6. SEISMIC CHARACTERISTICS OF ADANA-CEYHAN EARTHQUAKE AND FAULTING

The Çukurova Basin has been well instrumented with several seismic networks which were set-up independently from each other. The seismic networks of the Earthquake Research Department (ERD) have stations Ceyhan, Karataş, İskenderun, Hatay, İslahiye, Mersin, Kahraman Maraş, Elbistan, Gölbaşı. The seismic records by this network can be easily accessed through INTERNET. The main shock of the earthquake, which was recorded by a SMA-1 type accelerometer, was available on the INTERNET after 3 days of the main shock. Records obtained at stations with automatic digital accelerometers were even available on the INTERNET on the following day of the earthquake. This network is probably the first of its kind in the world in making available the records to the societies of seismology and engineering in such a short time. Therefore, the Earthquake Research Department of Turkey must be congratulated for their dedicated endeavors.

Marmara Research Center (MAM) of TÜBİTAK (Turkish Academy of Sciences), has also established its own seismic network and it is called TÜBİTAK-MAM network hereof. This seismic network has stations at Adana, Kurtkulağı, Türkoğlu, Kahraman Maraş, Gaziantep, Aslantaş, Berke, Kozan, Osmaniye, Feke, Samandağ, Hatay, Sakçagöz, Akgöl and has been in operation since 1993. Unfortunately none of the records by this network has been accessible until this report has been written.

Since many stations are on soil and rock foundations, the data will be very valuable for Turkey to study the attenuation characteristics of peak ground acceleration in soil and rock.

The main shock occurred at 16:55 (13:55GMT) on local time on June 27, 1998. Various institutes in Turkey and other countries predicted the hypocenter of the earthquake and its faulting mechanism. Figure 6.1 compares the locations of epicenters predicted by various institutes. Figure 6.2 shows an example of prediction done by Aydan (Ö.A.) using Omori's method with k=7.12 and data provided by the ERD. The locations estimated by the ERD, MAM and Ö.A. are very close to each other while locations given by USGS, HARVARD, KOERI, EMSC, ERI somewhat scattered. Taking the damage observed on the site, it seems that the locations provided by DAD-ERD, MAM and Ö.A. are quite acceptable. Table 6.1 compares the hypocenter parameters and Figure 6.3 and Table 6.2 compares the fault plane solutions. Most fault plane solutions predict a left-lateral strike slip faulting with a normal faulting component. These predictions are generally acceptable when the characteristics of active faults in the region are taken into account. The main faulting plane is predicted to have a strike in the direction of NE-SW. This fault plane seems to correspond to Misis-Ceyhan-Andırın fault. Using hypocenter data of mainshock and aftershocks, the geometrical position of faulting plane was found to fit the following equation

$$Z=-73940+2028 \times Lon+2092 \times Lat-57.4 \times Lon \times Lat$$

The unit of Z is kilometers. This function is illustrated in Figure 6.4. The predicted faulting plane is very similar to most of the fault plane solutions.

Table 6.1 Comparison of hypocenter parameters by various institutes

Institute	Latitude	Longitude	Depth	M_b	M_s	M_w	M_L
ERD	36.85	35.55	23				5.9
KOERI	36.67	35.49	10				6.3
TÜBITAK-MAM	36.89	35.55	22				
USGS	36.95	35.31	14	5.9	6.2	6.3	
HARVARD	36.94	35.42	15				
ERI	36.35	35.34	38		6.2	6.1	
EMSC	36.56	35.19	17			6.2	
O.A.	36.81	35.58	17				

Table 6.2 Comparison of fault plane solutions by various institutes

Institute	First plane			Second plane			P-axis		T-axis	
	Strike	Dip	Slip	Strike	Dip	Slip	Azm	Plg	Azm	Plg
ERD	207	70	-30	308	62	-157	165	35	101	5
USGS	323	77	170	55	80	14	189	3	279	17
HARVARD	319	73	154	57	65	18	9	6	276	30
ERI	321	72	160	58	72	20				
EMSC	326	79	169	58	79	11	12	0	282	16

Figure 6.1 Comparisons of epicenters of mainshock predicted by various institutes

