Learning from Earthquakes

Turkish Earthquakes: Two Reports
Lessons from the Adana-Ceyhan Quake and the Dinar Aftershock

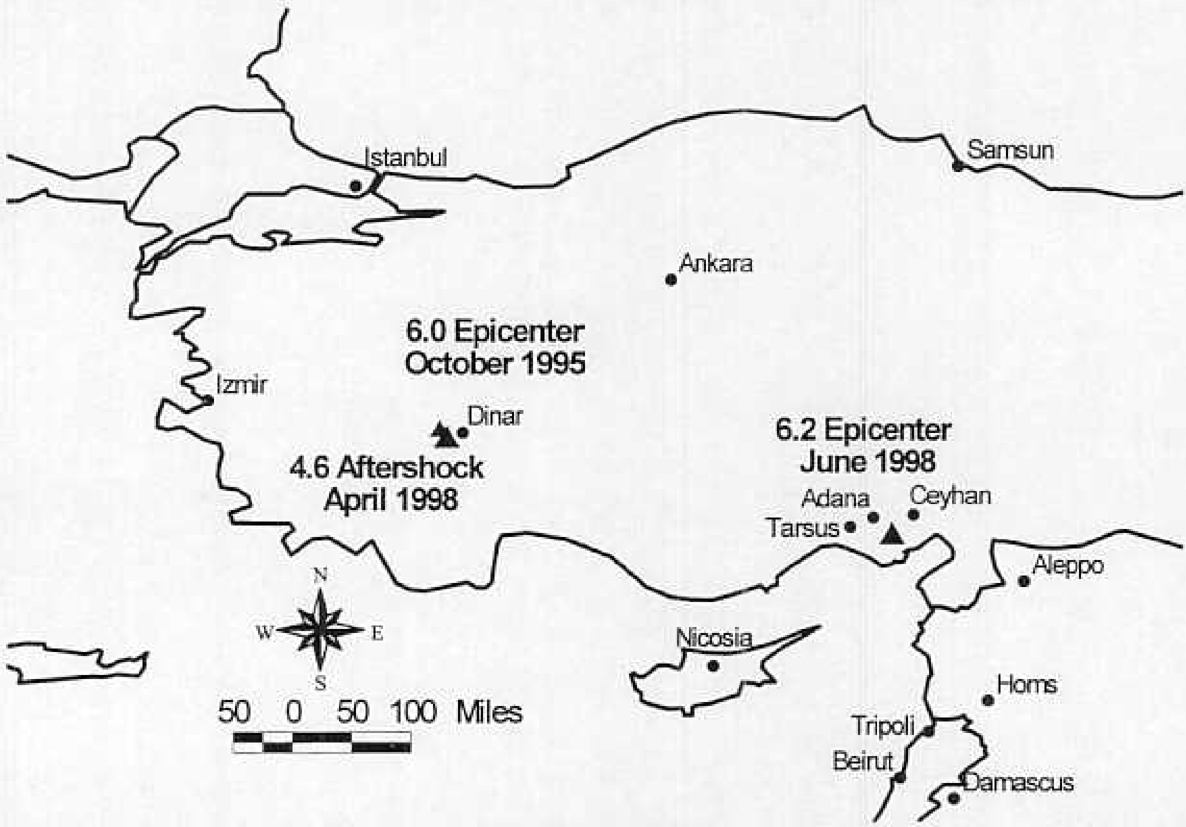

Figure 1 – Map of Turkey showing epicenters of Adana-Ceyhan quake and Dinar quake and aftershock.

The Adana-Ceyhan Earthquake of June 27, 1998

By Mehmet Çelebi

The Adana-Ceyhan earthquake (Ms = 6.2) struck at 16:56 local time on June 27, 1998. The National Earthquake Information Center in Golden, Colorado identified the epicentral coordinates of the earthquake as: 36.9 degrees North (latitude) and 35.3 degrees East (longitude). Local seismological stations reported the local magnitude of the earthquake as $M_L = 5.9$, and the coordinates as 35.85 N (latitude) and 35.55 E (longitude). The depth of the earthquake is given as 13 km and 22 km by two different sources (the Marmara Research Center in Gebze, and the Earthquake Research Center in Ankara).

