The Marmara, Turkey Earthquake of August 17, 1999: Reconnaissance Report

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Technical Report MCEER-00-0001
March 23, 2000

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MCEER
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The Multidisciplinary Center for Earthquake Engineering Research

The Multidisciplinary Center for Earthquake Engineering Research (MCEER) is a national center of excellence in advanced technology applications that is dedicated to the reduction of earthquake losses nationwide. Headquartered at the University at Buffalo, State University of New York, the Center was originally established by the National Science Foundation (NSF) in 1986, as the National Center for Earthquake Engineering Research (NCEER).

Comprising a consortium of researchers from numerous disciplines and institutions throughout the United States, the Center's mission is to reduce earthquake losses through research and the application of advanced technologies that improve engineering, pre-earthquake planning and post-earthquake recovery strategies. Toward this end, the Center coordinates a nationwide program of multidisciplinary team research, education and outreach activities.

Funded principally by NSF, the State of New York and the Federal Highway Administration (FHWA), the Center derives additional support from the Federal Emergency Management Agency (FEMA), other state governments, academic institutions, foreign governments and private industry.

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Foreword

Over the years, MCEER has supported many rapid surveys and reconnaissance visits to areas hit by severe earthquakes. Observations in the field as soon as possible following a major earthquake are one of the important ways in which vital data can be gathered and important lessons learned. In order to realize our vision of "earthquake resilient communities," these often tragic events must be investigated to validate our collective knowledge and to discover new insight into success stories and failures.

Our multidisciplinary team members conduct their reconnaissance visits primarily to support and foster knowledge development within MCEER's research program. The mission of the research program is to investigate how advanced and emerging technologies can be adapted and implemented to reduce earthquake hazards. Research efforts focus on development and calibration of loss estimation methodologies, damage evaluation, detection and response technologies, and development of retrofit strategies for critical facilities (such as lifelines, buildings and their contents, and bridges). The time period immediately following a destructive earthquake offers a critical window of opportunity to determine more closely the "weak links," reasons for failure or unacceptable performance, and to observe the success stories.

The observations and recommendations made by our team members are presented in this report, for the benefit of people in seismic regions throughout the world. Only by absorbing the technical and institutional lessons from these events, and then further developing our understanding and potential solutions in the laboratory and in our communities, can the potential for future tragedies be reduced.

George C. Lee
Director, Multidisciplinary Center for
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Preface

Early in the morning of Tuesday, August 17, 1999, a magnitude 7.4 earthquake struck along the Anatolian fault in the northwestern region of Turkey. Epicentered approximately 11 km southeast of the industrial city of İzmit, the earthquake lasted 45 seconds and was felt over thousands of square miles in Turkey's most densely populated region. Commercial and residential buildings from Adapazarı to İstanbul collapsed, resulting in large-scale loss of life. According to official government estimates (as of October 19, 1999), the earthquake killed over 17,000, and injured almost 44,000 people. Estimates of property losses (as of September 14, 1999) according to the World Bank range from $3 to $6.5 billion, which is equivalent to 1.5 to 3.3 percent of the Gross National Product of Turkey. It was the most devastating earthquake to strike Turkey since the 1939 Erzincan earthquake, which killed 30,000 people. According to official Turkish government estimates, the earthquake displaced more than 250,000 people. Approximately 120 tent cities were required for emergency housing. About 214,000 residential units and 30,500 business units were lightly to heavily damaged.

Within days, MCEER dispatched several researchers to the region - three of them simultaneously serving as part of the Earthquake Engineering Research Center (EERI) reconnaissance team - to examine the earthquake's impact. Their initial observations and impressions are reported in two publications, *MCEER Response* by M. Bruneau, J. Mander, W. Mitchell, A. Papageorgiou, C. Scawthorn and N. Sigaher, and in a *Preliminary Report* by C. Scawthorn. Both reports can be accessed from our web site at *http://mceer.buffalo.edu/research/turkeyeq/default.html*.

MCEER sponsored a second reconnaissance trip to Turkey together with the Earthquake Disaster Mitigation (EDM) Research Center in Miki, Japan. Team members visited Turkey from September 28 to October 4 to conduct high level reconnaissance using satellite imagery, differential global positioning systems and in-field GPS-GIS interfaces. In addition, restoration activities already underway were observed and documented.

This report includes observations from both these reconnaissance trips. It is the product of many authors representing several disciplines and, while not a final assessment of the topics addressed, represents an interim earthquake engineering evaluation of the natural, built and social environments. As noted by several of the authors, the analogies between the North Anatolian Fault Zone in Turkey and the San Andreas Fault in the United States are strikingly similar. The observations and conclusions herein form a springboard for future collaborative research efforts, which will advance society's ability to better withstand the destruction caused by earthquakes throughout the world.

Acknowledgments

This report and the reconnaissance effort which made it possible are a collaborative effort between many investigators and institutions. Sponsorship of these activities was provided primarily by the Earthquake Engineering Research Centers Program of the National Science Foundation and the Federal Highway Administration through the Multidisciplinary Center for Earthquake Engineering Research (MCEER). This support is gratefully acknowledged. Several of the authors were also members of the Earthquake Engineering Research Institute's (EERI) reconnaissance team, and/or the Geotechnical Reconnaissance team supported by the National Science Foundation.

The authors wish to collectively acknowledge the support and cooperation of the Turkish people who so willingly provided assistance during a very traumatic time. Many had the kindness and willingness to freely share information and provide access to damaged facilities.

The authors also wish to acknowledge the generous assistance of many organizations, agencies and individuals who made their visit possible and whose employees gave freely of their time and expertise. Some of these organizations and individuals are listed below and others are identified in the body of the report. They include:

- Professor Ayşe Akalın, Department of Sociology, Boğaziçi University
- Mr. Rafael Alaluf, YESA, İstanbul
- Mr. İsmail Barış, Mayor of Gölcük
- Dr. Nesrin Başöz, K2 Technologies
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Section 1
Introduction

Charles Scawthorn
EQE International, Inc.

The August 17, 1999 M_w 7.4 Marmara earthquake is a devastating catastrophe and great human tragedy for the Turkish people. Approximately 17,000 fatalities and 44,000 injuries occurred, with an estimated 20,000 collapsed buildings displacing more than 250,000 people, making it one of the worst natural disasters in recent decades.

The affected region around İzmit Bay is heavily industrialized and accounts for perhaps 10% of Turkey's GDP. Combined with other economic problems, the earthquake is expected to be a severe burden on the national economy, reducing national GNP by 0.6~1.0 % (World Bank, 1999).

The earthquake should have come as no surprise, since the long history of earthquakes is well-known (Ambraseys and Finkel, 1995), Table 1-1. Additional evidence for this event's potential was the clear pattern of sequential segmented rupturing of the North Anatolian Fault Zone (NAFZ) as pointed out by Toksöz et al. in 1979 and Stein et al. in 1997, (discussed by Papageorgiou in Section 2).

The approximately 125 km of fault rupture on the North Anatolian Fault Zone is clearly analogous to situations in other parts of the world, most notably with the San Andreas fault in the San Francisco Bay Area of California. The strong ground shaking due to this fault rupture, combined with soft soils around the perimeter of İzmit Bay and other areas (e.g., Adapazarı), resulted in significant geotechnical effects and permanent ground deformations (discussed by Mitchell and Holzer in Section 3). These geotechnical effects were consistent with those associated with other recent major earthquakes, and resulted in streets and buildings on the bayshore being submerged 1~2 meters in this event, and Adapazarı's water distribution system being virtually destroyed.

However, the most dramatic damage and greatest contributor to the disaster was the widespread collapse of numerous multi-story reinforced concrete apartment blocks. Almost the only building type in the region is non-ductile reinforced concrete frames with hollow clay tile infill which, combined with soft stories, results in a 'pancake' type of collapse (discussed by Bruneau in Section 4). Requirements for proper earthquake-resistive construction exist in the Turkish building code, which is a very modern code. Why weren't these requirements adhered to? One important factor has been the rapid development of Turkey in general, and particularly the Marmara region. From 1990 to 1997 for example, the province of Kocaeli's population grew 26%. Rapid development of the Marmara region overwhelmed local government's ability to monitor construction, and led to unregulated building, resulting in inadequate lateral force systems in buildings.