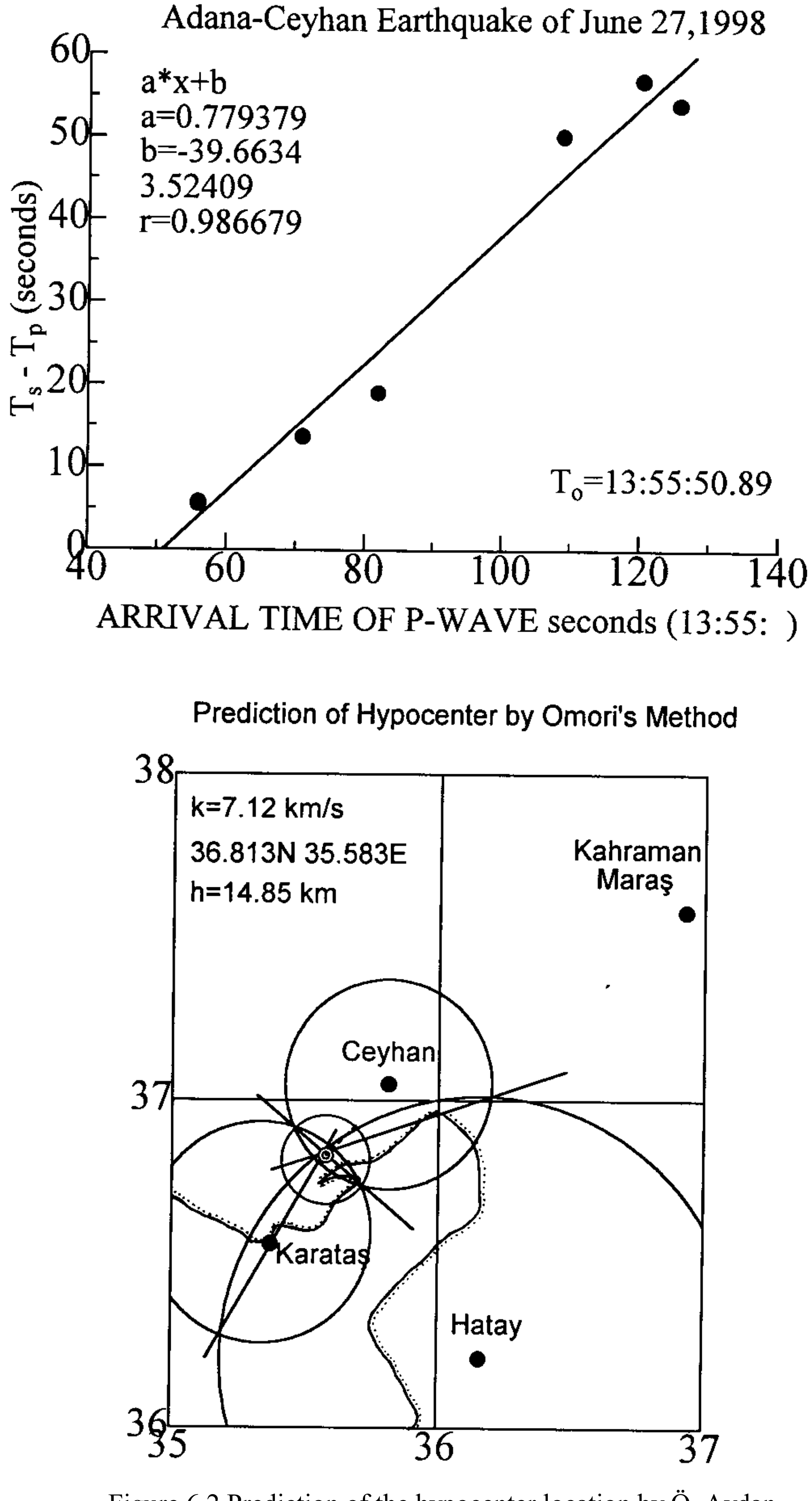

Figure 6.2 Prediction of the hypocenter location by Ö. Aydan

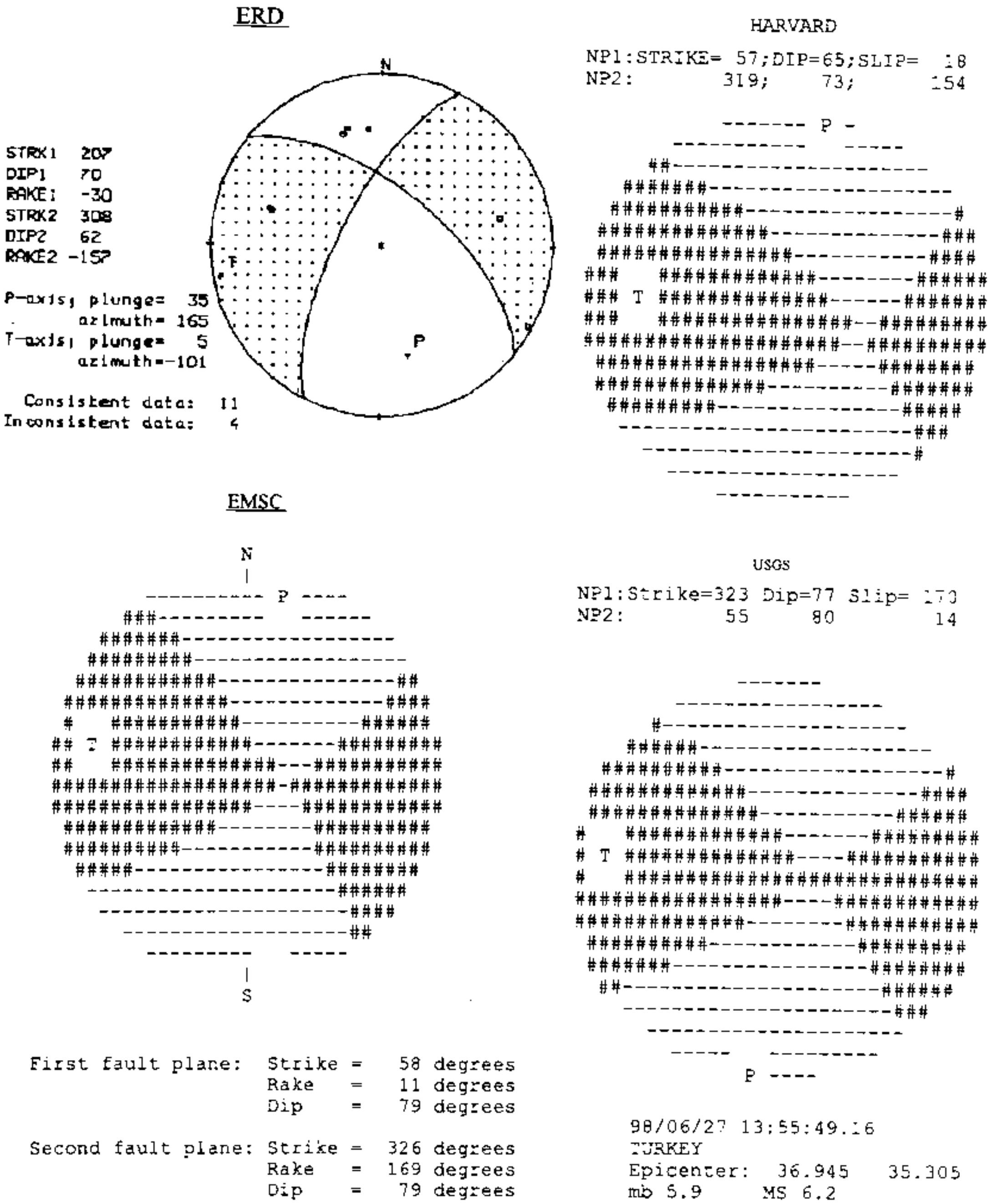

Figure 6.3 Comparisons of fault plane solutions predicted by various institutes

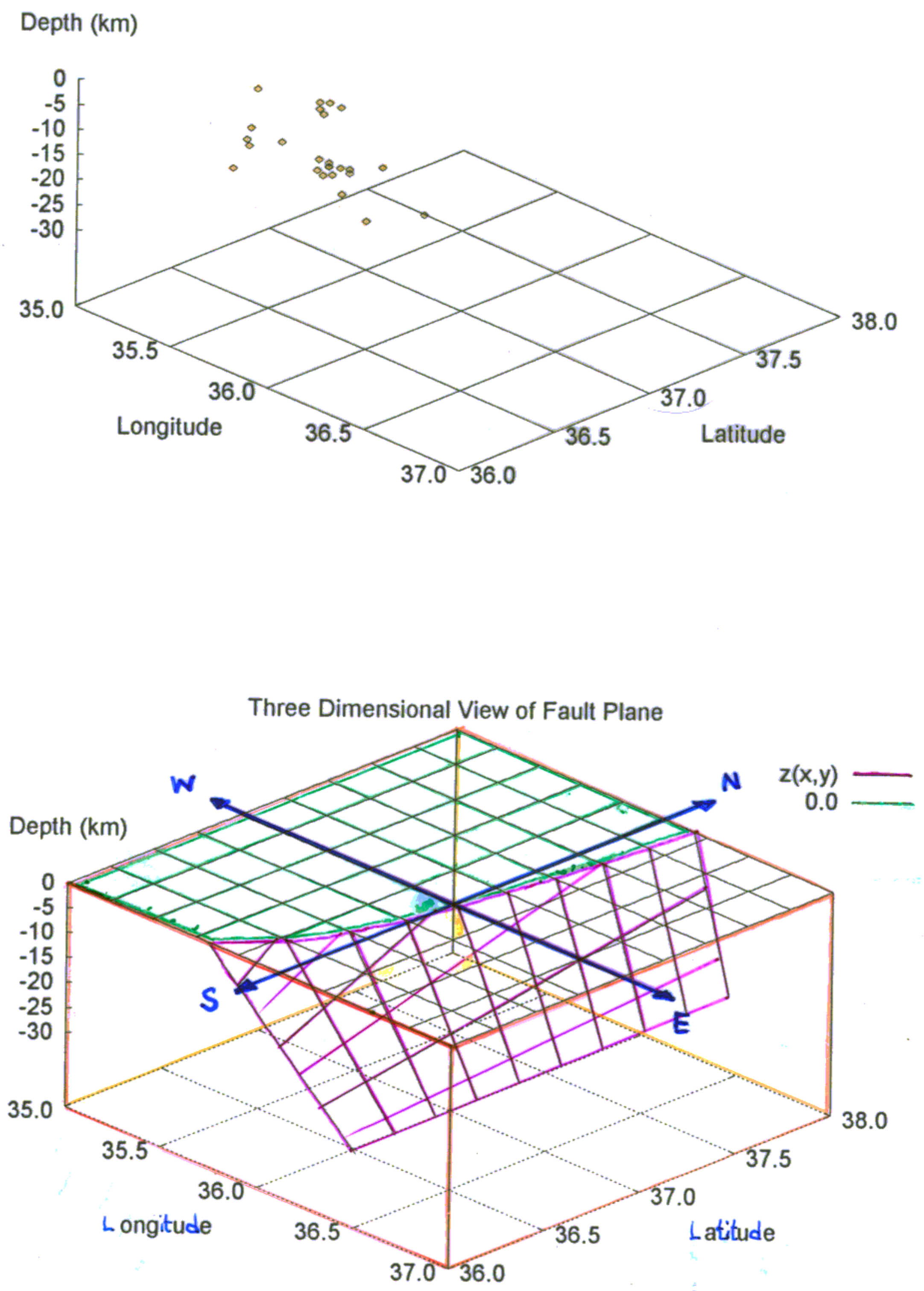

Figure 6.4 A spatial view of the fault plane predicted from aftershock distributions

6.1 Foreshocks

The TÜBİTAK-MAM network recorded no seismic event in the location of the hypocenter of this earthquake during a period between 1993 and 1998 