The earthquake epicenter is approximately 50 km to the east of Tarsus, the birthplace of Paul of Tarsus and the putative meeting place of Antonius and Cleopatra (see Figure 1 for the region, the epicenter, and major towns).

The earthquake caused 150 deaths and injured several thousand. The areas severely shaken by the earthquake covered an area of approximately 150 km radius, but the damage was within a 30 km radius of the epicenter. It was reported that the earthquake was felt as far south as Cyprus, Syria, Israel and Jordan.

On July 4, 1998, at 5:05 AM local time, a magnitude 5.1 aftershock occurred. Approximately 1,000 people were injured during this aftershock—most while jumping out of windows. The writer was on the ninth floor of the ten-story Ceyhan Hotel and experienced the strong shaking of the building for about 20 cycles at approximately one second per cycle. The hotel was not damaged during the main shock or the aftershock.

Geology and Seismicity

The left-lateral fault that caused the earthquake is called the Misis/ Ceyhan fault (Barka, 1998). The geology of the Adana-Ceyhan (Çukurova) basin is dominated by a Quarternary alluvial valley covered by clay and surrounded in the north by the Taurus Mountains (see Figure 2). The depth of the agro-clay surface varies between one and six meters from location to location. In Adana, for example, the depth is reported to be approximately one to three meters. Below the clay sur-

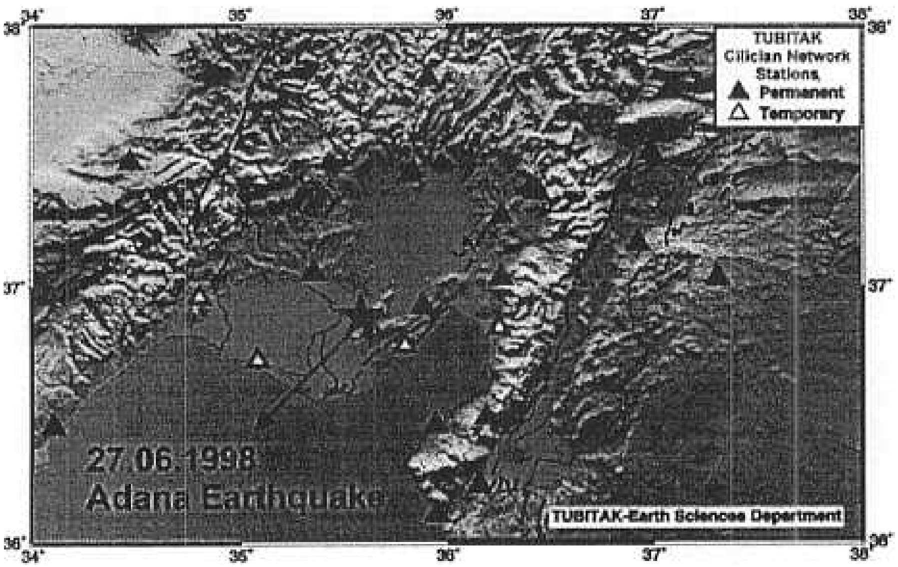

Figure 2 *– Map showing the epicenter of the earthquake and the seismic network operated by Marmara Research Center (www.nemrut.mam.gov.tr)*

face in the valley is, in general, loose gravelly or dense hard alluvium mixed with pockets of sand and clay-sand. In the northern part of Adana the dominant geological formation is hard conglomerate.

To the west of the epicentral region, there are two small mountains (elevation 763m). The Ceyhan River meanders to the east of these mountains. The Misis-Ceyhan Fault follows the general NNE direction of the two mountains (Barka, 1998). Below this, the young alluvial layers consist of gravels, sand and clay layers. Underground water can be located at one to three meters depth in young layers and at six to eight meters in older layers. Particularly in the epicentral area, there was considerable liquefaction (see Figure 3). The water table in this area is considered to be within one to three meters of the surface.

