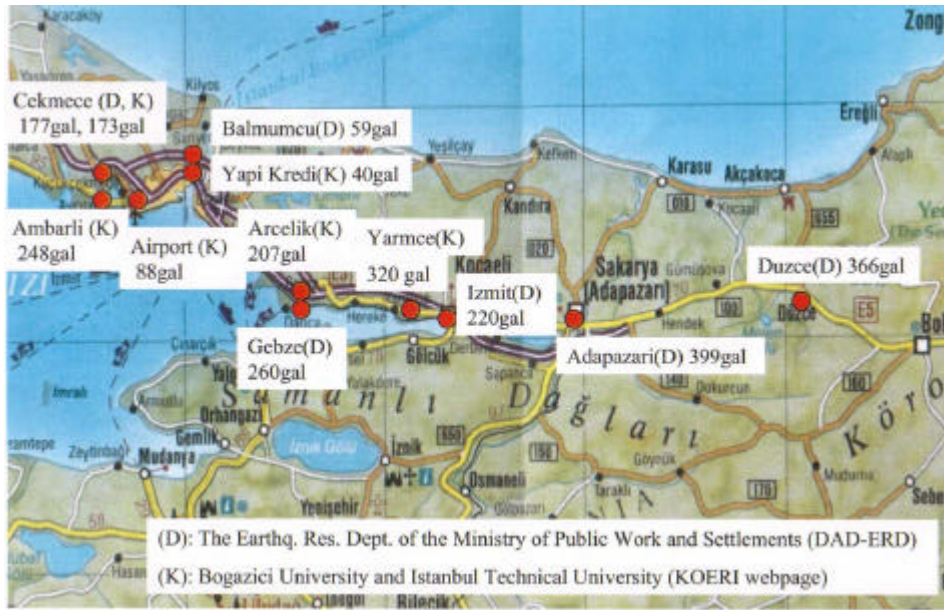


Figure 4.2 Maximum acceleration distribution (data from DAD-ERD-KOERI)

4.2 Observed Records

Three strong-motion observation networks are established in the region and are managed by the Earthquake Research Department (DAD-ERD) of the Ministry of Public Works and Settlements, Bo aziçi University and Istanbul Technical University (KOERI WebPages). Figure 4.2 shows the maximum horizontal accelerations recorded at the observation stations of DAD-ERD and Bo aziçi University. The peak acceleration of Düzce, the east end of the inferred fault, is 366gal. A peak ground acceleration of more than 300gal was also observed at Yar mca station of Bo aziçi University. The earthquake records observed at the Kobe Marine Observatory in the 1995 Kobe earthquake and at the DAD-ERD Sakarya observation station in the 1999 Kocaeli earthquake are shown in Figure 4.3. The peak ground accelerations are 817gal and 399gal respectively. A large pulse of the period of about 1sec is dominant in Kobe, while a long period component of 4–5sec is found in the wave at Sakarya station.

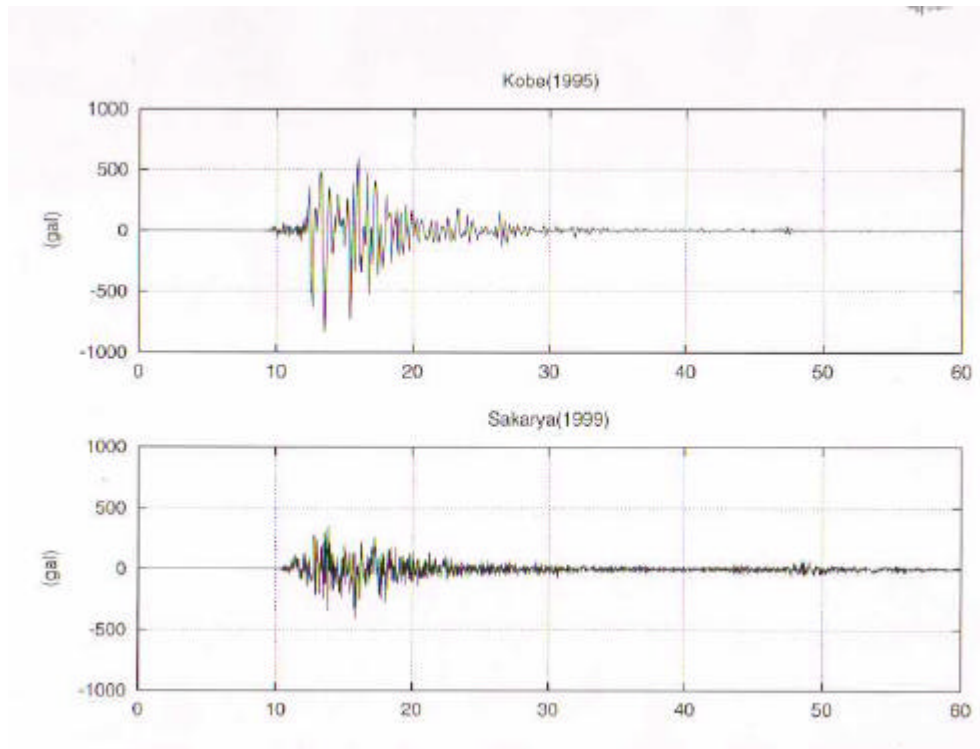


Figure 4.3 The earthquake records observed at Kobe and Sakarya

The JSCE team members visited the DAD-ERD observation stations at Düzce (Figure 4.4) and Sakarya (Figure 4.5). Shear wave velocity characteristics of ground at each station were measured by using a portable elastic wave exploration device (Figure 4.6). Because of the capacity of the exploration device the horizontal distance of the measuring line was restricted to 10-15 meters. Therefore, shear wave velocities could be measured only for depths of several meters. Table 4.1 shows the results. The ground was generally hard and the S wave velocities at several stations were more than 300 m/s except the city center of Adapazarı. The strong motion observation station of Adapazarı is a few kilometers away from the city center and the surface ground there is much stiffer than that in the city center ($>300\text{m/sec}$). Therefore, the ground motion in the severely damaged area in the city center might be quite different from that at the Sakarya (Adapazarı) station. Most of the heavily damaged areas was situated on the soft soil (Figure 4.7). In the case of the 1995 Kobe earthquake in Japan, the irregularity of the geological structure resulted in a large amplification of ground motion, which was one of the causes for the heavy damage. In Avcılar, the west of Istanbul, the peak acceleration was unexpectedly high more than 200gal. More detailed study on the surface topography besides the ground conditions is necessary to clarify the cause of the amplification of the ground motion.

Table 4.1 S-wave velocities at ground motion observation stations

Location	Installation site of the seismometer	S-wave velocity (m/s)	Comment
Düzce (DZC)	MO, Ground level	350	City center
Sakarya (SKR)	IIM Concrete foundation	310	Hill side (2-3 km SW of Adapazar)
Adapazar	1 st layer (30cm) 2 nd layer	70 150	50cm beneath ground surface
Izmit (IZT)	MO, Ground level	320	Hill top, hard soil
Yar mca (YPT)	Bo aziçi University	330 320 310 (1m) 510	West of Yar mca Center of Yar mca Oil Refinery
Gebze (GBZ)	TÜB TAK, Basement	500 (2m) 780	Flat ground on hilltop, rocky site
Balmumcu (IST)	IIM, Ground level	100(1m) 550	New town on hill top, weathered graywacke
Çekmece (CEK)	Institute of Atomic Energy, Basement	300 (1.4m) 640	Hill top, limestone

MO: Meteorological Observatory; IIM: mar skan Müdürlü ü



Figure 4.4 Düzce Station



Figure 4.5 Sakarya station



Figure 4.6 S- wave velocity exploration device



Figure 4.7 Ground conditions in the
city center of Adapazar

4.3 Maximum Aftershock

Before the 1999 Kocaeli earthquake, strong motion network was not dense enough to obtain the nearfield ground motion. The nearest observation station located several kilometers away from the fault. After the earthquake, several temporary stations have been installed for observation of the aftershocks. A large aftershock with magnitude 5.8 is occurred at 11:55(GMT) on September 13, 1999. Hypocenter information is as follows (after Earthquake Research Department).