This lesson is further emphasized by the performance of structures designed and constructed by more centralized organizations with access to modern engineering, such as

Table 1-1 Seismicity of the Marmara Region

Year	Earthquake Location and Damage
29	(Nov. 24) An earthquake damaged İzmit.
69	Nicomedia (İzmit) was destroyed by an earthquake.
121	Nicomedia (İzmit) was completely destroyed by an earthquake.
128	Nicomedia (İzmit) was destroyed by an earthquake.
269	Nicomedia (İzmit) and the region up to Daciviza (Gebze) were destroyed by an earthquake.
362	(Dec. 2) Nicomedia (İzmit) was totally destroyed by an earthquake.
446	(Jan. 26) Damaging earthquake at Gulf of İzmit.
478	(Sep. 25) Helenopolis (Karamürsel) and Nicomedia (İzmit) were totally destroyed with great loss of life.
554-558	Destructive earthquakes caused the collapse of the best part of Nicomedia (İzmit), damaged İstanbul extensively and, in 558, caused the partial collapse of the dome of Hagia Sophia.
740	(Oct. 26) Nicomedia (İzmit), Praenetos (Karamürsel) and Nicaea (Iznik) were damaged by an earthquake.
989	(Oct. 25) An earthquake in the eastern Marmara Sea caused heavy damage in Nicomedia (İzmit).
1064	(Sept. 23) Region between İstanbul and İzmit were damaged by an earthquake.
1509	Major damage in İstanbul, felt from Athens to Cairo.
1567	(Oct. 1) An earthquake centered at Sapanca caused damage between İstanbul and İzmit.
1672	(May 25) An earthquake caused damage at İzmit.
1719	(May 25) Major earthquake in the eastern part of the Marmara Sea destroying Yalova, Pazarköy, Karamürsel, Kazıklı , İzmit and Sapanca.
1754	(Sept. 2) A great earthquake in the Gulf of İzmit. Villages were totally destroyed and about 2,000 people were killed.
1878	(Apr. 19) An earthquake caused damage at İzmit.
1894	(Jul. 10) A destructive earthquake in the Gulf of İzmit caused extensive damage between İstanbul and Adapazarı . The maximum effects were in the Heybeliada, Yalova and Sapanca region, where most villages were totally destroyed with great loss of life.
1957	(May 26) Abant and July 22, 1967 Mudurnu earthquakes.
1957	(May 26) Abant earthquake had a magnitude of Ms = 7.0 and a macroseismic epicenter of 40.5 N - 31.00E. It is associated with a 40 km fault rupture and with a maximum and average offset of respectively 165 cm and 55 cm. The earthquake caused almost total destruction within the 40 km long narrow valley between Abant Lake (east) and Dokurcun (west), with intensities reaching lo = X.
1967	(July 22) Mudurnu earthquake (magnitude: Ms = 7.1, macroseismic epicenter: 40.60N - 30.80E) took place on the western extension of the fault rupture associated with the 1957 earthquake. The earthquake caused heavy damage in the Mudurnu valley.
1999	(August 17) Marmara earthquake (M=7.4) caused catastrophic damage in İzmit, Gölcük and other towns, with over 17,000 killed. Followed on November 14 by M=7.2 event in Bolu.

the transportation systems (discussed by Mander in Section 5), industrial facilities (discussed by Johnson in Section 6) and lifelines (Section 7). In these cases, relatively little damage occurred, and the major motorways, water treatment and transmission systems, gas systems, and national power grid, were all functional within hours of the earthquake. Industrial facility performance was more mixed, with some dramatic damage, such as at the Tüpraş refinery (site of a major fire), but many facilities performed very well.

The human dimensions of the August 17 earthquake continued for many days, as Turks and rescuers from around the world struggled to find and save those trapped in the literally thousands of collapsed buildings. This task, which re-played similar efforts seen in Mexico City in 1985, Armenia in 1988 and elsewhere, is simply overwhelming. As Mitchell discusses in Section 8, the organization and technology does not currently exist to perform this task with any real effectiveness, so that prevention of the problem, via effective retrofitting, is the solution. The cost of disasters is further increased by the resources that must be devoted to tent cities and more durable temporary housing, debris removal and other necessary tasks, as discussed by Webb in Section 9. Both sections 8 and 9 also offer excellent insights into the social and political ramifications of such a trauma to the social fabric.

Very interesting in this earthquake was the application of new technologies for rapidly assessing and reacting to the disaster, in near 'real-time.' Remote sensing, GPS, GIS and emergency decision support systems offer the promise of efficiently employing available

Photograph by C. Scawthorn

Figure 1-1 Crowd observing a rescue on Aug. 24 east of Gölcük – asked to remain silent and motionless so that rescuers can listen for the victim, buried in a 'pancake' collapse

resources in a timely manner, thus in the future, potentially saving those who are currently lost. Eguchi and co-workers in the final chapter discuss current efforts at applying and understanding these technologies, which are an extremely promising area for further research.

In a sense, the August 17 Marmara earthquake was a ‘narrow-banded’ event. That is, considering the entire spectrum of the built environment, the damage resulting from the event, while substantial, was generally within the resources of Turkey to manage and even tolerate, with one exception. The exception was the dismal performance of the reinforced concrete frames, virtually ubiquitous in the region. The collapse of thousands of these buildings transformed this earthquake from a damaging event to a catastrophe. Within the spectrum of the built environment, only this aspect was a ‘spike.’ Design and construction of reinforced concrete frames to withstand strong earthquake motions is possible, and the principles are well understood by Turkish engineers. Unfortunately, the rapid development of the region overtaxed the ability of the society to assure that these principles were followed. The result was inadequate buildings, when there need not have been, and a tragic catastrophe. The ultimate lesson therefore is that building and development is simply not a physical process - governmental institutions and social processes must develop in parallel, to keep up with the physical demands and assure minimum acceptable standards of construction and public safety. The alternative is seen in Figure 1-1, thousands forced to stand by, while victims die in the rubble.

1.1 References

Ambraseys, N.N. and Finkel, C.F., (1995), *The Seismicity of Turkey and Adjacent Areas, A Historical Review, 1500-1800*, EREN publ., Istanbul.

World Bank, (1999), *Turkey, Marmara Earthquake Assessment*, Europe and Central Asia Region of the World Bank, Washington DC.

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Section 2
Seismology

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The earthquake that struck the Kocaeli Province of northwestern Turkey (Figure 2-1) on August 17, 1999 (known as the *1999 Marmara earthquake*), originated on the North Anatolian Fault Zone (NAFZ) with its epicenter located in the vicinity of the easternmost end of İzmit Bay. The earthquake occurred in the middle of the night (03:01:39 a.m. local time) when the population of the region were home sleeping. In a characteristic pattern that the NAFZ has exhibited in the past, the above earthquake was followed by another major event on November 12, 1999 (known as the *1999 Düzce - Bolu earthquake*). This latter event completed the rupture on the Düzce Fault (a subparallel fault of the NAFZ) that was initiated by the 1999 Marmara earthquake, causing additional destruction and deaths in the already devastated area.

http://quake.wr.usgs.gov/study/turkey/

Figure 2-1 Simplified location map of the Marmara earthquake August 17, 1999 (M_w=7.4)

2.1 Seismological Parameters

The official data from the U.S. Geological Survey and the Kandilli Observatory for the 1999 Marmara earthquake are:

- Date/Time: 1999-08-17 at 00:01:38.56 (UTC)
- Surface Wave Magnitude: M_s 7.8

- Body Wave Magnitude: m_b 6.3
- Seismic Moment: $M_o = 1.4 \times 10^{20}$ N-m (i.e. Moment Magnitude $M_w = 7.4$)
- Epicenter: Latitude = 40.639N, Longitude = 29.830E
- Hypocentral Depth: 17 km
- Fault Mechanism: Strike $\varphi_s = 91^\circ$, Dip $\delta = 76^\circ$ Rake $\lambda = 179^\circ$.

The parameters of the 1999 Düzce - Bolu earthquake are:

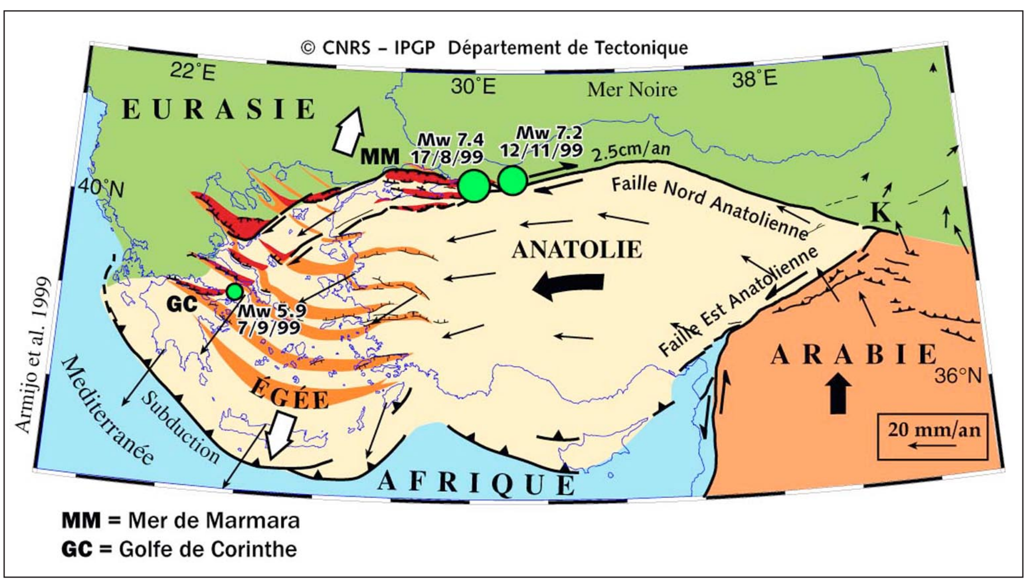
- Date/Time: 1999-11-12 at 16:57:20.31 (UTC)
- Surface Wave Magnitude: M_s 7.3
- Body Wave Magnitude: m_b 6.5
- Seismic Moment: $M_o = 4.5 \times 10^{19}$ N-m (i.e. Moment Magnitude M_w 7.1)
- Epicenter: Latitude = 40.8N, Longitude = 31.2E
- Hypocentral Depth: 10 km
- Fault Mechanism: Strike $\varphi_s = 276^\circ$, Dip $\delta = 59^\circ$, Rake $\lambda = -167^\circ$.

The 1999 Marmara earthquake did not come as a surprise, at least to the earth scientists, in view of the fact that it filled a seismic gap that had been previously identified by Toksöz, Shakal and Michael (1979) and thoroughly investigated by Stein, Barka and Dieterich (1997) and Nalbant, Hubert and King (1998).

The presentation that follows is based on the works of Stein et al. (1997), Udias and Buforn (1994), Barka and Kadinsky-Cade (1988), Barka (1992), Yeats et al. (1997), Aki (1992) and various very informative Internet sites about this earthquake.