The region is known to be seismically active, but because of the short length of the faults in the area, large earthquakes (with magnitudes greater than 7) are not historically known or expected. The historical database refers to several damaging earthquakes with magnitudes less than 7.

Adana and Ceyhan are in the Second Seismic Zone, according to the ***Seismic Zoning Map of Turkey***. (There are five zones, with Zone 1 and Zone 2 assigned seismic coefficients of 0.4 and 0.3, respectively, according to the new ***Seismic Design Code*** of Turkey, 1997.) One of the main concerns of the region in the last 25 years has been the planning of a medium-size nuclear power plant in Akkuyu approximately 100 km east of the epicenter). The site is identified as being in the fourth zone by the current ***Seismic Zoning Map*** (1996).

Strong Motion Records

According to the Ministry of Reconstruction and Resettlement, only a single strong-motion main shock record was obtained in the area. This record from Ceyhan had peak accelerations of 0.22 g (NS), 0.28 g (EW) and 0.086 g (UP). The records show several dominant frequencies (periods) at approximately 0.7, 1 and 1.5 Hz (1.4, 1 and .67 sec). These resonating frequencies are within the site frequencies that can be expected from alluvial media with depths ranging from 25-75 m. It is possible that double resonance was one of the main causes of collapses or severe damage in the mid-rise buildings in Ceyhan. Soil-structure interaction of the rather stiff buildings (reinforced concrete frame with masonry infill walls) may have contributed to lengthening of the buildings' periods to coincide with the dominant periods of the site. The response spectra demonstrate that the horizontal components of motion had several dominant peaks within a 0.2-0.7 second band.

Figure 3 *- Sand boils due to liquefaction in a field near the epicenter.*
Photo: Çelebi

Building Inventory

Typical building construction in the area is reinforced concrete framed building with (cinder block or hollow-brick) infill walls. Often, the slabs are also of cinder-block type. There are many older, timber-reinforced adobe, stone or brick masonry buildings. Some of the older structures in the older part of Adana or in the villages are of block stone masonry. Most of the industrial plants significant to the economy of the area are of prestressed and precast concrete construction. Steel construction is practically non-existent.

Types of Damage

The causes of damage can be attributed to one or a combination of the following: (a) soft first story, now an internationally known defect in design, (b) inadequate detailing and reinforcements of column-beam connections and columns (insufficient or lack of shear reinforcement, anchorages, inadequate spacing of ties, inadequate bonding of round bars used instead of deformed bars), (c) design of strong beam/weak columns rather than strong-column/weak beams, (d) creation of short-columns due to infill walls or offsets in design, (e) unreinforced or inadequately reinforced concrete and/or brick masonry piers or coupling beams, (f) age of deteriorated buildings with little lateral load resistance, (g) questionable quality of materials used (concrete, steel, mortar, brick, cinder block, river washed stone-masonry), (h) site effects, double-resonance and soil-structure interaction of the five to ten-story buildings on alluvial media with single story basements and no piles.

Structures in Ceyhan: Ceyhan suffered the most damage and loss of lives. Most of the damages and deaths occurred in only a few of the seven to ten-story apartment buildings located in two subdivisions (Konakoglu Mahallesi, Cumhuriyet Mahallesi). Two buildings—Ugur Apartmenta and Basher Apartments—caused a total of 57 deaths. Older buildings in Tuzlugol subdivision, apparently an old river bed, also suffered, but these were mainly one to two-story buildings built on irrigated or formerly irrigated agricultural areas. The Ceyhan Train Station, a very stiff, single-story, stone masonry building on Ismet Inonu Boulevard, was not damaged; however, many of the seven to eight-story buildings across from the train station were. As mentioned before, there is a strong possibility that damage to mid-rise buildings in Ceyhan was enhanced by double resonance and/or soil-structure interaction.