as shown in Figure 6.5 (Yalçın and Aktar 1998). However, the epicenters of seismic events in the region seem to be associated with the known active faults in the region as seen in this figure. The hypocenter location appears to be a seismic gap in the region with almost no seismic activity. Therefore there was no foreshock to warn people as it happened in the Dinar earthquake of Oct. 1, 1995.

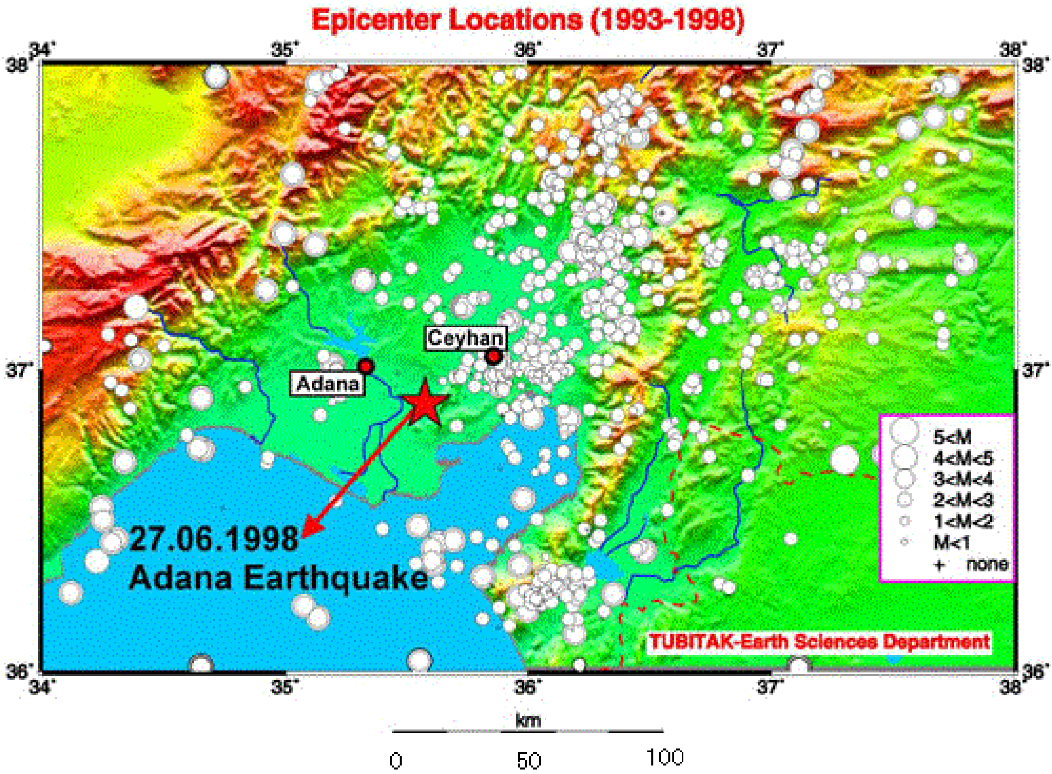

Figure 6.5 Epicenters of earthquakes between 1993-1998 (after TÜBİTAK-MAM)