2.2 North Anatolian Fault Zone (NAFZ)

The North Anatolian Fault Zone (NAFZ) (Figure 2-2) is one of the world's most active and best studied strike-slip faults. This arcuate right-lateral fault system has a length of 1500 km and constitutes the northern boundary of the Anatolian block which is drifting westward in response of the continental collision between Africa and Eurasia.



http://www.ipgp.jussieu.fr/

Figure 2-2 Regional tectonic map of the North Anatolian Fault Zone

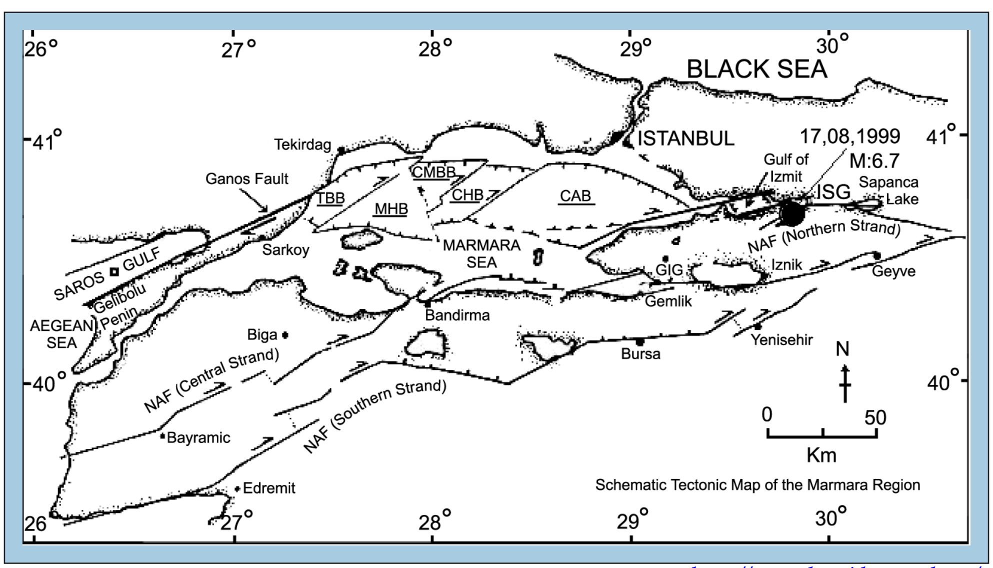
Despite its great length, the NAFZ has accommodated only 40 km of westward expulsion of the Anatolian block, all in the past 15 million years. Present day slip rate is about 2.5 cm/year.

At its eastern end, the NAFZ intersects with a southwest trending left-lateral strike-slip "*conjugate*" fault, known as the East Anatolian Fault, forming a triple junction (known as the Karlıova junction and indicated by the letter "K" in Figure 2-2) where the Anatolian, Arabian and Black Sea blocks converge.

At its western end, the NAFZ reaches the N-S extensional environment of the Aegean Sea and mainland Greece. Therefore, as is visually evident in Figure 2-2, the Anatolian block is trying to "escape" from the N-S compressional regime in Eastern Anatolia to the N-S extensional regime of the Aegean Sea and mainland Greece.

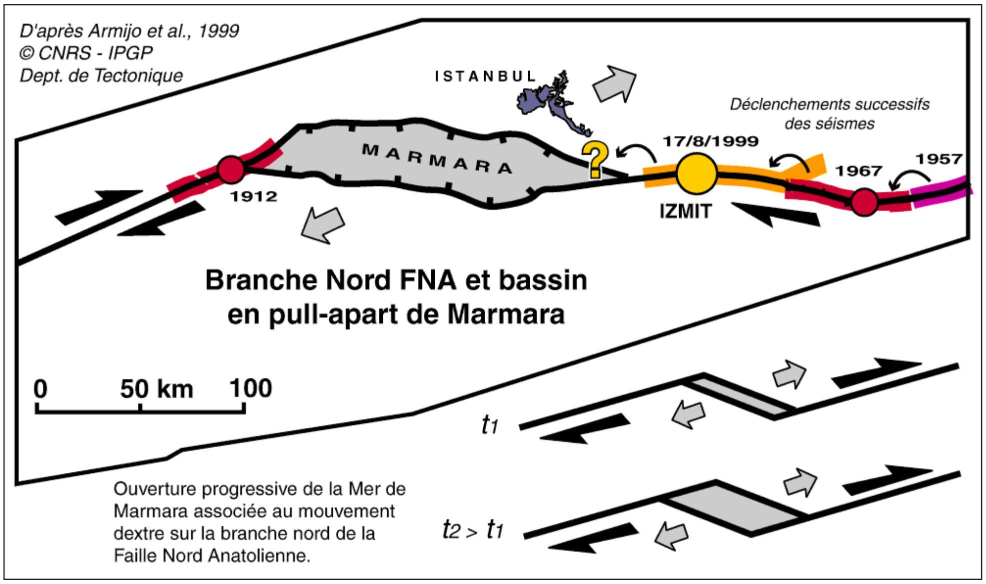
The westward drift of the Anatolian block may be considered as an expression of the rotation of the block relative to the Eurasian plate, with the pole of rotation located in the vicinity of the northern area of the Red Sea. Of course, the Anatolian block also sustains internal deformation, which includes extension in the western part similar to that of the Aegean Sea (Figure 2-2).

The NAFZ consists mainly of a single strand between the Karlıova triple junction and the Mudurnu Valley (the latter is located just east of the segment that ruptured during the August 1999 event) and then splays into three strands (the *northern*, the *middle* and the *southern strands*) in the Marmara and North Aegean Sea region (Figure 2-3a). The northern strand, east of the Marmara Sea, consists of a series of right-stepping en-echelon segments (through Gölcük and Sapanca Lake, where the August 1999 event originated), while west of the Marmara Sea, it continues as a single straight segment (referred to as the Ganos fault, Figure 2-3a) into the Gulf of Saros. The 1912 (M_w 7.55) earthquake event originated on this latter fault segment. Finally, the Marmara Sea region is composed of pull-apart basins separated by NE-SW trending strike-slip faults and bounded to the north and to



http://www.koeri.boun.edu.tr/

Figure 2-3a Schematic tectonic map of the Marmara Sea Region



http://www.ipgp.jussieu.fr/

Figure 2-3b Progressive opening of Marmara Sea

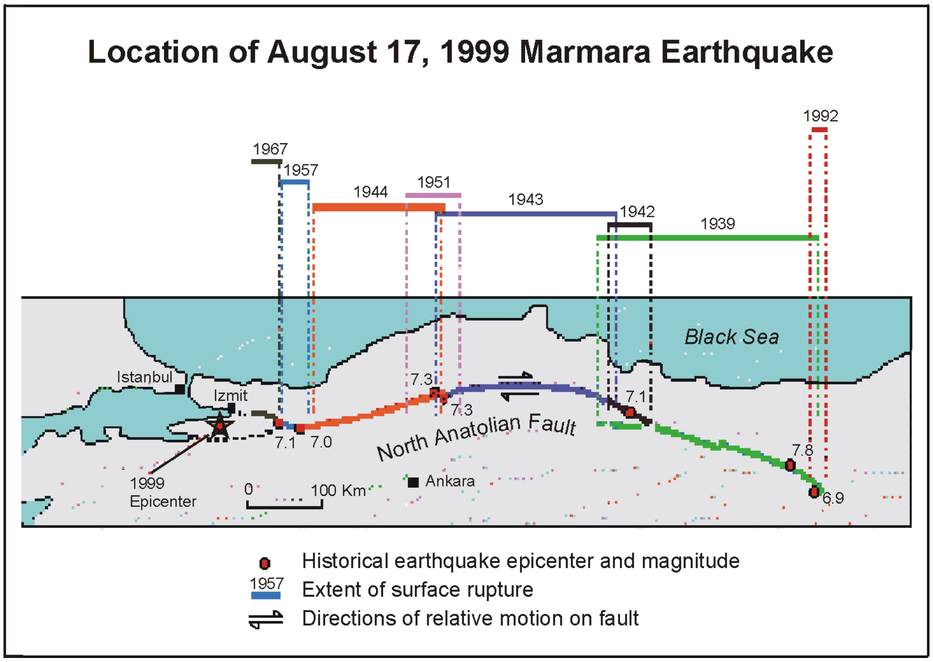
the south by normal faults. One of these normal faults ruptured in 1963 generating a M_s 6.3 earthquake event and providing the only focal mechanism available to date which is indicative of the NE-SW extension of the Marmara Sea. It is therefore evident that the Marmara Sea constitutes, on a large scale, a dilational (or release) stepover, as is clearly shown in Figure 2-3b.

Between 1939 and 1967, the NAFZ had a remarkable earthquake activity during which the 1939 Erzincan earthquake (M_s 7.8) was followed by a generally westward migrating sequence of earthquakes in 1942 (M_s 7.1), 1943 (M_s 7.3), 1944 (M_s 7.3), 1951 (M_s 6.9), 1957 (M_s 7.0), and 1967 (M_s 7.1) (Figure 2-4). The 1999 Marmara earthquake is a continuation of this westward migration. Investigation of historical documents reveal a similar series of events between 967-1053 A.D. (migrating from west to east) suggesting the possibility that migrating earthquake sequences such as the 1939-1999 may be a typical mode of strain release along the NAFZ.