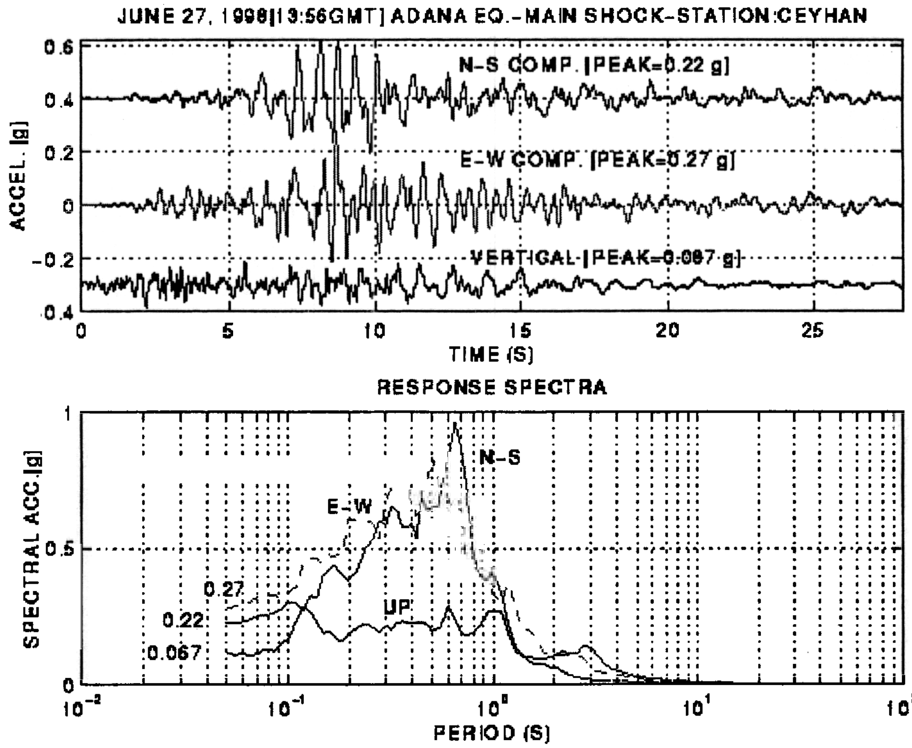

Figure 4 – Strong-motion records from the Ceyhan Station (on ground floor of three-story building) and corresponding response spectra.

Figure 5 - Ceyhan: unoccupied new eight-story structure pancaked.

Photo: Çelebi

Figure 6 - Deficient shear reinforcement at top end of column at Çukurova University. Photo: Çelebi

Structures in Adana: In general, most of the new mid-rise and tall buildings in Adana (5-15 stories) performed well. It is possible that the characteristics and the peak acceleration of ground motions in Adana were not as severe as in Ceyhan due to different soil-depth and site response characteristics. It appeared that the quality of construction practices in Adana was better than in Ceyhan. The buildings damaged and/or collapsed in Adana were older and shorter.

The Çukurova University Medical Facility Hospital Building was seriously damaged. This large complex was shut down immediately after the earthquake, but was reopened within 48 hours following inspections by a group of engineers. There were separation of infill walls from the frame, X-cracks of infill walls, some column damage due to insufficient ties and some due to short-column effect (see Figure 6). Reserve strength in the walls and/or frames with infill walls must have contributed to saving the integrity of the hospital building (see Figure 7).

Bridges and Lifelines: None of the bridges on the Ceyhan River in Adana was damaged, but the historical Misis bridge in Misis (at the epicentral area) was partially damaged (see Figure 8). All bridges on the Ceyhan River in Adana were intact. There were only minor damages to the overpass bridges along the Cukurova Toll Autobahn.

Industrial Facilities: Although the industrial facilities in Adana appeared not to be damaged from outside, the news media reported that there was significant contents damage in some of the plants.

Social and Legal Issues

Adana is the fourth largest city in Turkey, and the whole Çukurova Basin is a major industrial and agricultural region with significant contribution to the Turkish economy. The population in the region was caught completely off-guard when the earthquake occurred. Most people in the region probably had not experienced such a strong shaking before. Some families moved to the higher Taurus mountains in the period following the earthquake.