6.2 Main Shock

Main shock of the earthquake was recorded by a SMA type accelerometer with three components at Ceyhan Tarım İlçe Müdürlüğü. After the main shock, a Geosys-16 type automatic digital accelerometer has been installed at Ceyhan PTT Müdürlüğü. Figure 6.5 shows EW, SN and UD acceleration records at Ceyhan Tarım İlçe Müdürlüğü station. The peaks of EW, SN and UD components of acceleration waves are 273.6, 223.4 and 86.48 gals, respectively. The UD component of this earthquake is also quite high as it is observed in other earthquakes in Turkey and it is probably one of characteristics of in-land earthquakes. Fourier spectra of each component are shown in Figure 6.6. Figure 6.7 shows the traces of acceleration waves on the horizontal plane at several observation stations in the region. From this figure, one may also infer possible directions of toppling or shearing of structures and also slope and ground failures.

6.3 Aftershocks

According to the data released by the ERD, 224 aftershocks recorded until July 17, 1998. The largest aftershock with a magnitude of 5.0 (M_L=5.0;M_b=5.1;M_s=5.3) occurred at 5:15 (02:15GMT) on July 4, 1997. Figure 6.8 gives location and fault plane solution of the largest aftershock given by TÜBİTAK-MAM. It seems that this after shock occurred on a secondary fault. The largest accelerations recorded by the strong motion network of Turkey was at Mersin station and the peaks at Ceyhan station which is close to the hypocenter were less than those at Mersin Station. Figure 6.9 shows the frequency of aftershock numbers until July 14, 1998.

6.4 Faulting

During this earthquake no distinguished fault scarp was observed although many en-echelon type ground fractures with and without sand-boils were observed for a length of 50 km (Figure 4.7, Figure 6.11 and 6.12). En-echelon ground fractures observed near Abdioğlu village and Asmalı bridge area were all left-stepped. Ground fractures at Abdioğlu village were aligned in the direction of N20E while they were aligned in the direction of N70W in Asmalı bridge area. Furthermore, they were almost parallel to flow direction of Ceyhan river in each location. As the thickness of alluvial deposits is more than 100 meters, it is likely that deformations at ground surface would be diluted as it happened in Erzincan earthquake of March 13, 1992. Furthermore, the fractures developing as a result of lateral spreading due to liquefaction, which was seen widespread, may sometimes mis-lead conclusions on the nature of ground fractures to infer the sense of fault movement. Nevertheless, the damage occurred at Lokman Hekim Bridge of masonry type is due to the permanent ground deformation (Figure 6.13). The longitudinal axis is in the direction of N45W. If the fault is just beneath the river bed in that location and it has moved in the sense of left-lateral strike-slip, the SW abutment of the bridge must move in the direction NE while the NW abutment does in the direction of SW. When one carefully examines the deformation of bridge abutments, it would be easily noted that the permanent deformation and damage of the bridge support the sense of fault movement predicted both from fault plane solutions and geological evidences observed previously.

6.5 Comparisons with other Turkish Earthquakes and Attenuation

Aydan et al. (1996) and Aydan & Hasgür (1997) developed a data-base system for the seismic characteristics of Turkish earthquakes and several empirical relations among several seismic parameters. The seismic characteristics of this earthquake are shown in Figure 6.14 together with empirical relations. Observations and measurements made during this earthquake are generally consistent with those obtained from empirical relations developed for Turkish earthquakes.