The propensity of the NAFZ toward progressive failure was thoroughly investigated by Stein et al. (1997) who demonstrated that earthquakes interact. Specifically, when a large shock occurs, it changes the conditions for failure in its vicinity, altering the probabilities for future events and thus offering a new approach to updating forecasts of earthquake hazard.

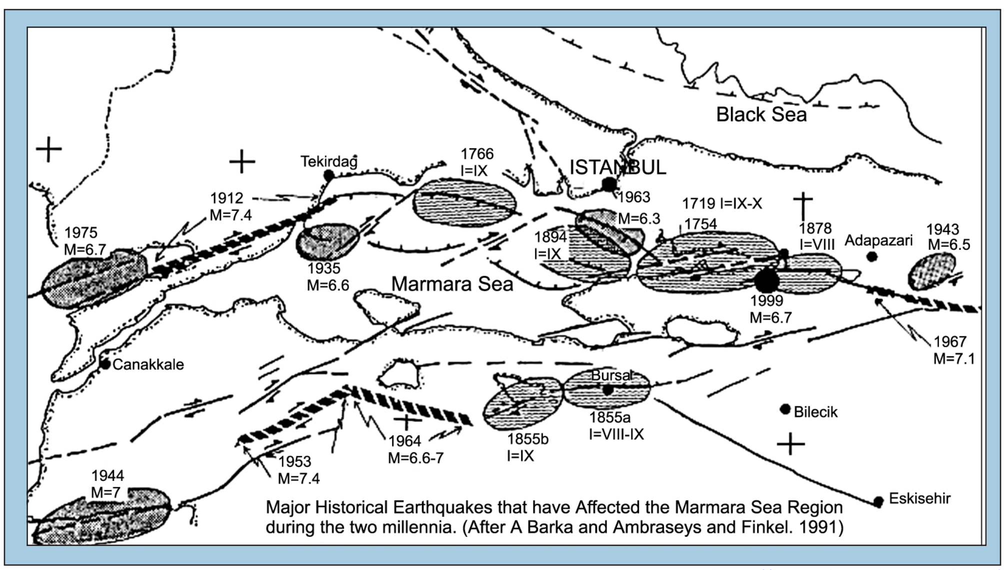
2.3 Fault Slip of the 1999 Marmara Earthquake

The 1999 Marmara earthquake ruptured a segment of the NAFZ that extends from at least Gölcük on the west to Eften lake to the east, just east of the town of Gölyaka and west of the town of Düzce. Historical data indicate that this area (i.e., the area of İzmit Bay) was frequently damaged by strong earthquake events (Figure 2-5). However, before the August 1999 event, the region had not experienced a major shock in the 20th century. The most recent notable earthquakes that originated on segments that ruptured during the



http://quake.wr.usgs.gov/study/turkey/

Figure 2-4 Progressive North Anatolian Fault rupture in adjacent earthquakes



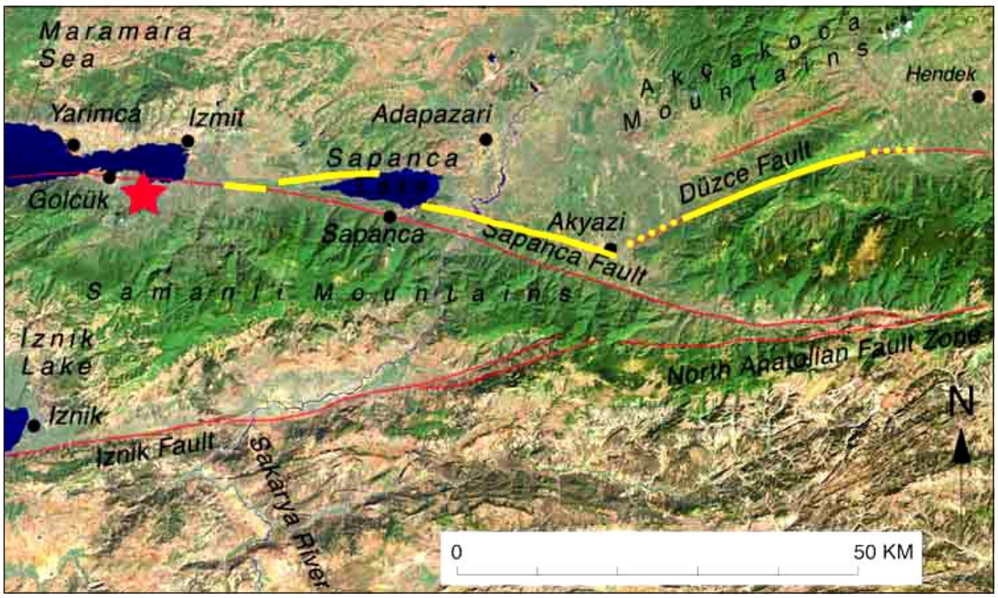
http://www.koeri.boun.edu.tr/

Figure 2-5 Major historical earthquakes that have affected the Marmara Sea Region during the two millennia

1999 Marmara earthquake are the 1719 (epicentral intensity MMI = IX), 1754, 1878 (estimated maximum magnitude 6.5), and 1943 (M_s = 6.5) events (Figure 2-5).

Three primary rupture segments have been identified (Figure 2-6). The east-west trending *western segment*, extends nearly 40 km from Gölcük to Sapanca Lake. The slip over this segment varies from 4-5 m at Gölcük to 3-4 m east of İzmit Bay. The fault zone over this segment has a complicated structure consisting of right-stepping en-echelon segments that form two major *dilational (release) stepovers* 4 to 6 km wide (Figure 2-3a). (The tectonic movement of these dilational stepovers contributed to the substantial subsidence of the coastal areas of Gölcük). One of the above en-echelon fault segments bends to the southwest (Figure 2-3a) forming thus a *restraining bend* that explains the large dip-slip (i.e., vertical slip) movements (~2.0 m) observed west of Gölcük (see Figure 2-7).

After an approximately 3 km wide right stepover at Lake Sapanca (Figure 2-6), the rupture continues over the middle fault segment which extends for about 26 km from Lake Sapanca to the town of Akyazı. This fault segment - referred to as *Sapanca* or *Sakarya segment* - experienced large slip up to 5 m at its westernmost end. The slip gradually decreases eastward of the area of high slip. The rupture then jumps to the Düzce fault which is a subparallel fault to the NAFZ.



http://quake.wr.usgs.gov/study/turkey/

Figure 2-6 Fault segments of the 1999 Marmara earthquake (M_w =7.4)

East of the town of Akyazı, the *Düzce segment* extends the 1999 rupture an additional 35 km, albeit with considerably less slip which dies out eastward towards the town of Düzce.

The last time that the Düzce segment slipped was during the 1943 Adapazarı-Hendek (M_s 6.5) earthquake (Figure 2-4). On the other hand, the segment of the NAFZ (just south of the Düzce segment) that did not slip during the 1999 Marmara earthquake, had experienced slip during the 1967 Mudurnu Valley (M_s 7.1) earthquake.

The November 12, 1999 Düzce - Bolu earthquake, which ruptured the rest of the Düzce segment (or at least a significant part of it), did not come as a surprise. As Toda, Parsons and Stein reported on the Internet (*http://ncweb-menlo.wr.usgs.gov/study/turkey*), the August 17, 1999 Marmara earthquake stressed the rest of the Düzce fault, which subsequently ruptured generating the November 12, 1999 Düzce - Bolu earthquake.

Photograph by Mark Milstein, A.N.S.

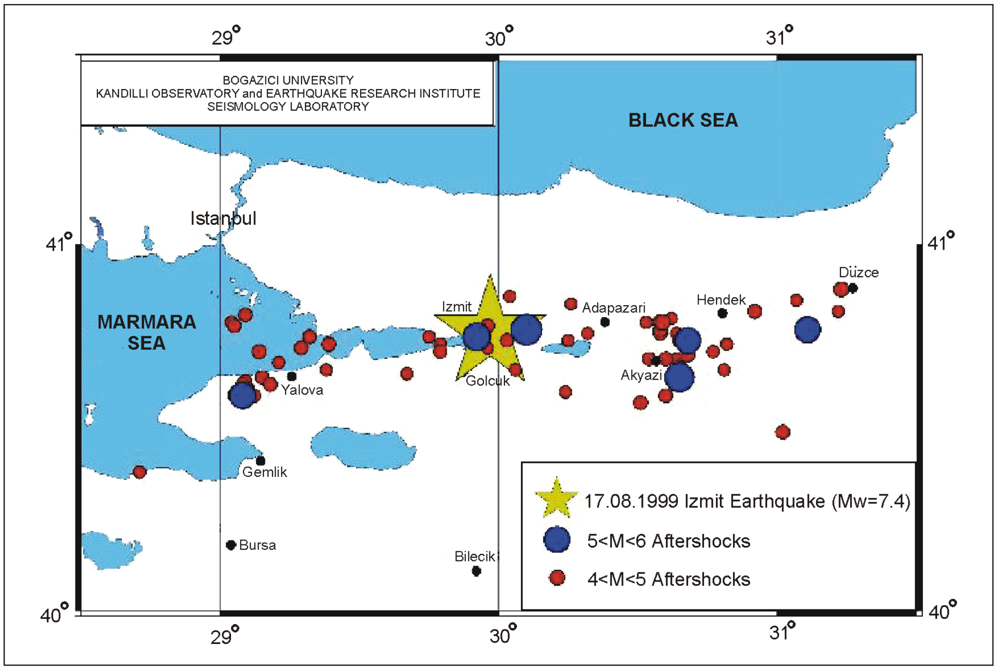
Figure 2-7 Approximately 2.2 m vertical offset measured on main fault, Gölcük

Any slip that may have occurred west of Gölcük during the 1999 Marmara earthquake is not well defined. However, the aftershock activity west of Gölcük (Figure 2-8) coincides well with the region of stress increase due to the 1999 August event calculated by Toda, Parsons and Stein (see above website).