The extent of damage to the mid-rise buildings, particularly in Ceyhan, caused extensive concern about the fact that there is no licensing requirement for contractors. It was determined that a significant number of the "contractors" were not trained. Those who are capable of financing a construction project are able to have a construction contracting business. Within ten days of the earthquake, six unqualified contractors were arrested for their faulty construction that caused loss of lives and property. There were calls for strict licensing processes for contractors, and demands for better construction control by municipal and government engineers.

Good Performance from Many Structures

In both Adana and Ceyhan there were many buildings that performed well. The well-designed and numerous shear walls present certainly contributed to the satisfactory performance of buildings dur-

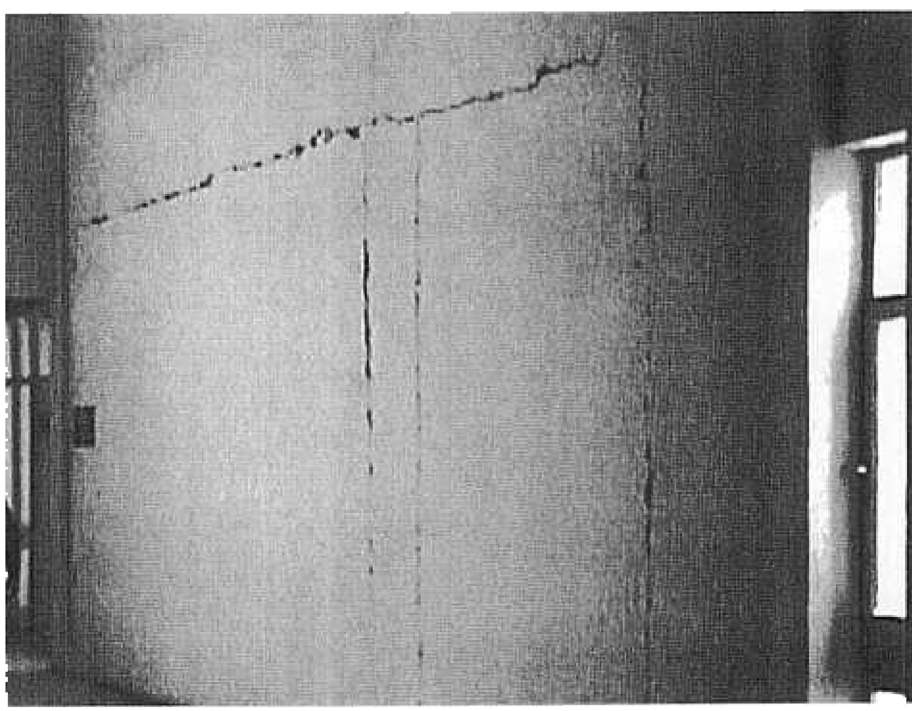

Figure 7– Separation of infill walls at the Çukurova University Medical Facility Hospital Building. Photo: Çelebi

ing this earthquake. The infill walls may have contributed positively by adding to the requisite reserve strength and stiffness of the reinforced concrete frame buildings (refer to the discussion of the Çukurova University Hospital Building).

Approximately ten miles east of Adana is the Incirlik Air Force Base. A significant number of buildings here suffered damage, but none collapsed. Much of the damage resulted from fallen false ceilings in the base shopping unit.