Latitude: N40.80

Longitude: E30.03

Depth : 4.3km

Magnitude: 5.8

The recorded accelerations are published (<http://angora.deprem.gov.tr/sept13after.htm>). The maximum acceleration record is obtained at TPT(Tepetarla) temporary station. This station is about 3 m from the fault surface break. It is on the southern side of the fault and on a clayey soil. The accelerations are shown in Figure. 4.8. The maximum acceleration is over 612 cm/s^2 and predominant period is about 0.8 seconds. The maximum velocity is briefly estimated as 80 cm/s.

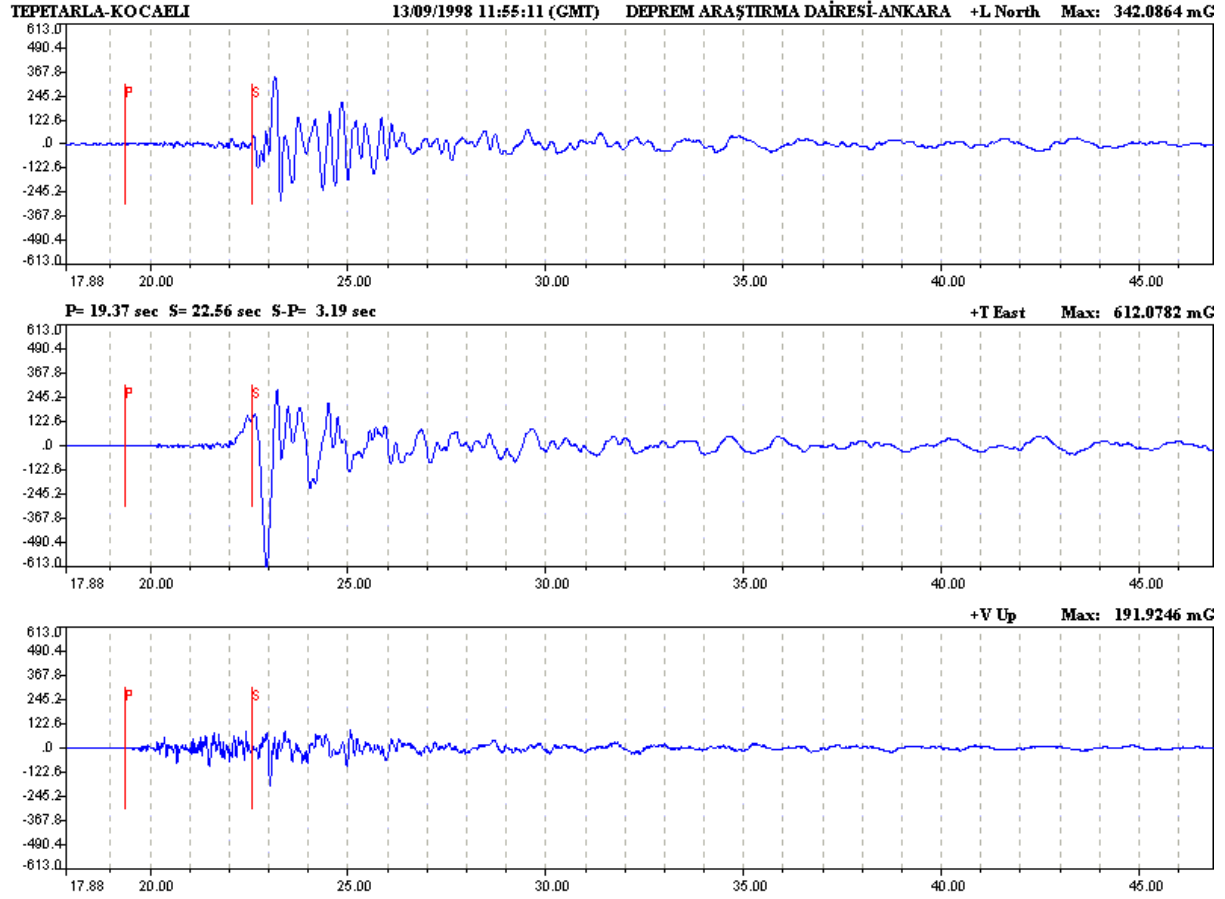


Figure 4.8 Acceleration records at Tepetarla station measured during 13.9.1999 aftershock by DAD-ERD

4.4 Surface Fault Trace

Surface ruptures occurred close to known geological active faults. Figure 4.9 shows the main trend of the surface fault rupture traces (Gülen and Kalafat 1999 <http://kandilli.koc.net/rupture.htm>). The western end of the surface fault ruptures was observed in Gölcük. Figure 4.10 shows the right lateral strike-slip fault of more than 4m in Gölcük. The surface fault rupture extends to the Navy Base in Gölcük and goes into the Izmit Gulf. The fault passes through the sea from Gölcük and appears again on the land at Ba iskele and extends towards Sapanca Lake. Figure 4.11 shows about 2m right lateral displacement near Kullar village. A large displacement can be seen near the

TCDD Tepetarla station. Here, rails and embankment of a railway were deformed by the fault movement. The fault goes into the Sapanca Lake and appears in the land near Arifiye as shown in Figure 4.12. In Arifiye, an over the Trans-European Motorway (TEM) bridge collapsed due to the fault movement. The eastern end of the fault could be traced as far as the southwest of Düzce.

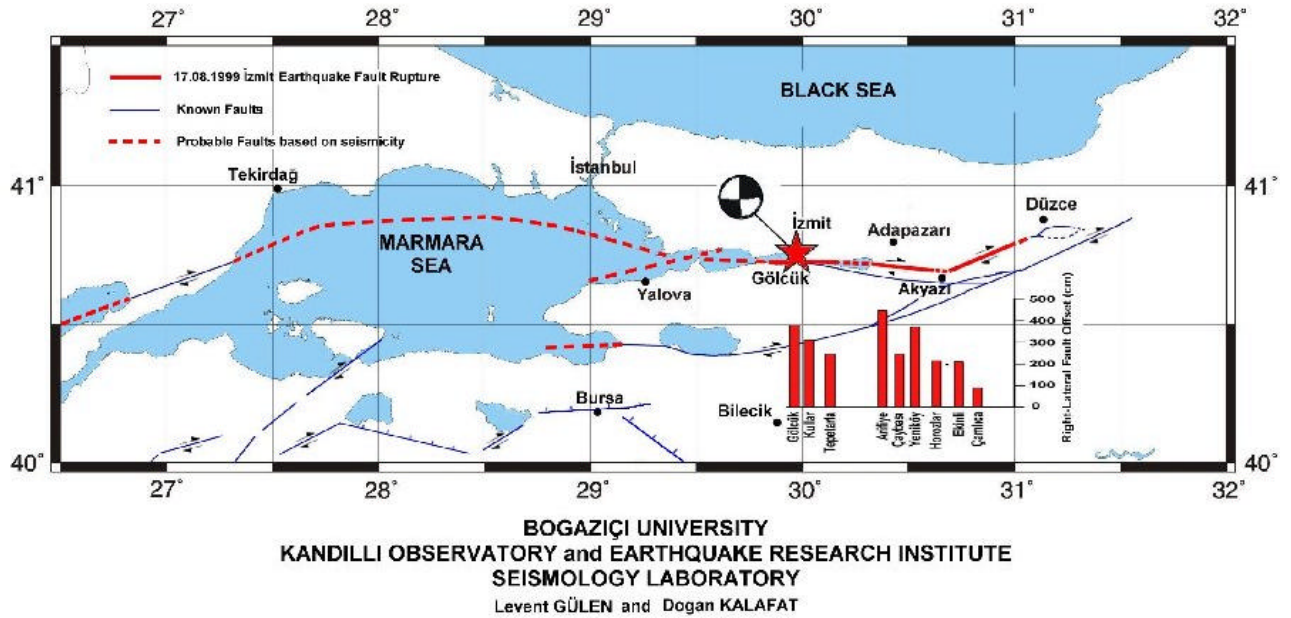


Figure 4.9 The main trend of fault breaks (after Gülen and Kalafat 1999)



Figure 4.10 Faulting in Gölçük



Figure 4.11 Faulting in Kullar village

In Gölçük, a large subsidence of the ground was observed in wide area. The maximum vertical displacement was more than 2m and it was caused by a normal fault which was secondarily caused by the main strike slip fault (Figure 4.13). This might be caused by tensile force caused two stepping strike-slip faults. However, the direction of the normal fault is varying and any strike slip fault was not found at the southern end of the normal fault. It is supposed that there may be a large graben structures in the Izmit Gulf and that the graben structure is further grew up by this earthquake. This

triggered a huge slippage of unstable sediments had slipped down into the graben, resulting high waves (Tsunami). It can be guessed that a large coastal area of Gölcük had subsided for this reason.