Inversions of the teleseismic data of the two events are shown in Figures 2-9 and 2-10. (Yagi and Kikuchi, 1999; *http://wwweic.eri.u-tokyo.ac.jp/yuji/trk2/*). Regarding the August 1999 Marmara earthquake, clearly the rupture was characterized by an asymmetric bilateral rupture propagation and smooth dislocation motion. The maximum slip and slip-velocity are about 7 m and 2.5 m/sec, respectively. The slip distribution consists of a patch of massive release of seismic moment, located roughly in the Gölcük - İzmit area, and a second subevent, located about 30 km to the east, approximately in the vicinity of Sapanca Lake.

In view of the above, the following plausible scenario of rupture nucleation, propagation and arrest emerges, which is consistent with the enlightening analysis of Aki (1992).[1]

[1] Aki (1992), in an effort to understand where earthquakes nucleate and where they stop, and using the 1966 Parkfield earthquake as a prototype example, has classified the geometry of a fault zone into two types: (1) Type 1: The fault trace is straight with or without a slight bend; (2) Type 2: The fault is significantly bent (10° or more), stepped, or branched.

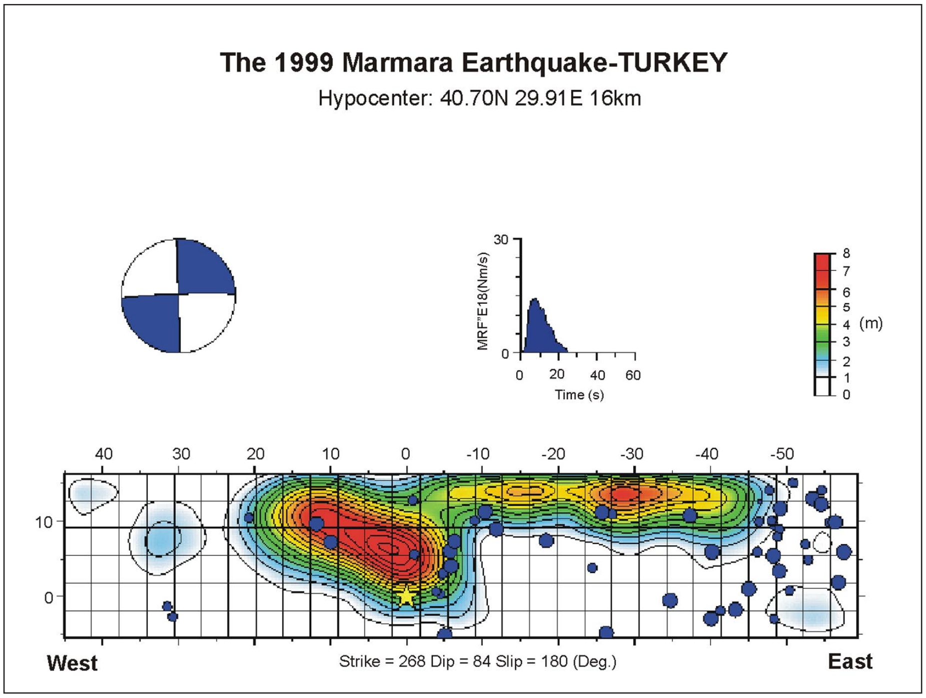


http://www.koeri.boun.edu.tr/

Figure 2-8 Major aftershocks of the 1999 Marmara earthquake (M_w =7.4)

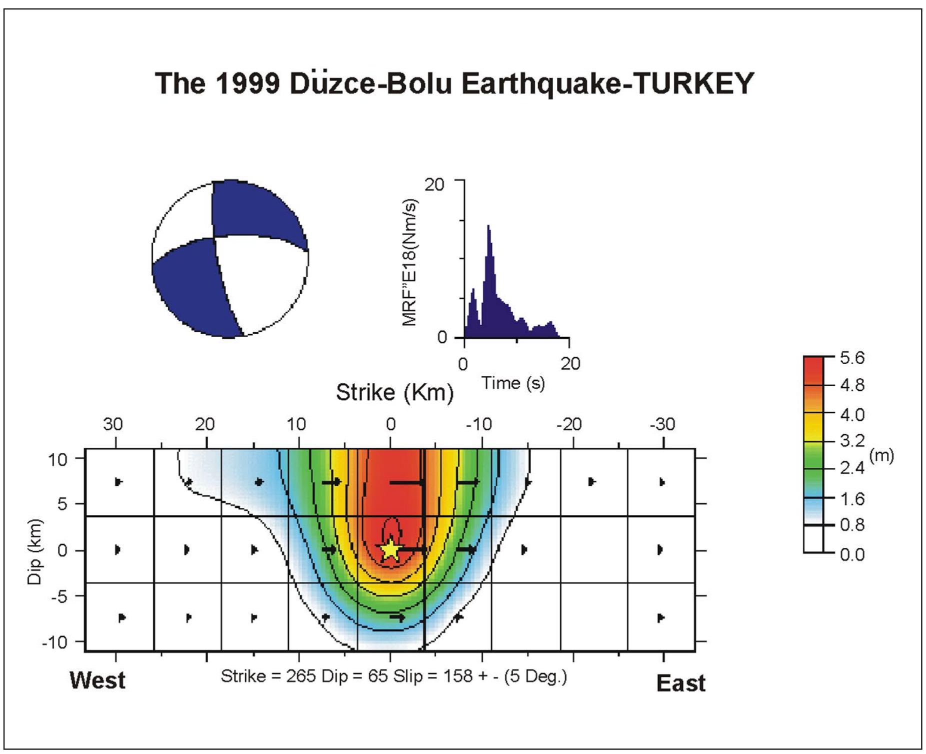
The rupture was initiated at a *restraining bend* of one of the en-echelon segments of the Gölcük - İzmit segment (Figure 2-3a) that acted as a stress concentrator (*Type 2* fault trace geometry according to the classification of Aki, 1992). Once the rupture was initiated, it propagated bilaterally. To the east, the rupture skipped the step of the Sapanca Lake in a manner similar to that found in the numerical simulations of Das and Aki (1977). This step was also acting as a stress concentrator and probably caused the second subevent located most likely on the western end of the Sapanca-Sakarya segment. The rupture continued on this segment up to the *branching point* where the NAFZ meets the Düzce Fault (vicinity of the town of Akyazı). This branching point acted as a *barrier* (e.g., Papageorgiou and Aki, 1982) - as is evident by the considerable concentration of aftershocks in this area - and decelerated the rupture, which jumped from the NAFZ and continued on the Düzce Fault. On this latter fault, the slip diminished considerably and eventually the rupture stopped at the point/region where the Düzce fault has a significant (~20°) bend. This restraining bend (which also has the characteristics of Type 2 fault trace geometry; Aki, 1992) acted as a barrier and arrested the rupture. Subsequently, this bend, being a barrier, acted as a stress concentrator and, when it broke, generated the 1999 Düzce - Bolu earthquake.

To the west of the epicenter, the rupture progagated for about 20 km and was arrested by one of the dilatational steps of İzmit Bay mentioned above (i.e., Type 2 fault trace geometry; Aki, 1992).



Yagi and Kikuchi, 1999, *http://wwweic.eri.u-tokyo.ac.jp/*

Figure 2-9 Preliminary results of fault slip distribution of the 1999 Marmara earthquake (M_w=7.4)



Yagi and Kikuchi, 1999, *http://wwweic.eri.u-tokyo.ac.jp/*

Figure 2-10 Preliminary results of fault slip distribution of the 1999 Düzce-Bolu earthquake (M_w=7.1)

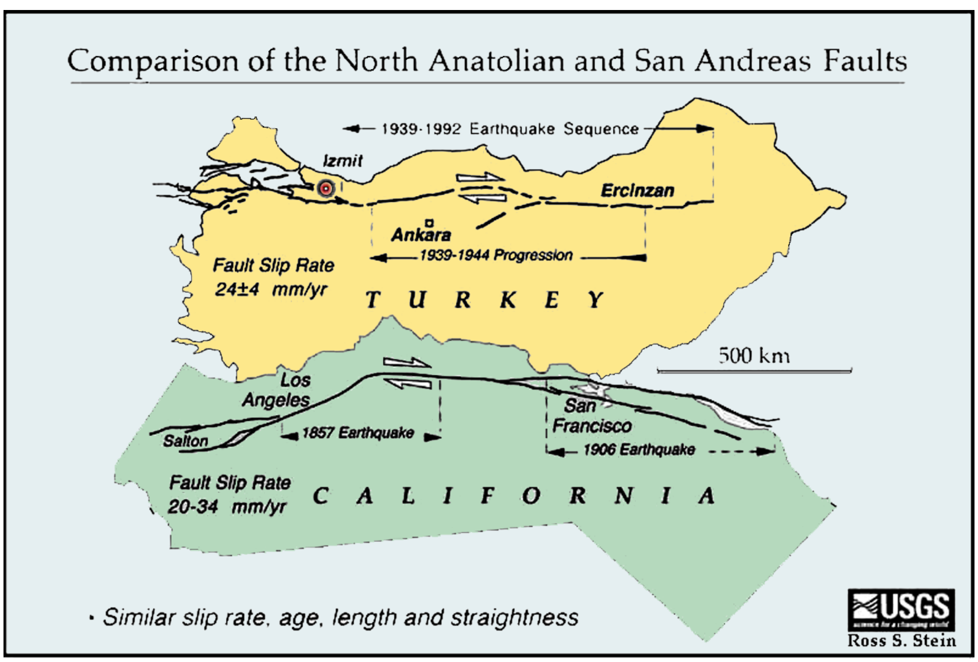
2.4 Similarities and Differences Between the North Anatolian Fault and the San Andreas Fault

The causative fault, the NAFZ, is a textbook example of a right lateral strike-slip fault that has been extensively studied in the past. It is considered a close analogue of the San Andreas Fault (SAF) in that it exhibits similar rates, total length, and straightness relative to their pole of rotation (Figure 2-11).