Acknowledgements

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More photos from Ceyhan-Adana are on the EERI web page. See them at: *http://www.eeri.org*

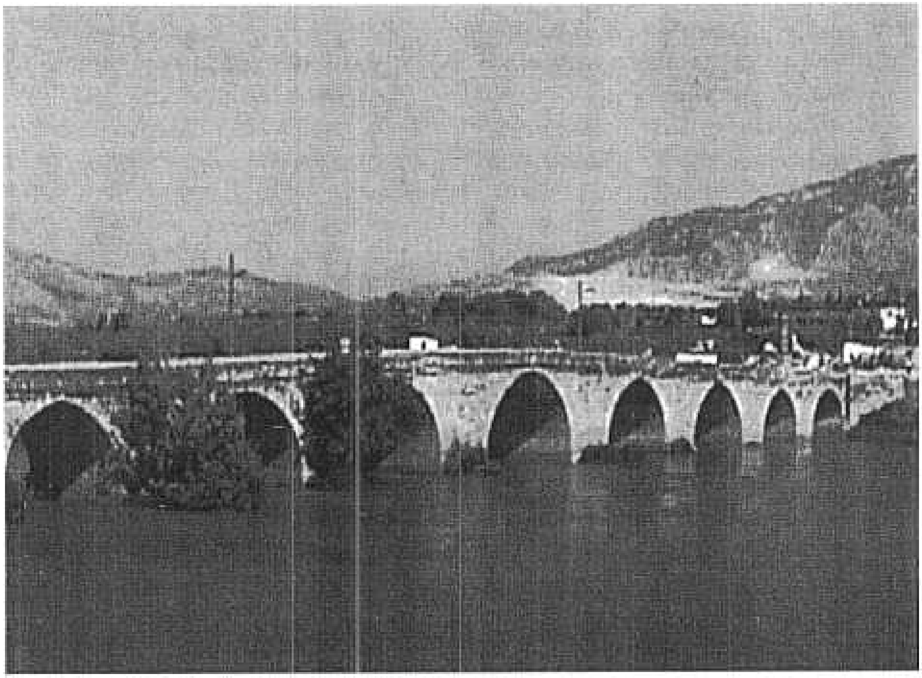

Figure 8 – *Historical Misis bridge in the epicentral area.* Photo: Çelebi

Figure 9 - *Soft first story of new construction resulted in cracks in columns.* Photo: Çelebi

Learning from Earthquakes

Dinar Aftershock Tests Retrofitted Buildings

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Introduction

In September and October of 1995, an earthquake swarm affected Dinar and smaller nearby settlements in southwest Anatolia, Turkey (see the map, Figure 1). A magnitude 6 main shock struck on October 1, and was followed by a magnitude 4.9 aftershock two hours later. These shocks caused 92 deaths and injured more than 200 people in Dinar, a city with a population of 35,000. A total of 201 buildings collapsed, and about 1000 buildings were damaged to varying levels. (For more information, see the November 1995 ***EERI Newsletter***.)

The Turkish government undertook an extensive retrofit program after this disaster. One third of all dwellings were sufficiently damaged to require repairs. By the end of 1996, 110 multistory reinforced concrete buildings and 215 masonry houses had been repaired and strengthened in Dinar and its vicinity.

On April 4, 1998, a magnitude 4.6 earthquake struck Dinar, at an epicentral location within 5 km of the 1995 main shock. Seismologists consider it a strong, delayed aftershock. The most interesting aspect of the event was the strong ground motion at Dinar—with a peak acceleration of 0.13g —which led to required structural capacity on the order of the design standards for the retrofitted structures. Therefore, the 1998 earthquake may be regarded as a mild, in-situ testing of the retrofitted structures.

Figure 10 *- Reinforced concrete building retrofitted by shear wall insertion.*

Seismological Characteristics of the Quakes

A comparative evaluation of the 1995 mainshock and aftershocks with the 1998 aftershock reveals interesting features of the strong ground motion recorded at the Dinar Meterological Station (see Table 1). Events 1-4 date from 1995, and event 5 is the 1998 earthquake. The NS and EW components of the five sets of ground accelerations are shown in Figure 11 in the same order as in Table 1. Basic features of the five events and their associated ground motion parameters are presented in the same table.

The waveforms of events 1, 2 and 5 are similar, as are the waveforms of events 3 and 4. This is not surprising since seismic waves from events 1,2 and 5 traveled through the same source-receiver paths, as did the waves from events 3 and 4. All accelerograms contain a transient pulse indicating the arrival of S-waves, followed by steady-state vibrations in the coda.