Figure 4.12 Faulting in Arifiye



Figure 4.13 Normal faulting in Kavaklı (Gölcük)

4.5 Fault Rupture Model

Yagi and Kikuchi(1999) have published waveform inversion results on their web site (<http://www.eri.u-tokyo.ac.jp/yuji/trk/izumit.html>). Figure 4.14 shows the fault plane location. The total length of the fault is 105km and strike is almost E-W direction. The fault slip distribution is shown in Figure 4.15. The figure shows that major slips are concentrated in deep portion 0-10km west from the hypocenter and in shallower portion 20-35km east from the hypocenter. The maximum slip was reported as about 7m. The slip duration is estimated about 15 seconds. The large slip area of this model seems to be correspond to the area where the surface ruptures were observed. However, this model was based on the earthquake ground motion record in far field. The details of fault rupture mechanism shall be carefully studied by using near field strong motion records.

4.6 Strong Motion Simulations

By using the fault rupture model by Yagi and Kikuchi (1999), a near field strong ground motion simulation was carried out. Figure 4.16 shows target sites and Figure 4.17 is the asperity model for the simulation. The asperity area is about 22% of total rupture area and slip contrast is assumed as 2.0(asperity) and 0.72(other). The rise time is set as 2.37sec. These values are the average rupture parameters for crust earthquakes given by Somerville et al. (1999). There is no enough information about sedimentary structure. The shear wave velocity was assumed as 3.5km/s for the rock sites and 1.5km/s with 1.0km thickness for the sediment sites.

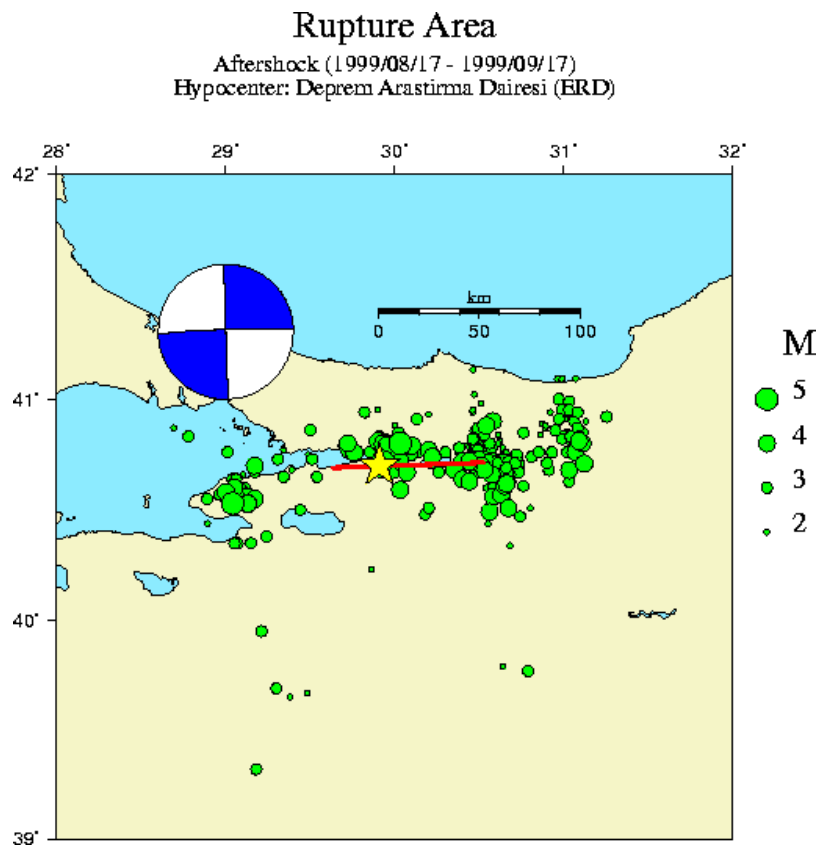


Figure 4.14 Rupture area assumed in Yagi & Kikuchi's solution

The stochastic Green's function method was applied for the simulation. The basic concept of the method for the simulation is shown in Figure 4.18. First, stochastic wave traces that follow w^2 scaling law are generated with random phase characteristics [Boore(1983)]. Frequency dependent radiation patterns, path effects including Q-value, the effect of site responses with layered structures are taken into the consideration. Green's functions are summed up along the rupture propagation, to generate strong ground motion [Irikura(1983)].

Figures 4.19 to 4.23 show the simulated earthquake ground motions in comparison with the observed ones. The amplitudes of the simulated ground motions are rather smaller than the observed. This may result from the lack of the data about the sedimentary structure. However, the simulated ground motions can mostly explain major characteristics of the observed records. This result shows that the strong ground motions can be explained by the average fault rupture model.

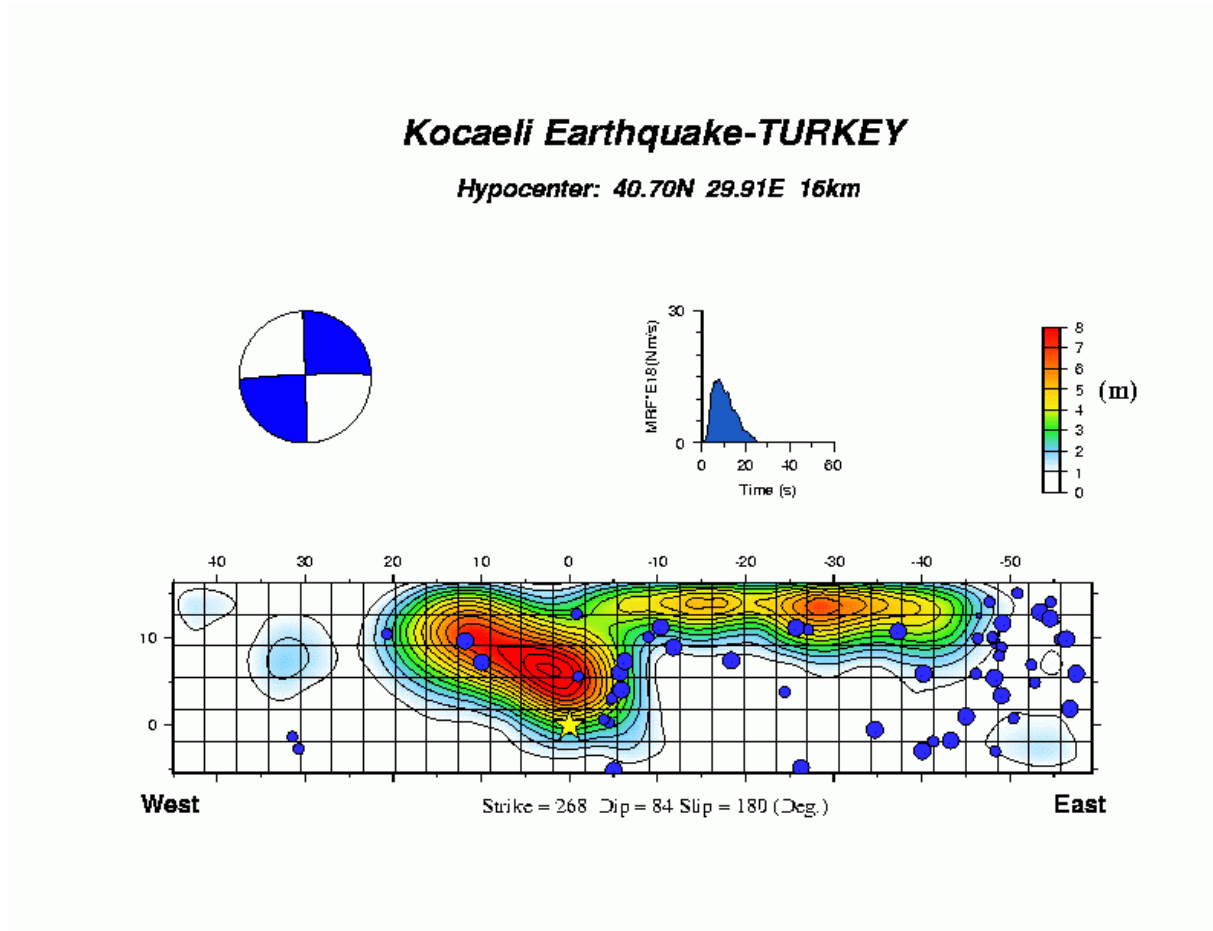


Figure 4.15 Slip distribution along the fault (Yagi and Kikuchi 1999)