As the USGS field investigators who visited the various fault segments of the 1999 Marmara earthquake pointed out in their report (*http://quake.wr.usgs.gov/study/turkey*): "…understanding how the Marmara earthquake linked together [the] various fault segments may provide a new understanding of the range of possible earthquakes that can occur near San Francisco and will ultimately help us more accurately estimate hazards in many regions."

Despite their similarities, the NAFZ and SAF also have important differences. As Stein et al. (1997) clearly state, the propensity of the NAFZ toward progressive failure is a product of (1) its simple, straight geometry which makes the efficient transfer of stress possible, (2) its isolation from other faults, which effectively minimizes stress transfer to competing faults, and (3) its en-echelon character which keeps the entire fault from rupturing at once.

On the other hand, the lack of the SAF for a propensity for an orderly, progressive pattern of rupture may be attributed to the fact that (1) it produces larger earthquakes along



http://quake.wr.usgs.gov/study/turkey/

Figure 2-11 Comparison of the North Anatolian and San Andreas Faults

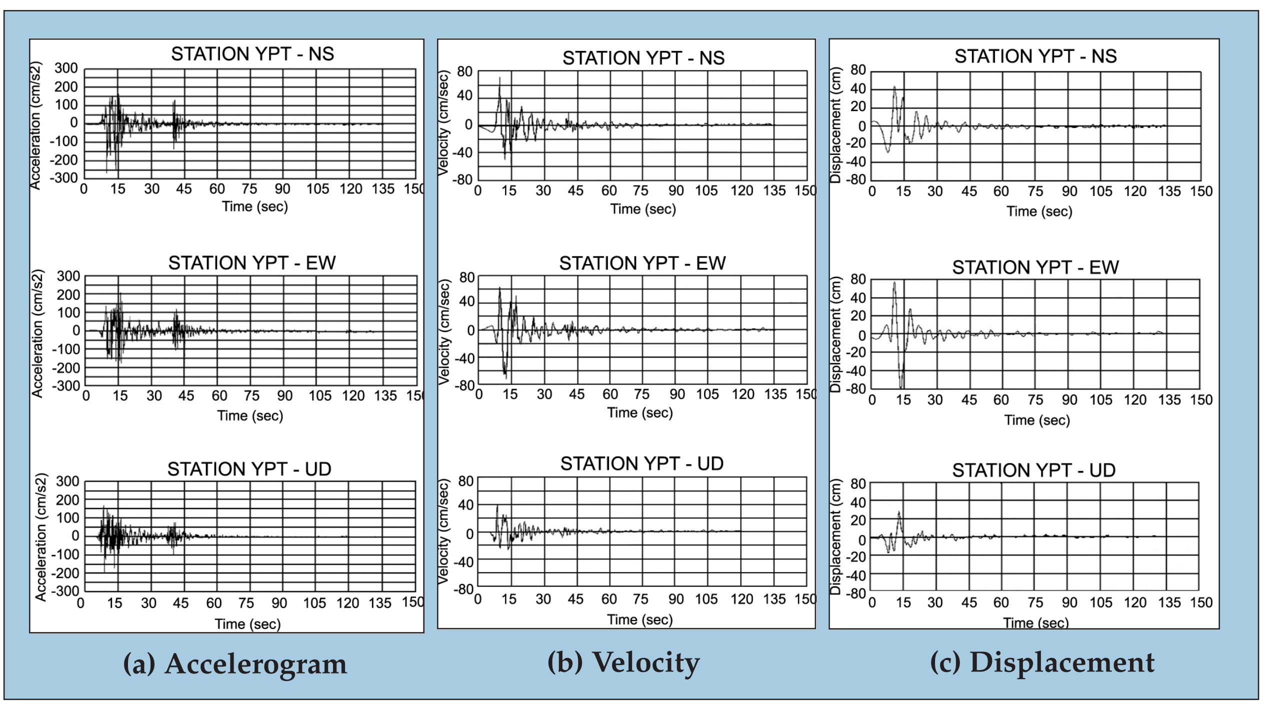
its smoother trace and (2) it lies closer to other major competing faults which makes stress transfer from segment to segment of the SAF more irregular and complex.

2.5 Strong Motion Recordings

Numerous strong motions were recorded by the National Strong-Motion Network of Turkey which is operated by the Earthquake Research Department, General Directorate of Disaster Affairs, Ministry of Public Works and Settlement, and by Boğaziçi University and İstanbul Technical University. These records were almost immediately posted on the Internet (*http://geophysics.gg.utk.edu/izmit*) and thus were made available to the research and engineering communities. The peak accelerations recorded on a series of stations running parallel to, and within 20 km from, the NAFZ are rather moderate (e.g., Yarımca 0.32 g; Adapazarı 0.41 g; Düzce 0.37 g) even though the surface expression of the fault reveals a non-smooth rupture.

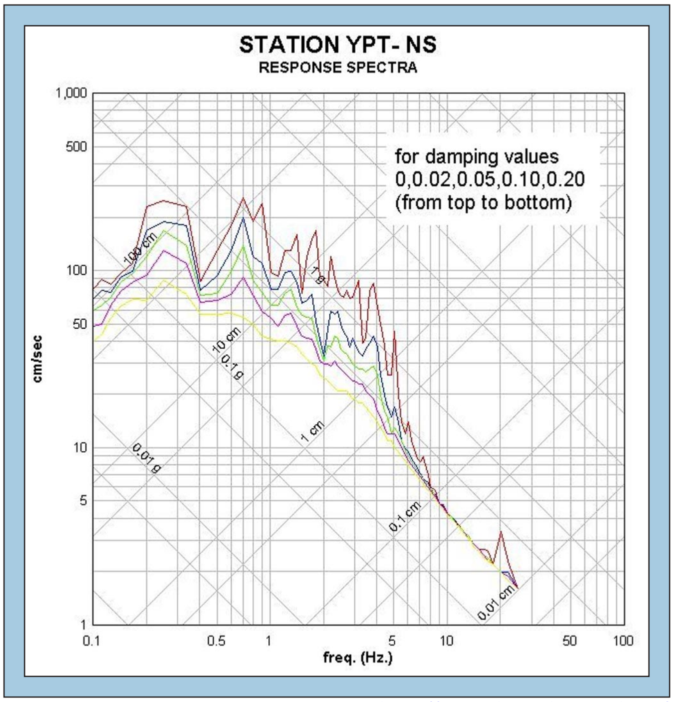
Figures 2-12a, b, c show the acceleration, velocity and displacement, respectively, of the motion recorded at Yarımca (YPT) station, 10 km to the northwest of Gölcük, while Figure 2-13 shows the corresponding response spectra. The two subevents mentioned above are evident on the record. Furthermore, the presence of strong intermediate period (3-4 sec) pulses on the records reveal near source phenomena such as *passage of the rupture front*.

Finally, Figure 2-14 shows the acceleration time histories of the motion recorded at Maslak, which are representative of the motions that İstanbul experienced on compe-



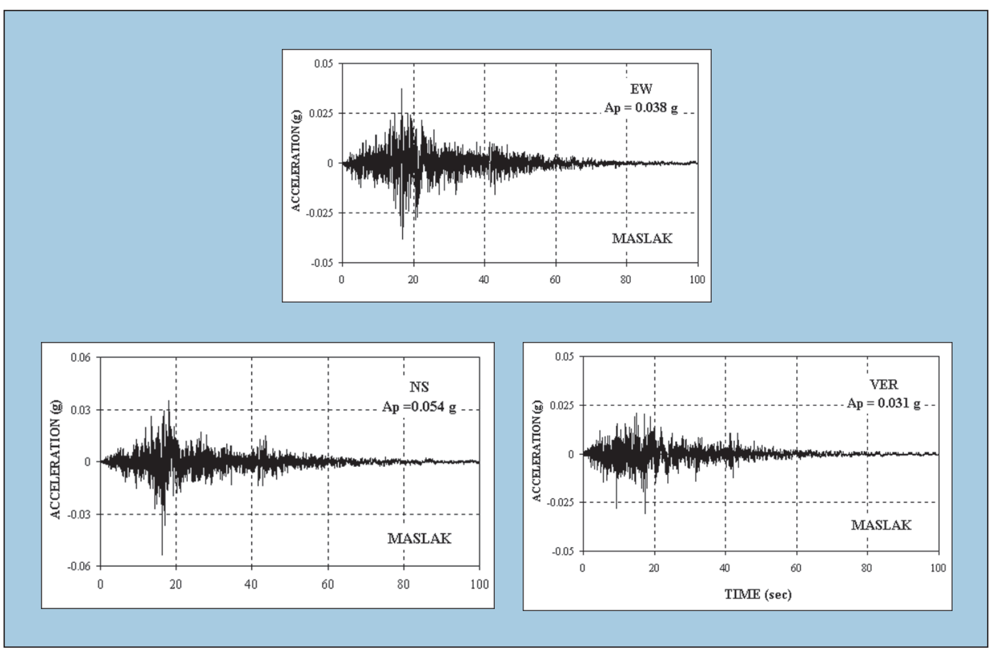
http://geophysics.gg.utk.edu/izmit/earthquake.htm

Figure 2-12 (a) Accelerogram, (b) Velocity and (c) Displacement recorded at station Yarımca (YPT) during the 1999 Marmara earthquake



http://www.koeri.boun.edu.tr/

Figure 2-13 Response spectra of the NS-component of motion of the 1999 Marmara earthquake recorded at station Yarımca (YPT)



http://geophysics.gg.utk.edu/izmit/earthquake.htm

Figure 2-14 Acceleration record of the 1999 Marmara earthquake recorded at Maslak (İstanbul)

tent ground. The presence of long period surface waves is evident on the record around t=20 sec.