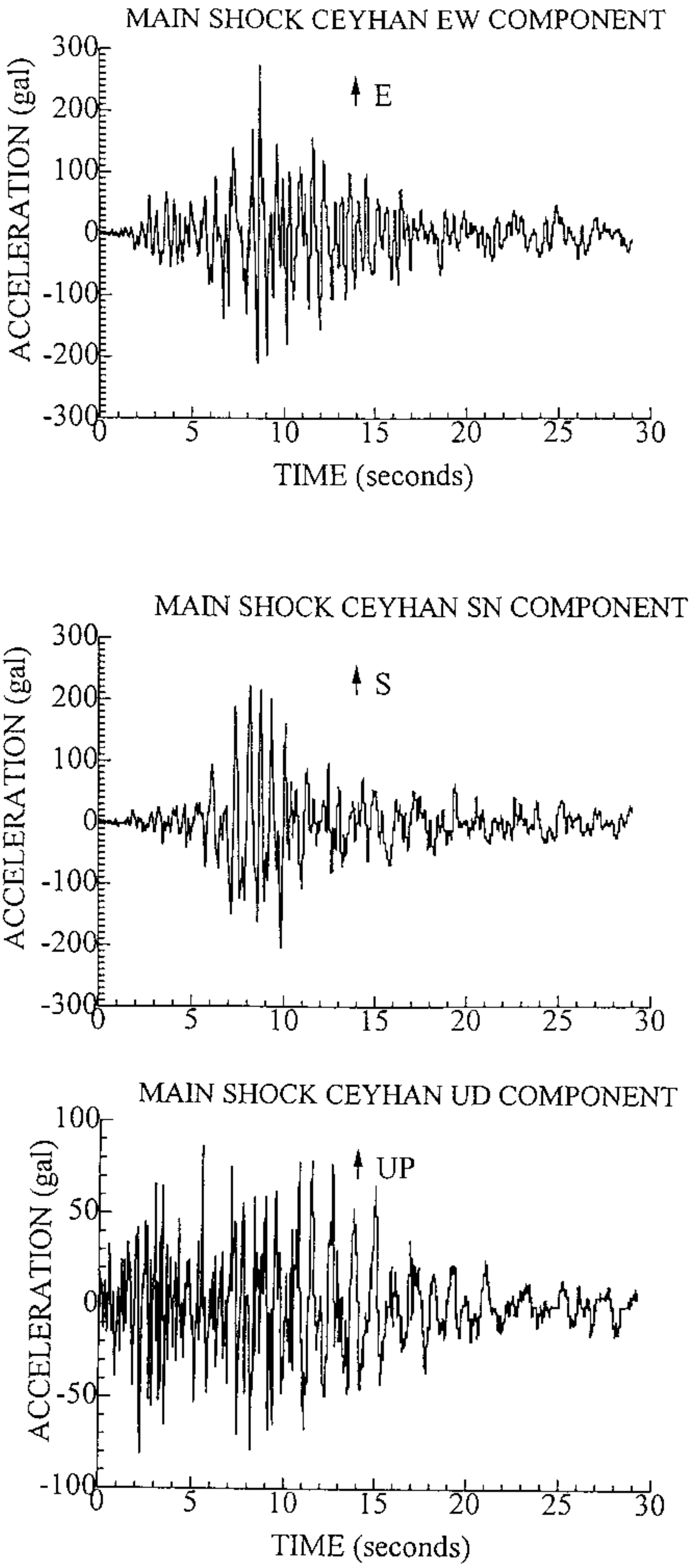

Figure 6.6 Accelaration records for the directions of NS, EW and UD at Ceyhan

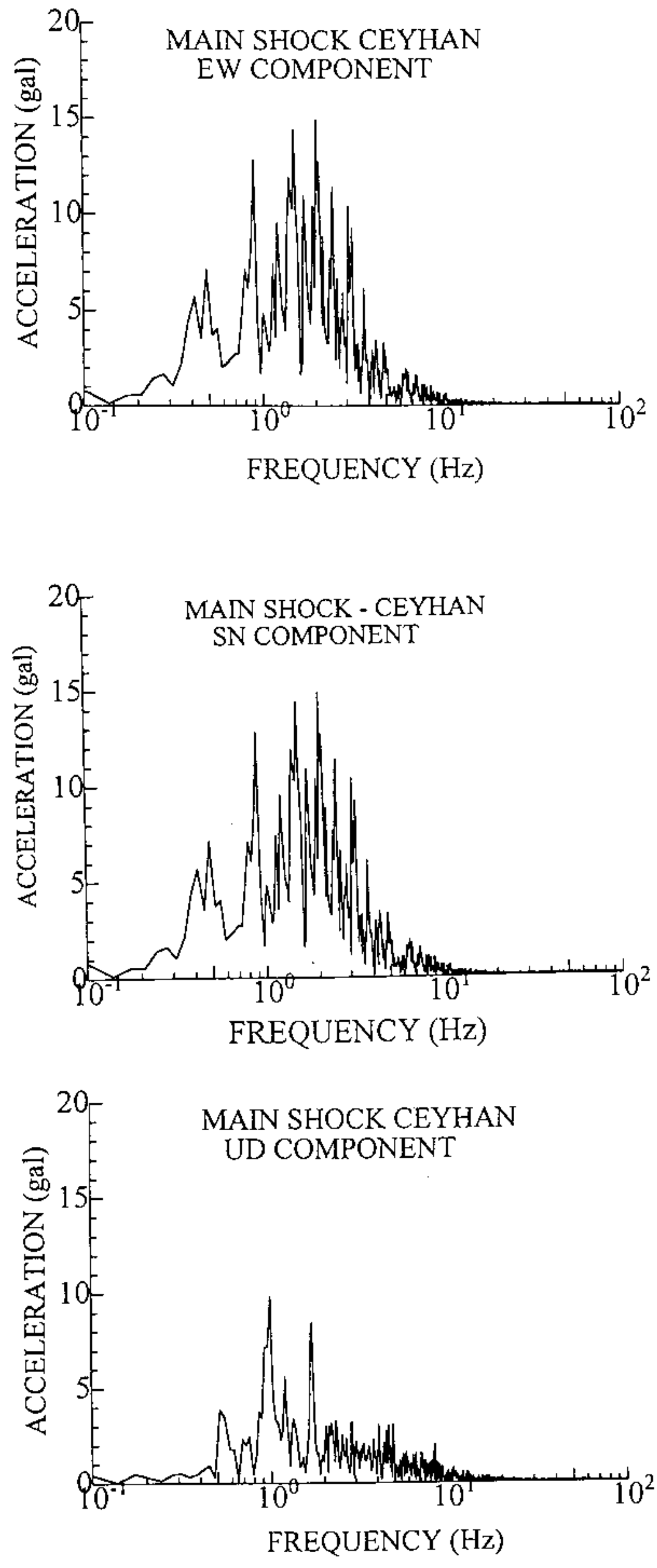

Figure 6.7 Fourier spectra of Accelographs of the main shock shown in Figure 6.6

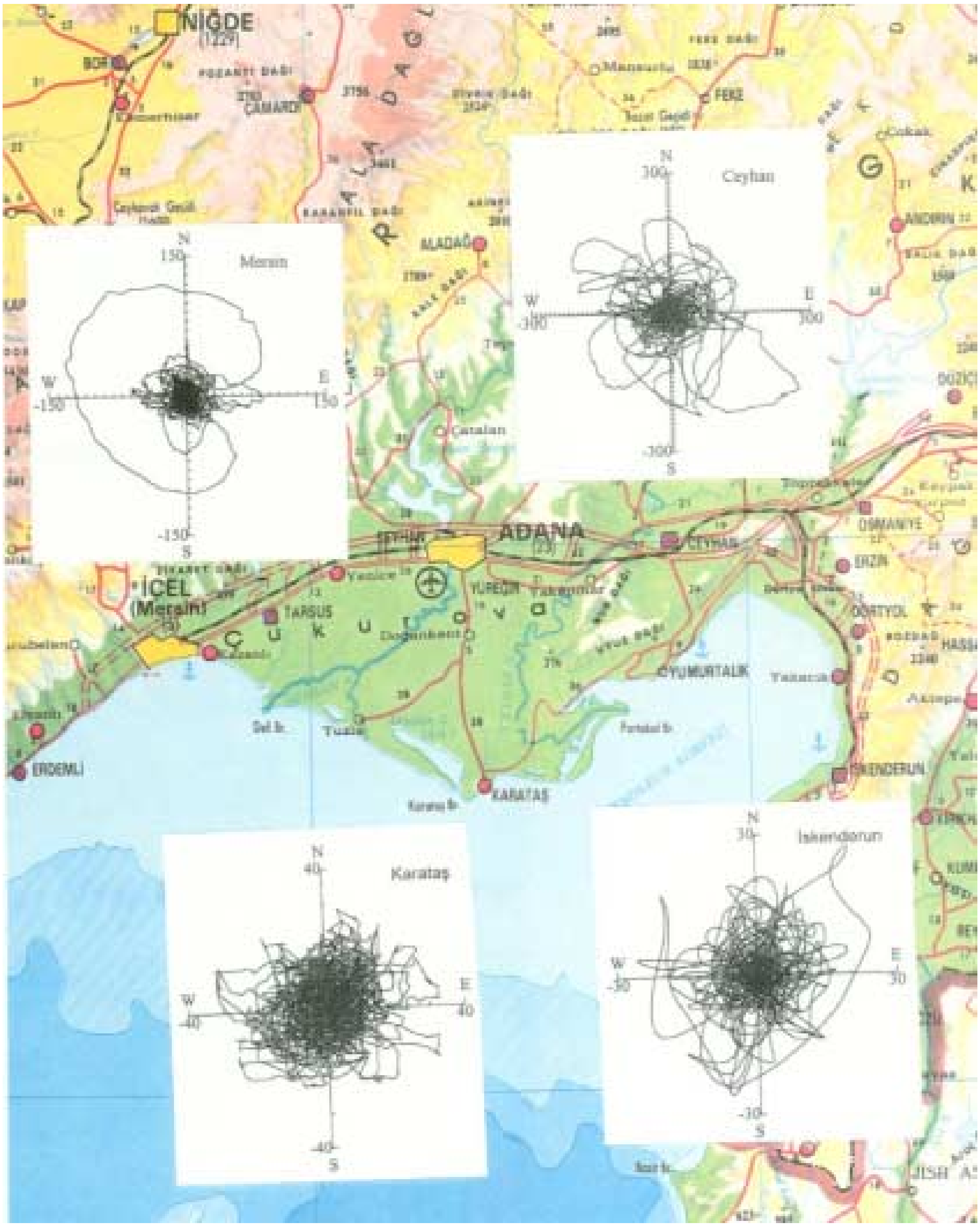