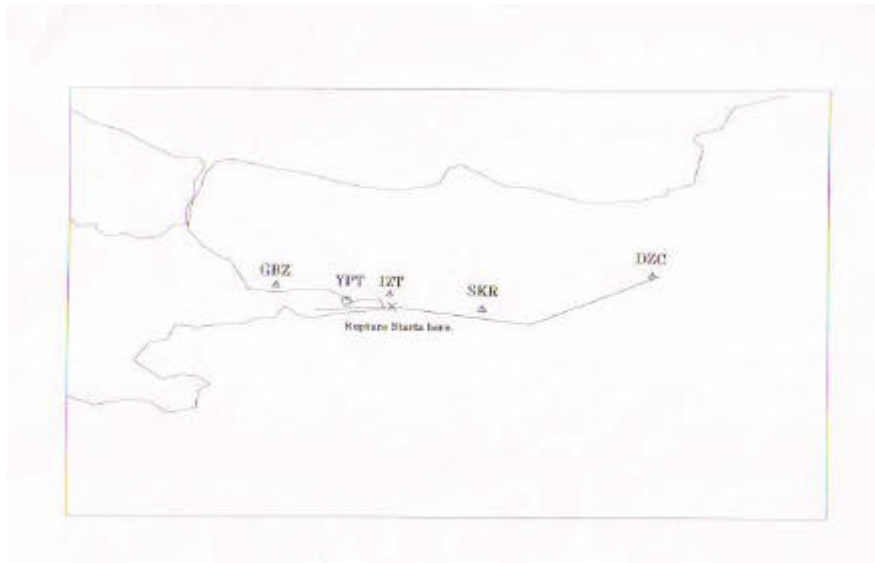


Figure 4.16 Sites for simulation of the ground motions

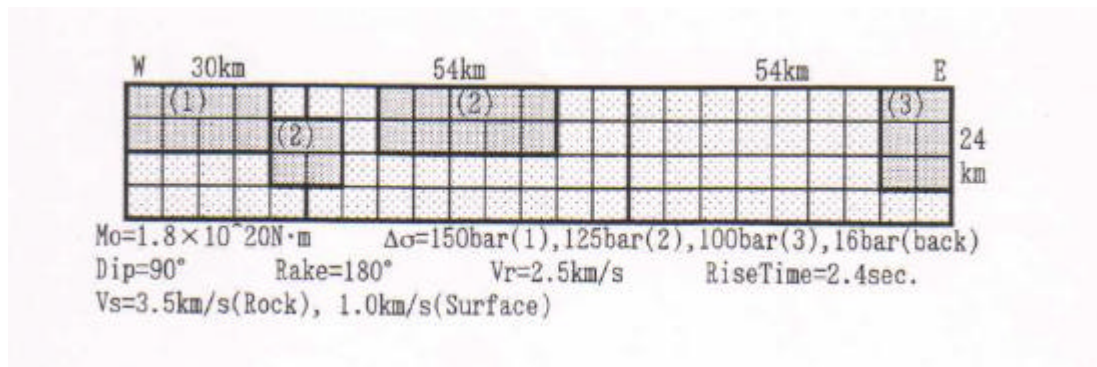


Figure 4.17 Asperity for Simulations of Ground Motion

4.7 Conclusions

After the earthquake, a plenty of informatio about the earthquake records and the fault rupture mechanism has been published through the web sites of the National Earthquake Research

- 1) At the strong ground motion observation sites, soil conditions, geological structures, site responses are necessary.
- 2) Measurements of fault movements and ground deformations are necessary through a detailed field measurement and aerophotography analysis. Furthermore, seismic explorations in the Izmit Bay and the Sapanca Lake are required.
- 3) Survey of fault rupture process of the main is essential to explain observed strong ground motion records.
- 4) Survey of ground conditions and geological structures is required in damaged area and the strong ground motion should be re-estimated in the area.