2.6 Conclusion

Some of the reasons why the 1999 Marmara earthquake was so destructive include: (1) the quality of construction of the infrastructure; (2) the fault segments which ruptured crossed one of the most densely populated regions of Turkey; (3) very energetic near-source pulses in the immediate vicinity (within 3 km) of the fault; and (4) the right-stepping en-echelon right-lateral strike-slip segments in the vicinity of Gölcük and İzmit have created elongated sedimentary basins which probably trapped and amplified the incident seismic waves, thus enhancing the destructive power of the event.

The surface expression of the 1999 Marmara rupture consists of a number of segments. How these segments were connected during the earthquake, as well as how the earthquake nucleated and eventually how the rupture was arrested are important research questions that need to be addressed with regard to this earthquake. Answers to the above questions and lessons learned from this earthquake will be very valuable for other strike-slip fault systems around the world, such as the San Andreas Fault.

Another important issue is the reconciliation of the segmented and complicated fault rupture with the rather moderate accelerations recorded in the vicinity (within ~10 km) from the fault.

Equally important is to gain a better understanding of the near-source pulses. Specifically, it will be very important for future events to relate important features of these pulses (such as waveform and intensity) to important characteristics of fault slip.

Finally, the 17 August, 1999 Marmara and 12 November, 1999 Düzce - Bolu earthquakes, and more generally the NAFZ system, provide an excellent opportunity to test and validate new approaches to updateable forecasts of earthquake hazard.

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Contents

Section 3
Geotechnical Effects

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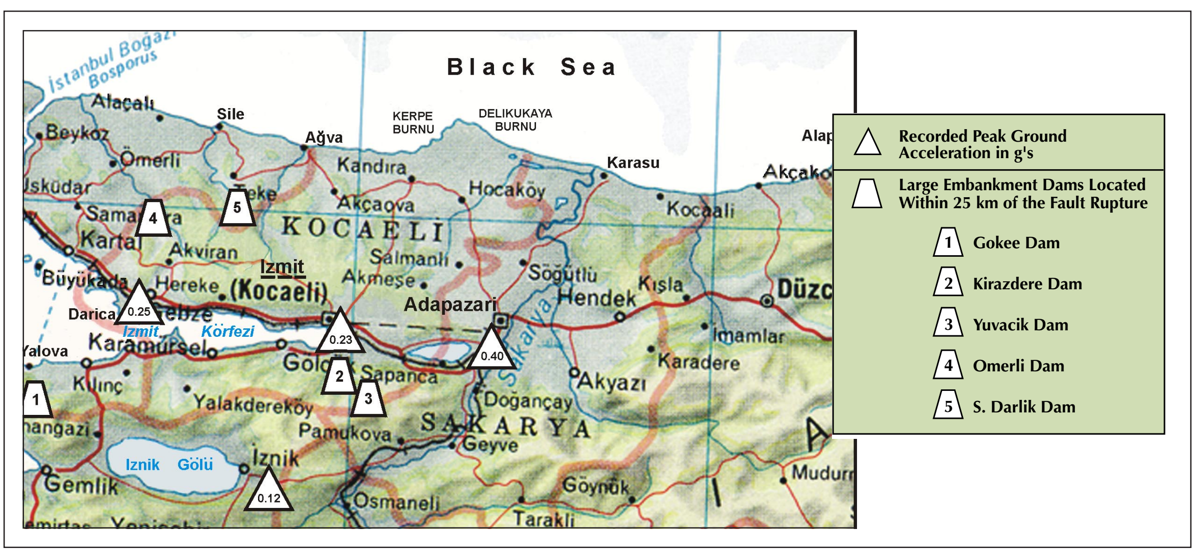
The 126 km long surface rupture and seismic shaking associated with the August 17, 1999 M_w 7.4 Marmara earthquake on the North Anatolian Fault were responsible for large ground displacements and many soil failures. Geotechnical effects were particularly destructive in urban areas underlain by recent sediments and along shorelines. Local soil conditions were responsible for substantial amplification of rock motions, ground subsidence, liquefaction, loss of structure support, lateral spreading, and slope failures.

The geotechnical aspects of the August 17, 1999 Marmara earthquake were investigated by a Geotechnical Reconnaissance Team supported by the National Science Foundation. A report on the results of this reconnaissance will appear in a special issue of *Earthquake Spectra* published by the Earthquake Engineering Research Institute. Key geotechnical findings and conclusions from the forthcoming *Earthquake Spectra* report are presented in summary form here.

3.1 Geological Setting

The area impacted by the North Anatolian Fault rupture in the Marmara earthquake (see Figure 3-1) is composed largely of low lying sediment filled basins overlying volcanic and sedimentary bedrock. The sedimentary basins, from west to east, are İzmit Bay, the Çuhahane and Kiraz River plains, Lake Sapanca, Adapazarı, and Düzce. The sediments



Map prepared by Kemal Onder Cetin, University of California, Berkley

Figure 3-1 Area impacted by the Marmara earthquake

in the basins are derived from the mountains to the north and south. Late Holocene and recent alluvium from active river systems is found in some of them. Descriptions of sediments specific to some of the basins are given by Rathje, et al. (2000).

3.2 Ground Motions and Site Response

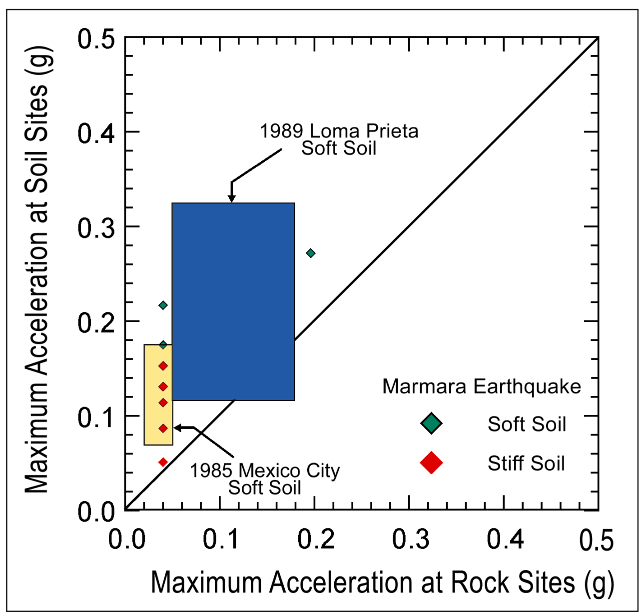
Twenty-three ground motion records from within 200 km of the fault rupture are available. Information from these records, including some time histories and spectral data, is presented and discussed by Rathje, et al. (2000). Six of the records are from locations within 20 km of the fault (three are shown in Figure 3-1), which adds significantly to the sparse prior database of near field, large magnitude ground motion records. Several important findings from the ground motion and site effect studies by Rathje, et al. (2000) are:

1. The maximum horizontal ground accelerations were less than predicted using current attenuation relationships at distances less than 20 km from the fault rupture.
2. The ground motion at a site was impacted by directivity; i.e., whether the direction of fault rupture was towards or away from the site.
3. The ground motions at distances greater than 20 km from the fault rupture generally fell within plus or minus two standard deviations of current attenuation relationships.
4. Spectra from recorded motions were generally lower than current UBC design spectra.
5. Rock accelerations were amplified through overlying soil, with greater amplification for soft soil than stiff soil. This is illustrated by Figure 3-2, which shows maximum acceleration at soil sites as a function of rock acceleration. Amplifications observed for soft soil sites in the 1985 Mexico City earthquake and the 1989 Loma Prieta earthquake are shown for comparison.
6. The greatest damage was concentrated in areas underlain by the most recently deposited (Holocene) alluvium. These areas included Adapazarı, Gölcük, Degirmendere, the Avcılar area of İstanbul, and along İzmit Bay.

3.3 Soil Liquefaction

Buildings in several communities, including Adapazarı, Gölcük, and Sapanca, sank or settled into the ground during the August 17, 1999 Marmara earthquake. In areas where buildings sank, surface manifestations of liquefaction, a process by which shaking during an earthquake causes saturated sandy materials to become fluidlike, were observed. The observed surface manifestations included sandy subsurface materials that had vented to the surface (known as sand boils), and lateral shifting of the ground (lateral spreading).