Figure 6.8 Traces of accelerations on the horizontal plane at several observation stations around the hypo-center

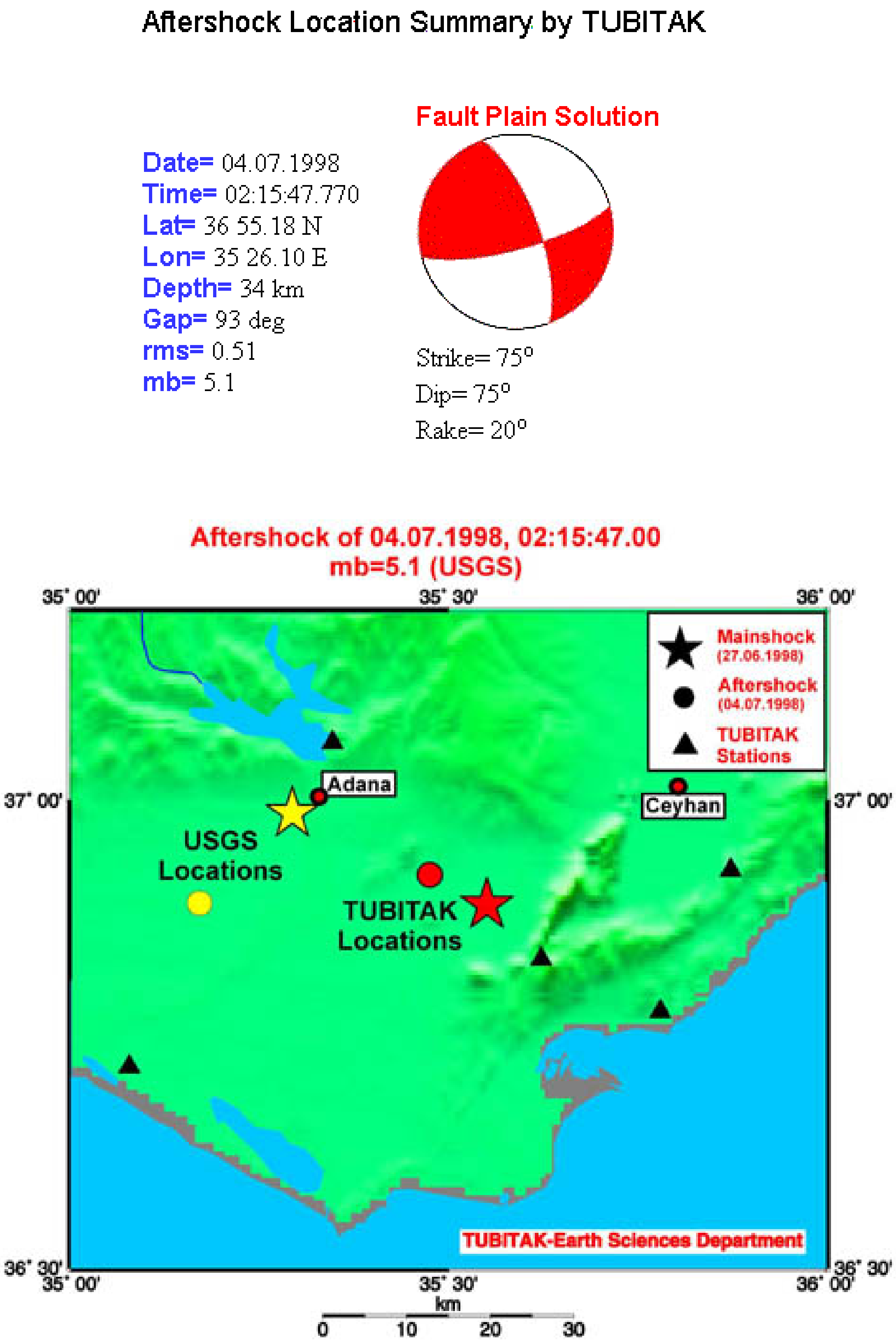

Figure 6.9 Epicenter location and fault plane solution for the largest aftershock on July 4, 1998 by TÜBİTAK-MAM