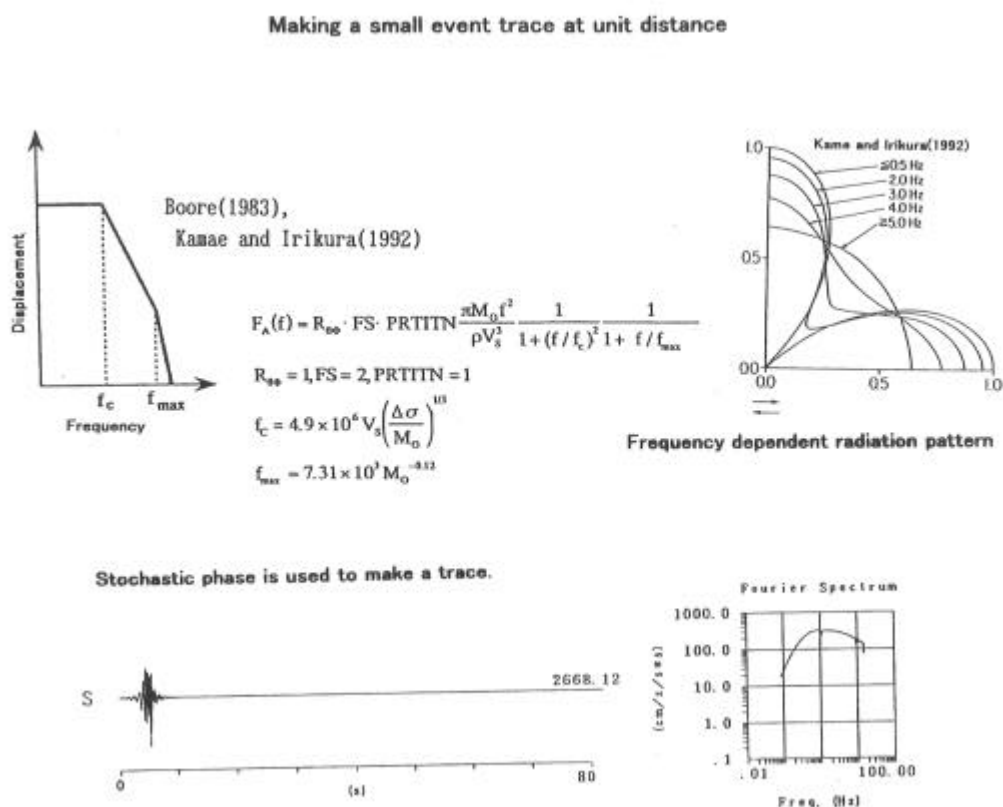


Figure 4.18 Basic concept of the method for the simulation

Fig. 4-19(a) Observed wave traces at SKR site

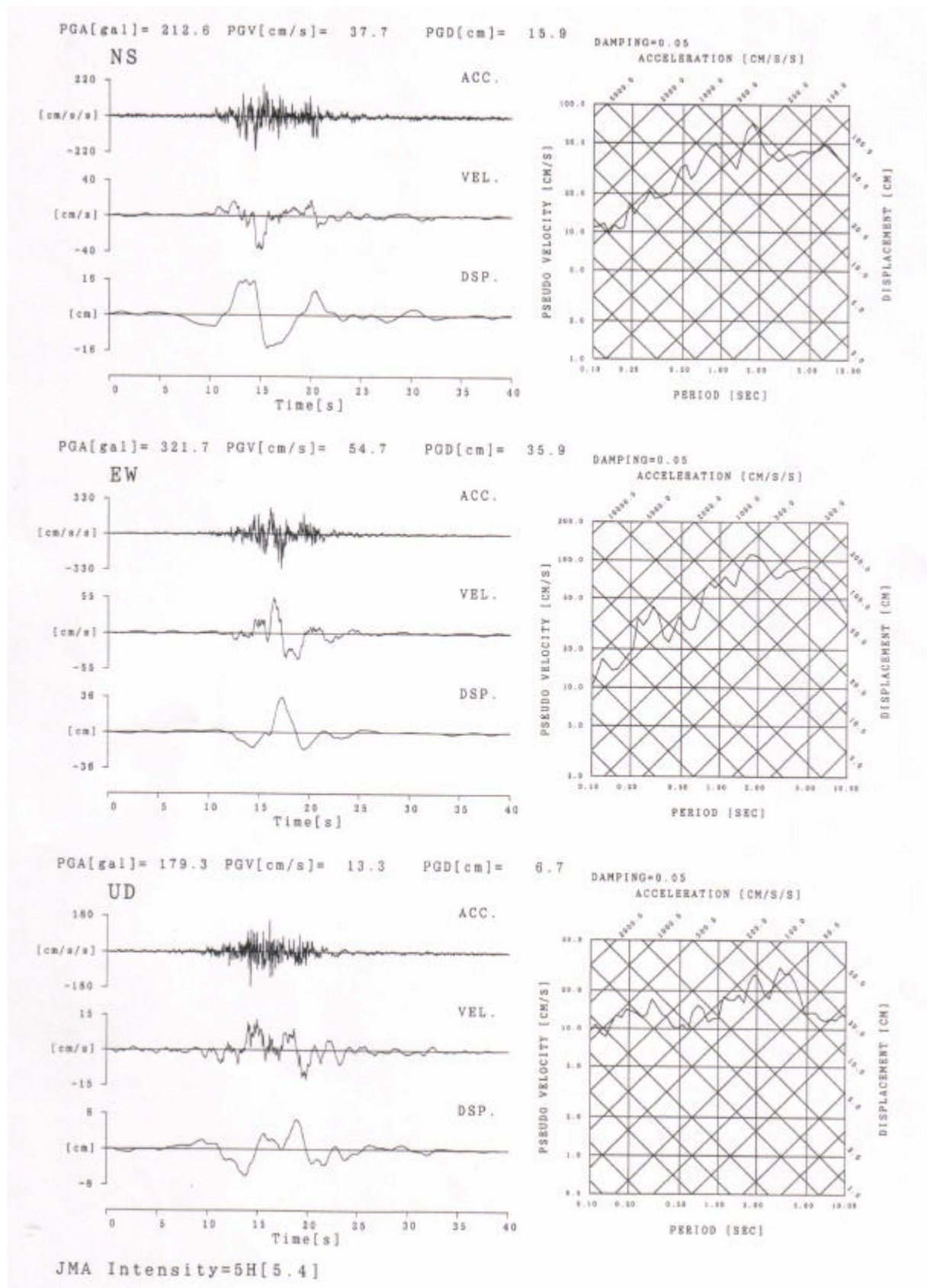
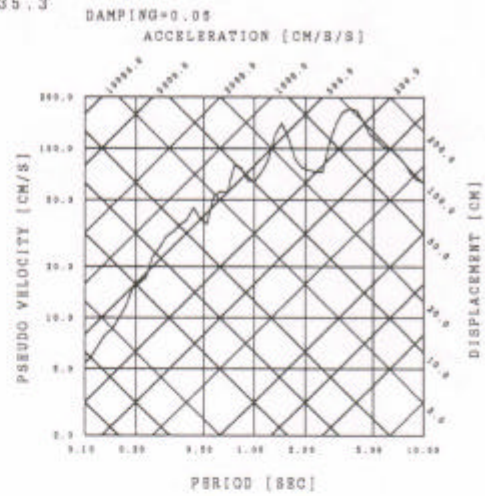
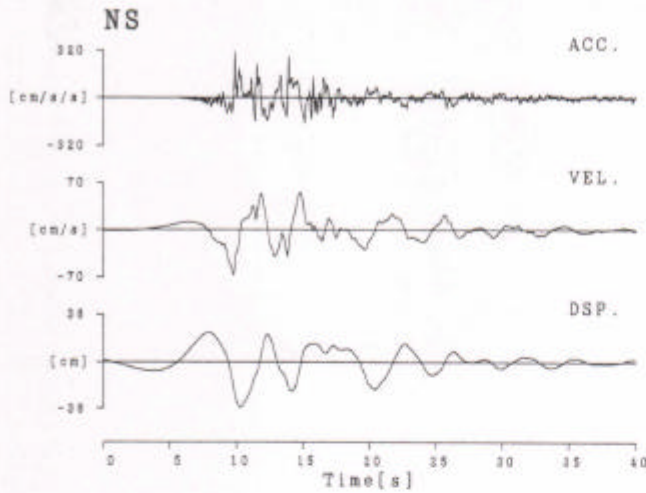
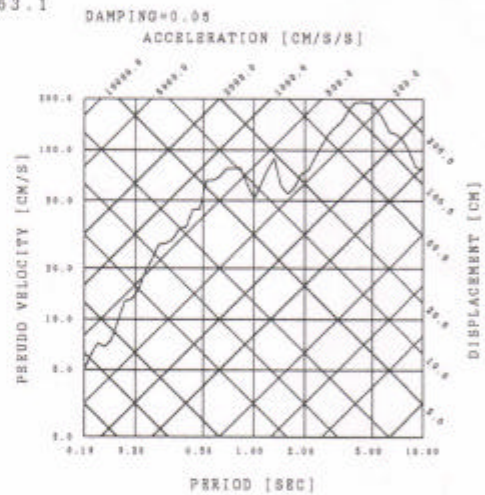
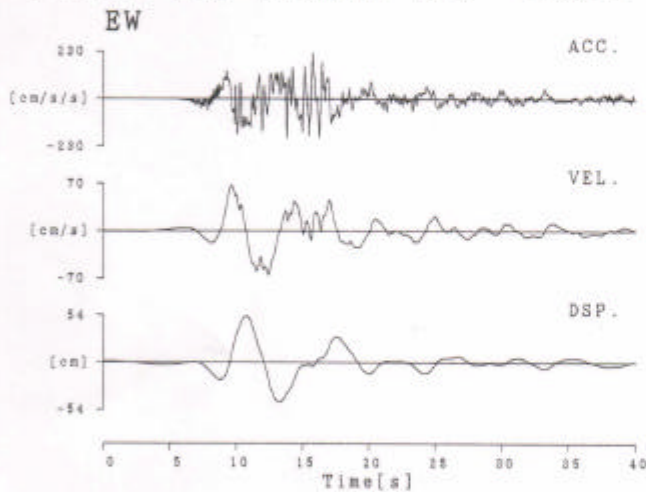


Fig. 4-19(b) Simulated wave traces at SKR site

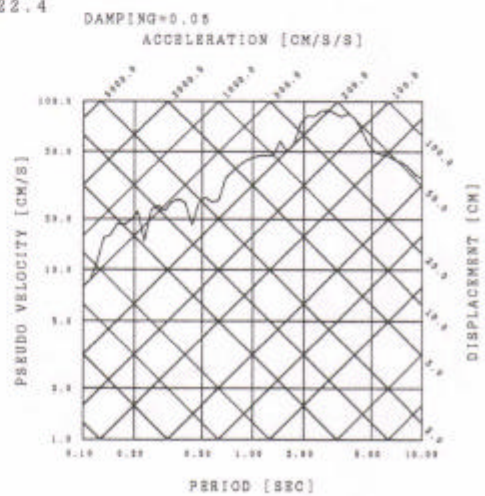
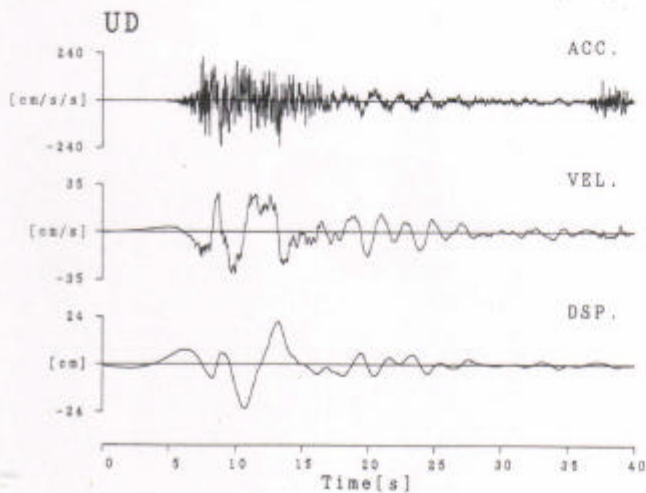
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PGA[gal]= 225.1 PGV[cm/s]= 88.0 PGD[cm]= 53.1



PGA[gal]= 238.3 PGV[cm/s]= 30.4 PGD[cm]= 22.4



JMA Intensity=5H[5.4]

PGA[gal]= 528.0 PGV[cm/s]= 81.4 PGD[cm]= 40.1

NS

ACC.