The transient pulses perhaps reflect the rupture characteristics of the associated sources, typical of near-source ground motions, becoming more complex with increasing magnitude. On the other hand, the steady state portions are more influenced by the travel path characteristics of the seismic waves and the soil conditions of the instrument site—on an alluvial valley approximately 200 m deep.

The peaks of the EW components of ground velocity are consistently higher than the NS components, although there is no such consistency for the peak ground acceleration. Moreover, peak ground velocity exhibits a steady increase with magnitude in both directions, which is not the case for the peak ground accelerations of smaller magnitude earthquakes. These anecdotal observations suggest that PGV is a better indicator of strong ground motion intensity as related to magnitude than is PGA.

Building Performance

The building stock in the urban area of Dinar performed poorly during the main event of October 1, 1995. The causes have been identified in many earthquakes, and not only in Turkey. The main cause for poor building performance is the prevalent unsupervised construction. Professional liabilities are diffuse: material quality, workmanship, and detailing are poorly inspected or cross checked, or never inspected at all.

The severity of damage to a property determines the levels of government compensation for homeowners. In keeping with recent government rehabilitation schemes, the decision was made in late 1995 to repair reinforced concrete buildings having moderate damage when property owners so requested. Rehabilitation of reinforced concrete structures was followed in 1996 by a similar program to upgrade masonry housing units.

How Were Buildings Repaired?

The urgent need for functionally useable buildings was instrumental in convincing the Turkish Ministry of Public Works and Settlement that the most effective way of producing habitable buildings was to engage teams of engineers from universities supervised by members of the academic staff.

Event No.	Date Time	Magnitude M_L	Component	PGA cm/s^2	PGV cm/s
1	01.10.1995 15:57	6.0	NS	283	17.4
			EW	205	20.7
2	01.10.1995 18:02	4.9	NS	201	15.5
			EW	109	17.8
3	05.10.1995 16:15	4.6	NS	84	4.6
			EW	143	11.5
4	06.10.1995 16:16	4.4	NS	89	2.9
			EW	146	8.8
5	04.04.1998 16:17	4.6	NS	131	6.1
			EW	126	13.2