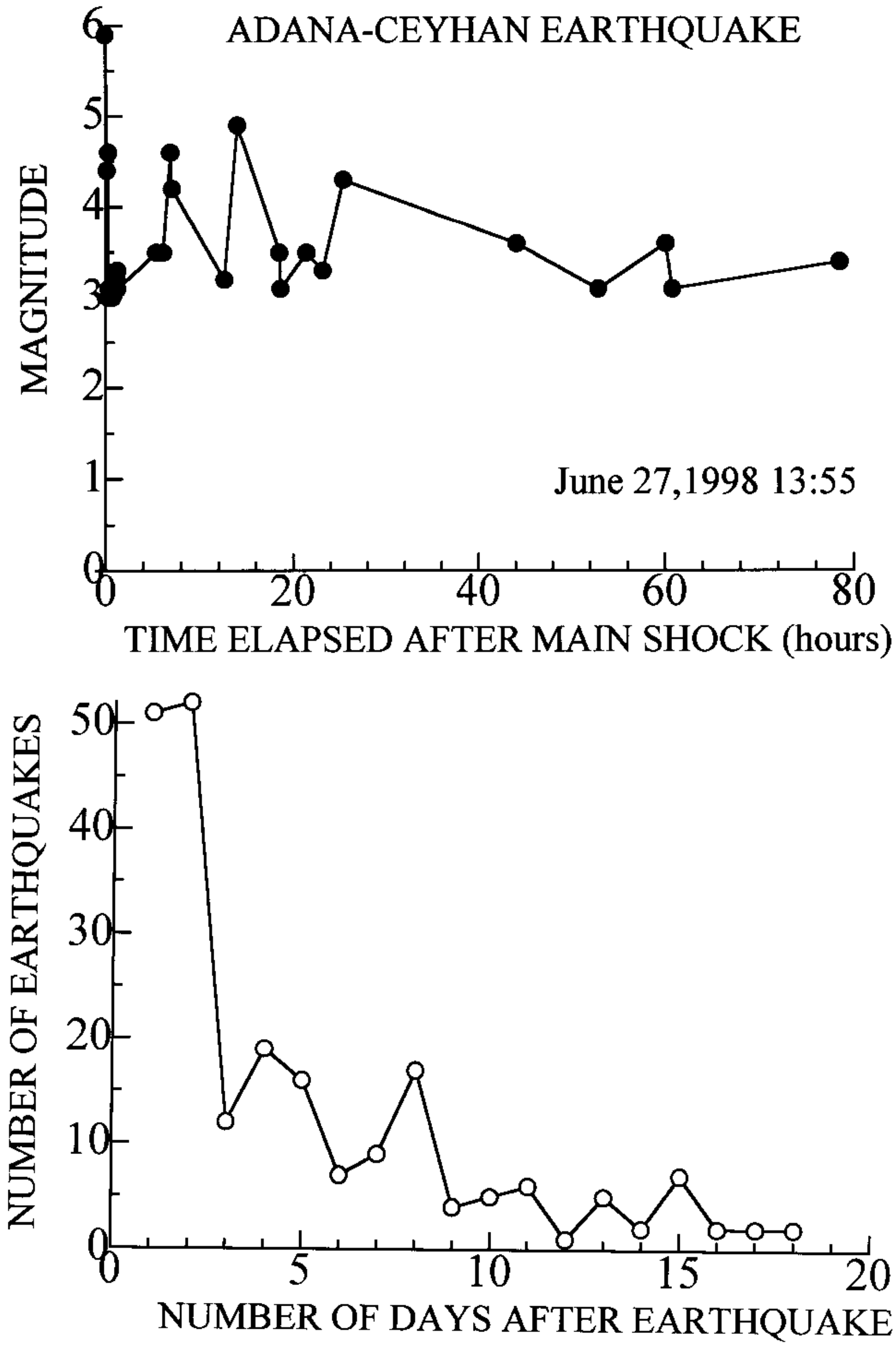

Figure 6.10 Variation of magnitude and frequency of aftershocks with time

Figure 6.11 En-echelon fractures at near Abdioğlu village with sand boiling

Figure 6.12 En-echelon fractures at near Asmalı bridge with sand boiling