VEL.

DSP.

Time[s]

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PSEUDO VELOCITY [CM/S]
PERIOD [SEC]
DISPLACEMENT [CM]

PGA[gal]= 519.3 PGV[cm/s]= 79.1 PGD[cm]= 30.1

EW

ACC.

VEL.

DSP.

Time[s]

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PSEUDO VELOCITY [CM/S]
PERIOD [SEC]
DISPLACEMENT [CM]

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UD

ACC.

VEL.

DSP.

Time[s]

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PSEUDO VELOCITY [CM/S]
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DISPLACEMENT [CM]

JMA Intensity=6L[5.9]

Fig. 4-20(b) Simulated wave traces at YPT site

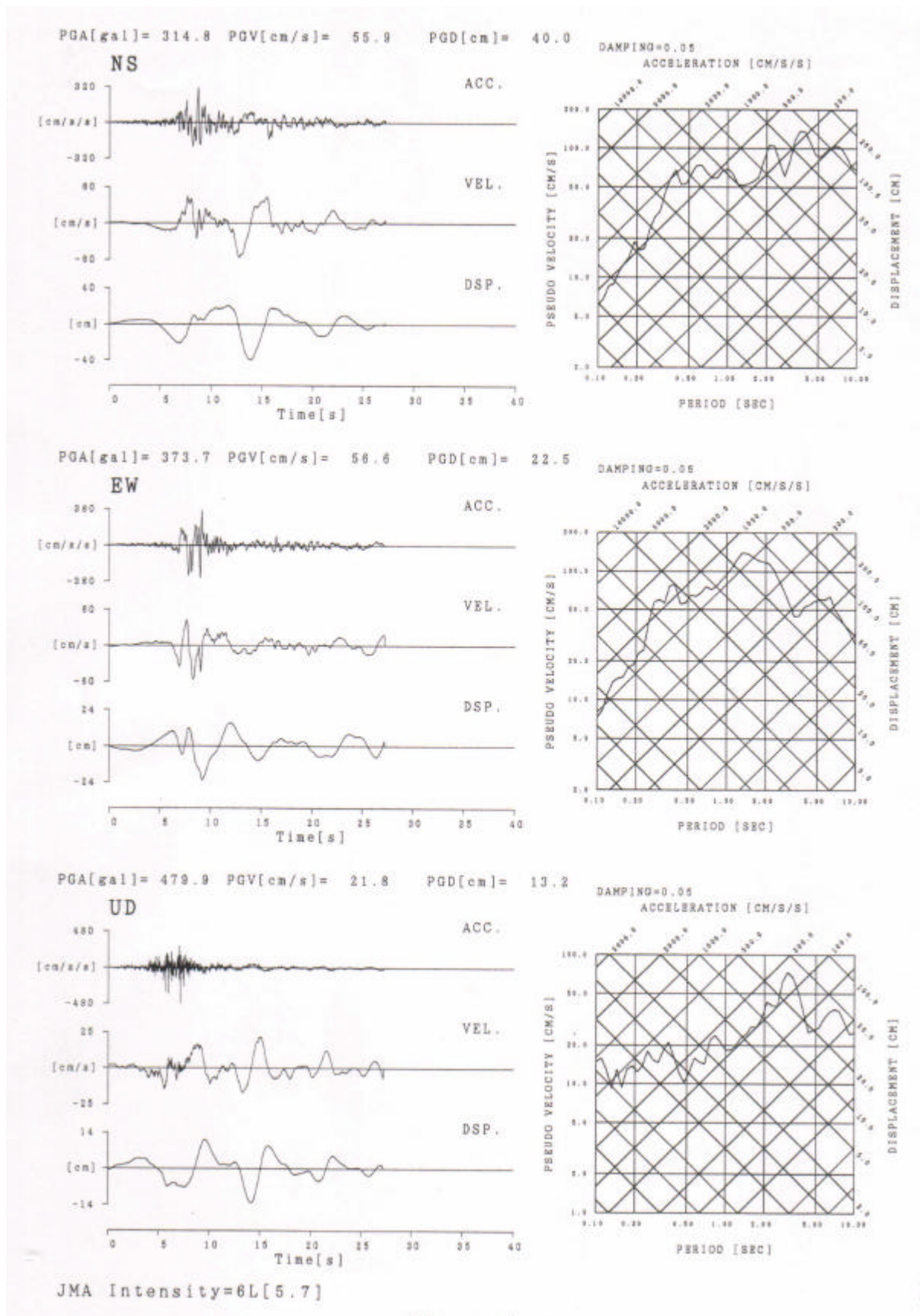


Fig. 4-21(a) Observed wave traces at DZC site

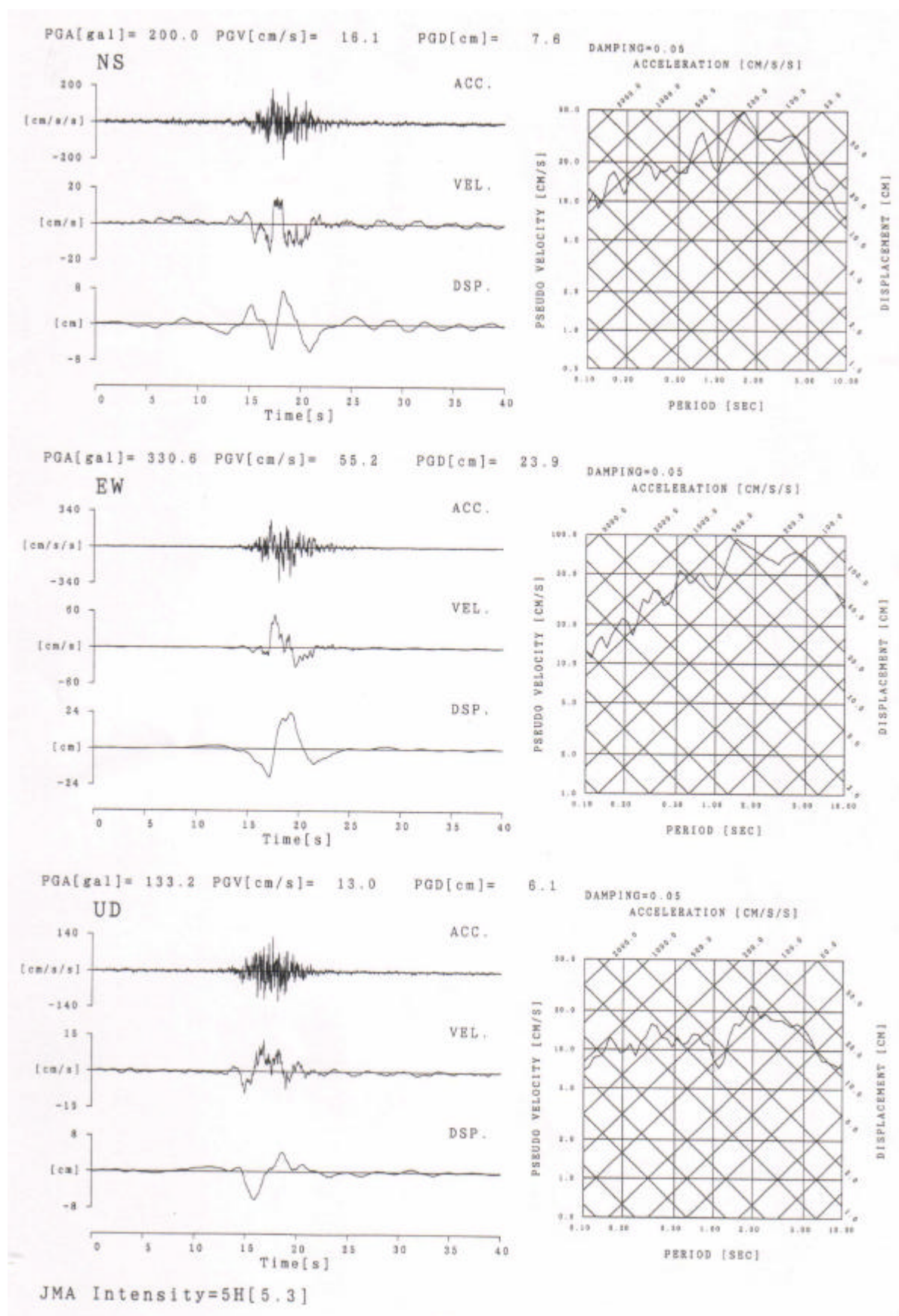


Fig. 4-21(b) Simulated wave traces at DZC site