Table 1 *- The 1995 and 1998 Dinar Earthquakes.*

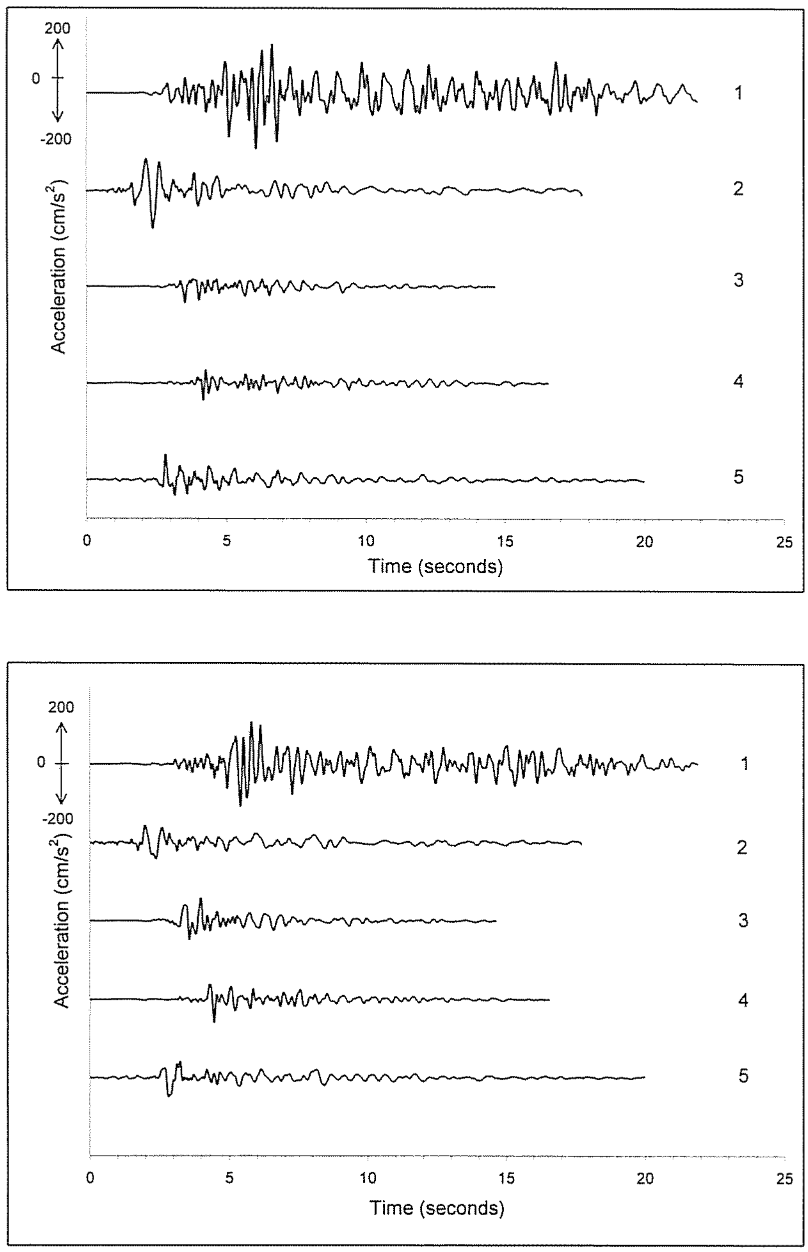

Figure 11 *- The NS and EW components of ground accelerograms.*

The diversity of buildings required that individual evaluations be conducted for each one. Careful on-site examinations recorded the location and severity of damage. A capacity control analysis was conducted to determine which spans to reinforce with insertion of shear walls (see Figure 10 for an example), or enlargement of column cross section with the use of jacketing. The design spectrum had a zero period ordinate of 0.2g.

For masonry buildings, an effective retrofit scheme was difficult to develop. The basic technique involved bonding a layer of reinforced grout shell on the outside of walls. The shell was made to function integrally with the wall through studs arranged over a 0.5m square grid. The studs were hooked and welded to the mesh reinforcement on the outside, and tightened with nuts and bearing plates on the inside. Figures 12 and 13 show plain masonry buildings retrofitted in this manner.

The Aftershock: A Mild Test

Instances of earthquake-damaged and repaired structures undergoing a second earthquake have been rare. The $M_L = 4.6$ event on April 4, 1998 provided a rare opportunity to evaluate the effectiveness of repairs. This evaluation is necessarily an incomplete one because the recorded ground motion (at one site) was relatively weak and produced no reliable measure of ground motion. In terms of intensity, duration and spectral parameters, the event corresponded to between one third and one half of full capacity for the rehabilitated buildings.

Reinforced concrete frame buildings strengthened with new shear walls passed the $M_L = 4.6$ test with flying colors, with one exception (discussed below). Minor cracking at the interface of old and new concrete could be expected, but no yielding or wide cracks were observed.

The performance of the Temporary Municipal Services Building was worrisome. Because of adjoining buildings on both sides, reinforced concrete wall panels could not be inserted fully into the exterior frames. The framing included approximately 1m-long cantilevered extensions of the floor slabs in the front and rear of the building above the ground floor. Walls added to the inner frames apparently were insufficient to limit the drift along the cantilevered facades above the first story.

Evidence of the drift was seen in inclined cracks in the masonry pier above ground story, and sliding along the existing girder and subsequently inserted wall interface along the interior frame.

The April 4, 1998, earthquake provided a platform on which a large number of buildings could be retested. Most of the rehabilitated buildings met our expectations.

***Figure 12** – Masonry house retrofitted by grout shell on outside walls.*

***Figure 13** - Masonry building retrofitted by bonding a layer of R/C grout shell on the outside walls. Pre-existing fourth story removed for weight.*