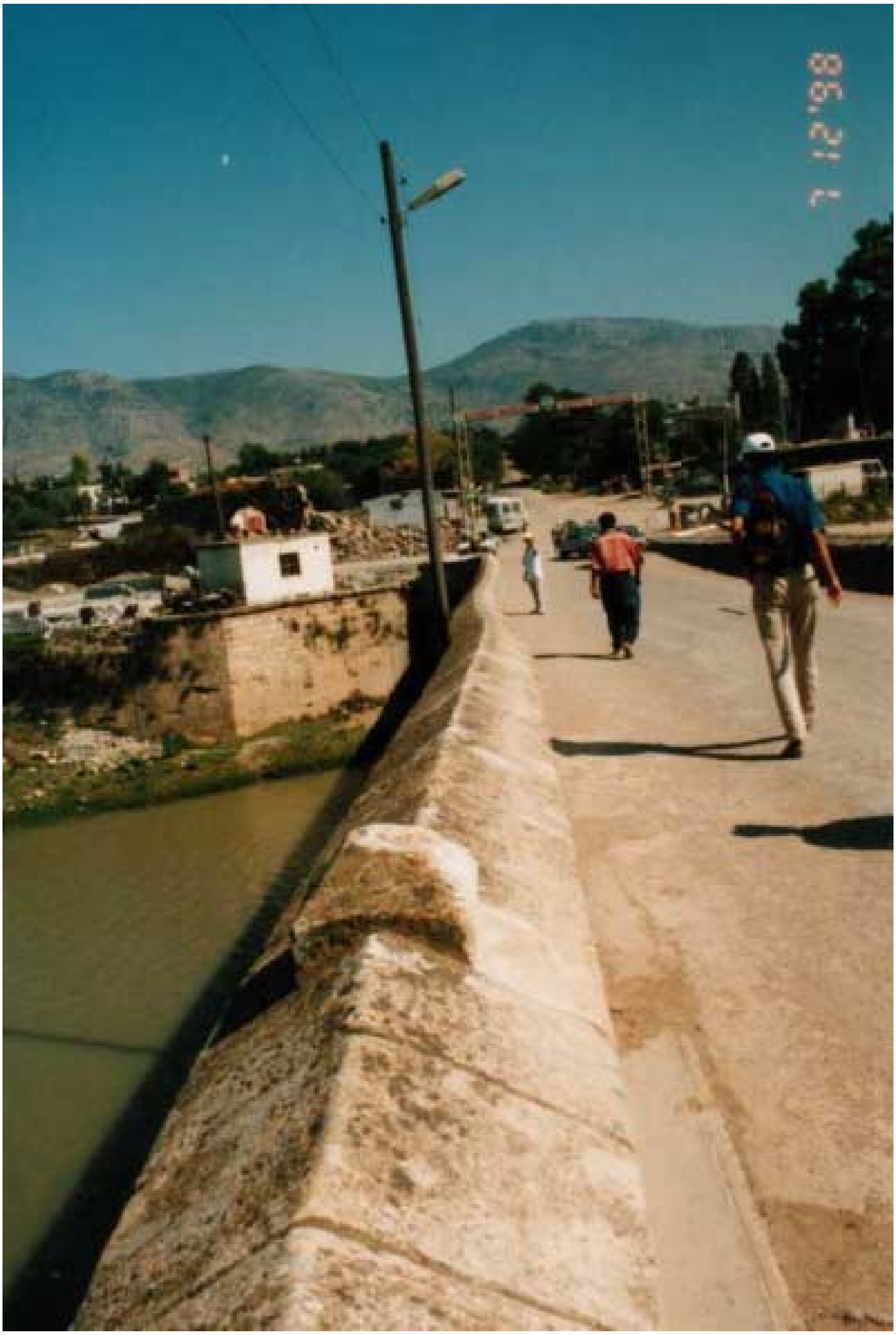

Figure 6.13 permanent deformation of Lokman Hekim Bridge

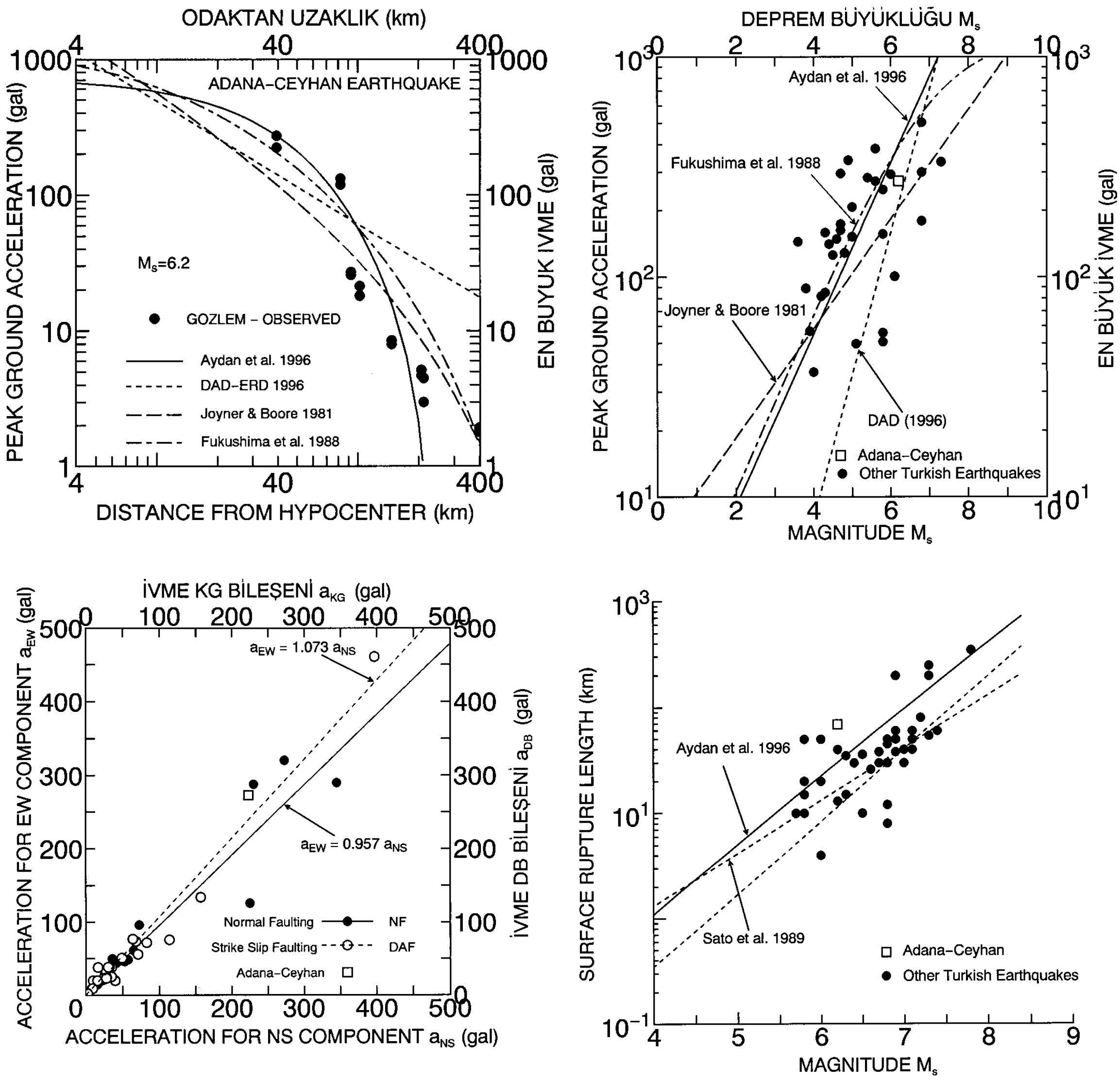

Figure 6.14 Comparison of the seismic characteristics of Adana-Ceyhan earthquake with empirical relations proposed by Aydan et al. (1996).