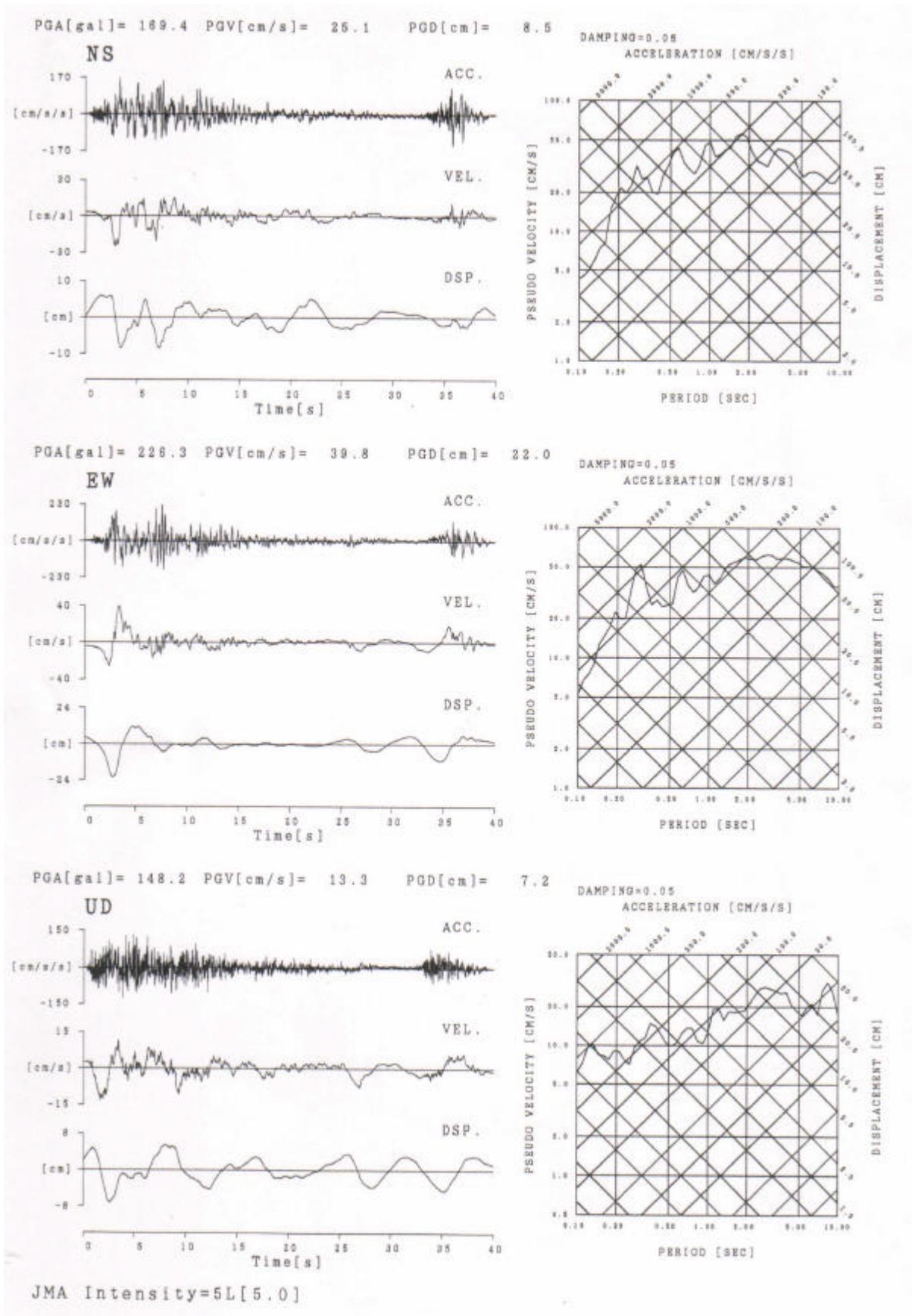


Fig. 4-22(a) Observed wave traces at IZT site

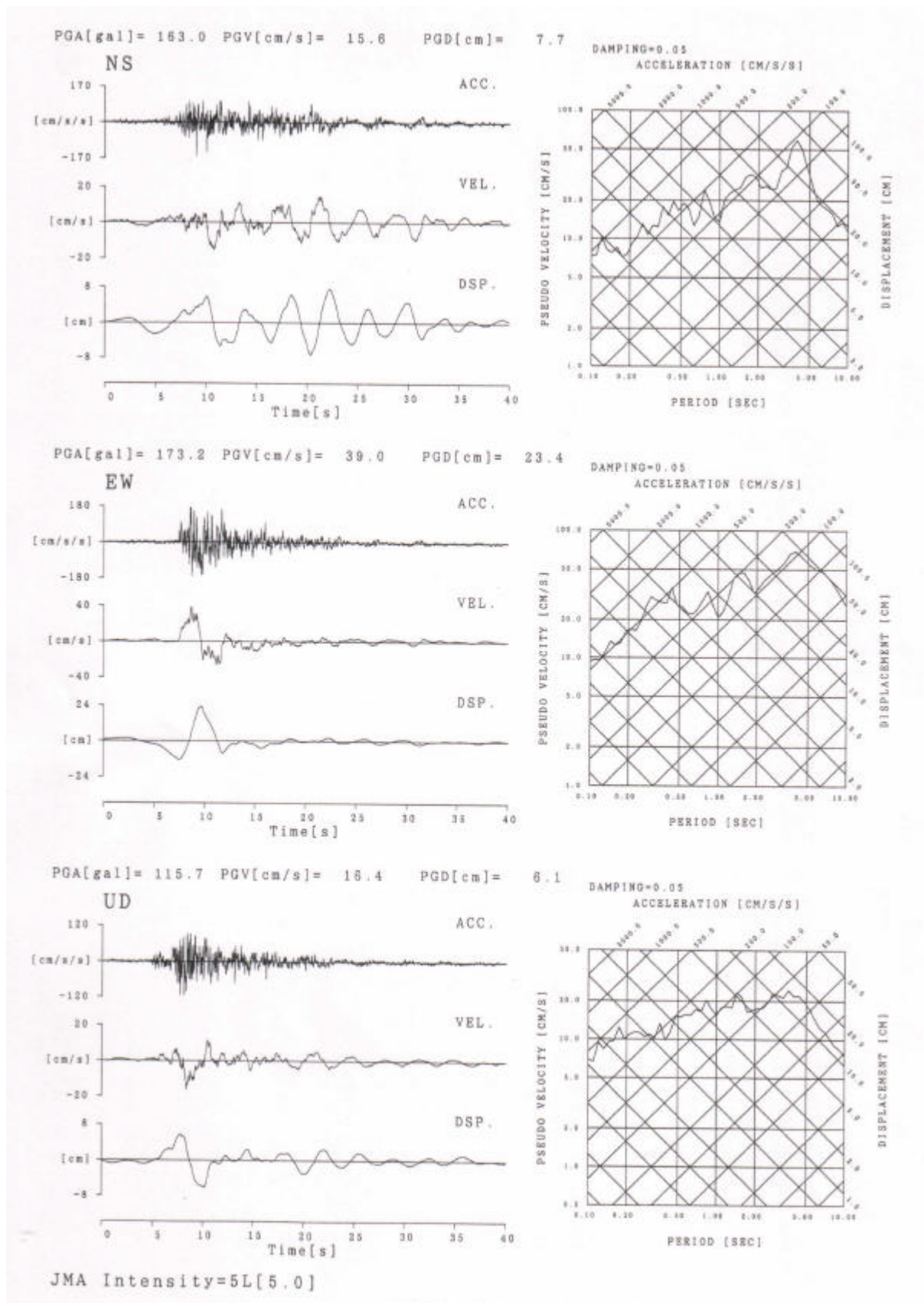
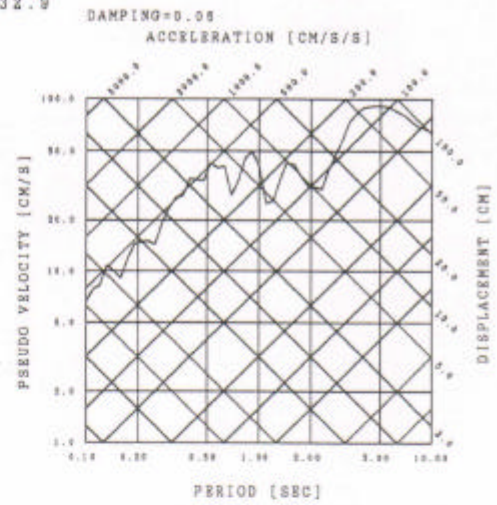
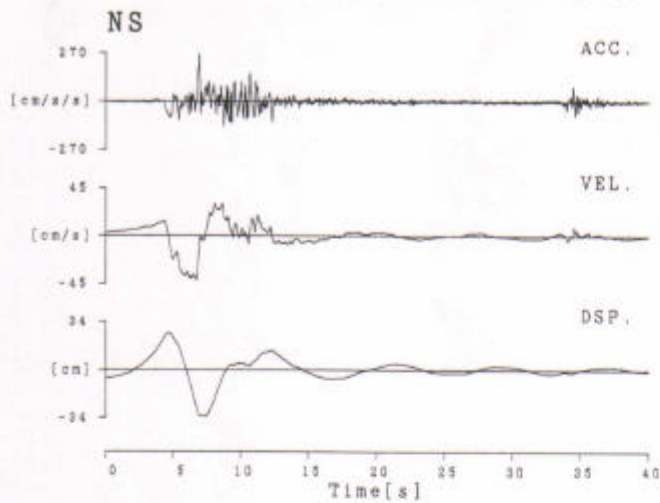
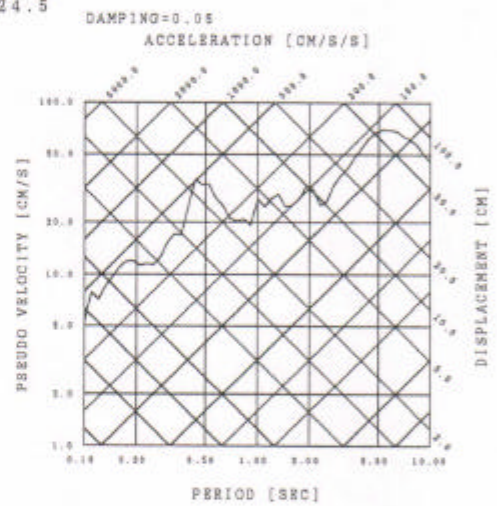
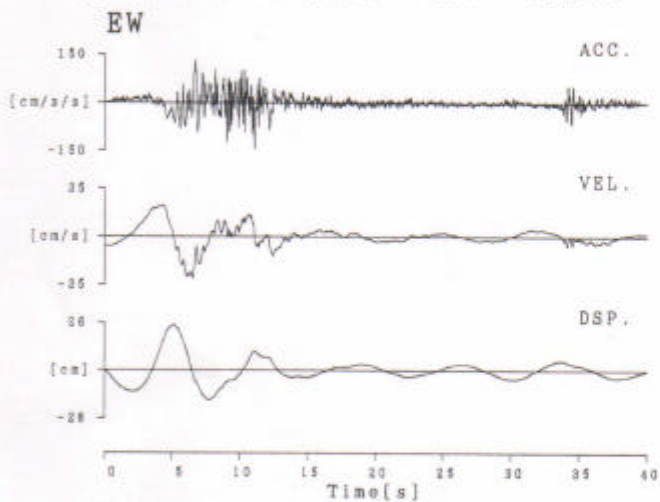


Fig. 4-22(b) Simulated wave traces at IZT site

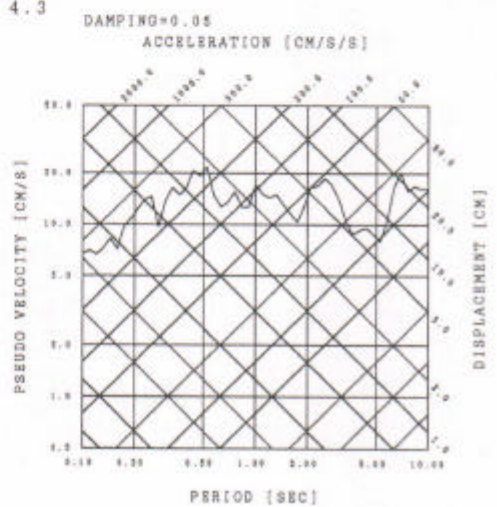
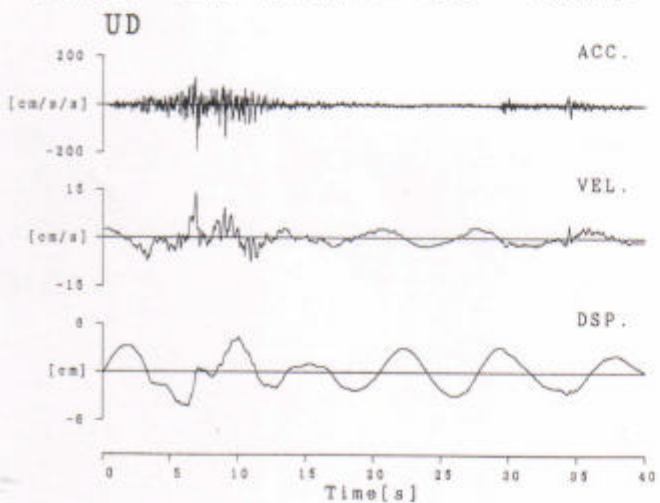
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PGA[gal]= 196.3 PGV[cm/s]= 14.1 PGD[cm]= 4.3



JMA Intensity=5H[5.0]

Fig. 4-23(a) Observed wave traces at GBZ site

Fig. 4-23(b) Simulated wave traces at GBZ site

Acknowledgements

We would like to extend our thanks to Dr. H. Güler and E. Inan (General Directorate of Disaster Affairs, Earthquake Research Department), Dr. O. Özel (Boğaziçi Univ., Kandilli Observatory). We also thank to Dr. H. Komiyama (JICA, Ankara) and T. Osumi for providing a lot of important information.

References

- Boore, D. M., 1983, Stochastic simulation of high-frequency ground motions based on seismological models of the radiation spectra, *Bull. Seism. Soc. Am.*, **73**, 1865-1894.
- Irikura, K., 1986, Prediction of strong acceleration motion using empirical Green's function, *7th Jpn. Earthq. Eng. Symp.*, 151-156.
- Somerville, P.G., K. Irikura, R. Graves, S. Sawada, D. Wald, N. Abrahamson, Y. Iwasaki, T. Kagawa, N. Smith and A. Kowada, 1999, Characterizing crustal earthquake slip models for the prediction of strong ground motion, *Seismological. Research. Letters*, **70**, 59-80.
- Yagi, Y. and M. Kikuchi, 1999, <http://www.eri.u-tokyo.ac.jp/yuji/trk/izumit.html>.