Building settlement was widespread in the city of Adapazarı. Hundreds of build-



Rathje, 2000

Figure 3-2 Variation of horizontal accelerations at soil sites versus rock sites

Upper photograph by Thomas L. Holzer; lower photograph by National Institute of Standards and Technology

Figure 3-3 Building in Adapazarı that sank 1.5 m uniformly into the ground when the soil beneath it liquefied and was pushed outward from beneath the building. Magnitudes of sinking were generally proportional to weight of building.

ings were affected; in many city blocks, the majority of buildings sank. Buildings in Adapazarı locally sank as much as 1.5 m (Fig. 3-3). The part of Adapazarı in which buildings settled is an area built on young flood-plain deposits of the Sakarya River. The groundwater table in these deposits is shallow, only about 1–2 meters. Although most buildings simply sank upright into the soil, a few were also overturned, which exposed their foundations (Fig. 3-4). The sunken buildings in many cases were less damaged from shaking than adjacent buildings that were on soils that did not liquefy during the earthquake. In addition, items on shelves in many stores in the settled buildings were not even dislodged. This suggests that once the foundation soils liquefied, seismic waves were unable to propagate through the liquefied soil and shake the buildings that settled as violently as adjacent buildings on non-liquefied soil. Sand boils were the primary surface evidence of liquefaction (Fig. 3-5); these sand boils vented onto sidewalks adjacent to buildings and into the first floor of buildings that settled. Many sidewalks around the buildings that settled were heaved upward, indicating bearing capacity failure after liquefaction and displacement of liquefied material outward from beneath buildings as they sunk into the ground. Settling also appears to be proportional to the weight of the building; multistory buildings sank more than adjacent single-story buildings. Delayed building settlements were also reported for foundations on silt that developed high pore pressures, but only experienced marginal liquefaction.

Along the southeast shore of Lake Sapanca, soils also liquefied and the Lake Sapanca Hotel was dramatically affected. The hotel, which was built on an old stream delta that

Upper photograph by Thomas L. Holzer; lower photograph by Richard S. Olsen

Figure 3-4 Buildings in Adapazarı that either toppled or partially overturned because soil beneath them liquefied and weakened the foundation

Photograph by Mehmet Çelebi

Figure 3-5 Sand boil on sidewalk in Adapazarı. Sand ejected from underground when sandy soils beneath the ground-water table liquefied during the earthquake.

had prograded into Lake Sapanca, sank about 0.3 m into the ground. The regional land surface around the hotel also lowered causing the shoreline to submerge (Figs. 3-6, 3-7). In addition, the hotel was displaced about 0.5 m toward the lake by a lateral spread along the shoreline of the lake. Large quantities of subsurface sand vented to the surface and covered much of the driveway and the landscaping around the hotel.

Minor sinking of buildings occurred along the shoreline of İzmit Bay in Gölcük. A few multistory buildings sank about 0.1 m. Sand boils and lateral spreading, which caused parts of the coastline to move bayward less than 0.5 m, were observed and provide evidence of liquefaction along the coast.

Sand boils were sampled at Adapazarı, Gölcük, and Sapanca. Liquefied material was predominantly fine grained; grain-size distributions of the material typically ranged from silts to silty sands (Fig. 3-8). The two coarser sand boils sampled at the Sapanca site contained cobbles and other coarse-grained material. These sand boils may have been contaminated with cobbles contained in the base of a driveway. The other sand boil at Sapanca was in an open area and not susceptible to contamination.

Sunken and overturned buildings have been observed in other large (magnitude ≥ 7) earthquakes, including the 1964 Niigata, Japan, and 1990 Philippines earthquakes. Magni-

Photographs by Thomas L. Holzer

Figure 3-6 Submergence of shoreline at Lake Sapanca and settlement of Sapanca Hotel. "Moat" adjacent to wall indicates the hotel has sunk into the ground because of liquefaction of underlying sandy soil.

Photograph by Thomas L. Holzer

Figure 3-7 Sunken entryway into Sapanca Hotel created when building sank into liquefied soil

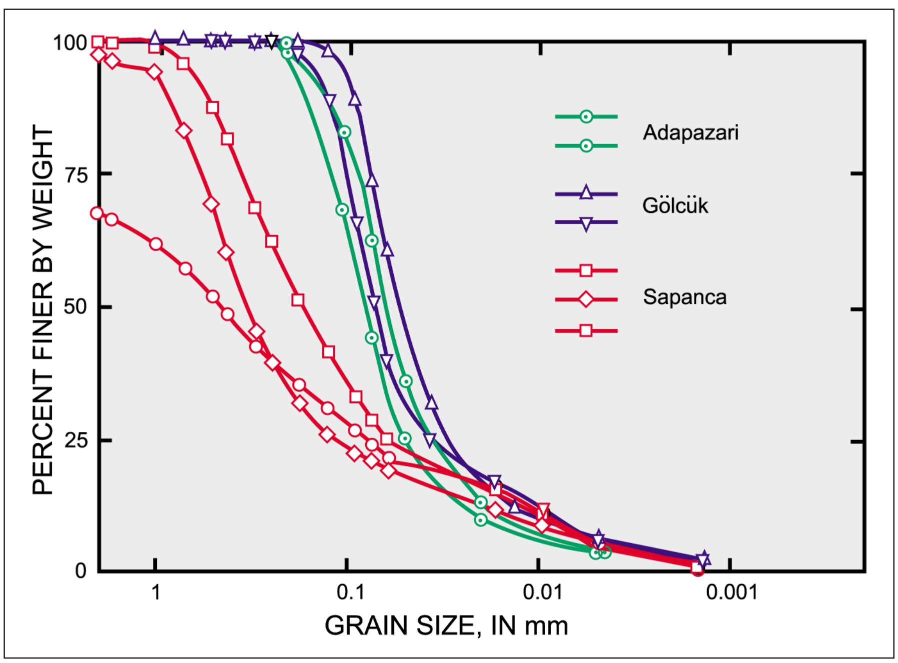


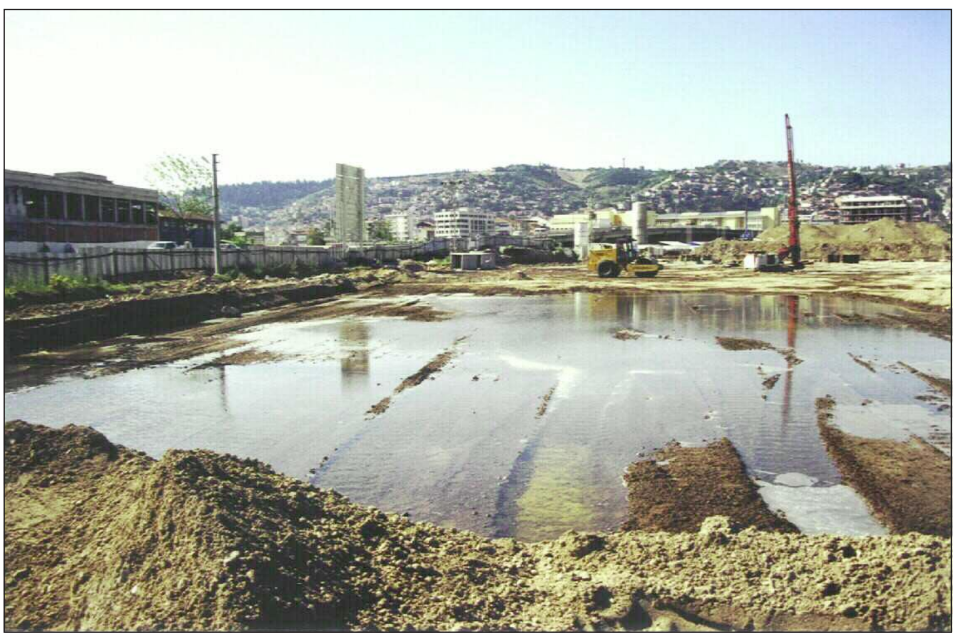
Illustration prepared by Michael J. Bennett. Data from U.S. Geological Survey and Army Corps of Engineers Engineering Research Development Center

Figure 3-8 Grain-size distributions of sand boils sampled near sites of sunken buildings in Adapazarı, Gölcük, and Sapanca. Vertical axis is percent of sample by weight finer than the grain size shown on the horizontal axis.

tudes of sinking of buildings during smaller, less than magnitude 7 earthquakes, typically have been small. In general, the duration of strong shaking is proportional to earthquake magnitude. These observations suggest that the magnitude of sinking is dependent not only on the weight of the building but on the duration of strong shaking, which both keeps the liquefied soil in a fluid state and potentially liquefies a greater thickness of soil.

A very important and instructive set of measurements of liquefaction consequences was made at a site being developed for the Carrefour Shopping Center complex near İzmit. This project is one of those where ground improvement is being used, and is included in the summary of improved ground behavior in Section 3.6, and described in greater detail by Mitchell and Martin (2000). Soils in the Lot C area of this site were under improvement in anticipation of future development. The area was under a surcharge of 3.3 m of fill, and wick drains had been installed to a depth of 20 meters to accelerate the drainage and consolidation of compressible clay layers at depths of 2.5 to 6.0 m and below a depth of 8 to 10 m. A layer of liquefiable loose to medium dense sand, classified as (SP-SM) lies between the two clay layers. Settlement columns were installed and monitored frequently to determine settlements at several depths in the soil profile.

The Lot C area was found inundated with water the morning following the earthquake, as may be seen in Figure 3-9. Field inspection supported the conclusion that the surface water was discharged from the wick drains as a result of the seismically induced pore pressure generation leading to liquefaction of the sand layer. By comparing settlement readings obtained immediately before and following the earthquake, the seismically in-



Mitchell and Martin, 2000

Figure 3-9 Lot C area of Carrefour site showing ground surface inundated with water following the morning of the earthquake. Water is attributed to pore pressure buildup and subsequent drainage of the underlying loose sand layer through wick drains that were in place at the time of the earthquake.

duced settlement of the sand layer could be determined. The data indicated a liquefaction generated settlement of about 100 mm occurred in the sand, which corresponds to a volumetric strain of about 5 percent, as the sand layer is 2 m thick at the instrumented location. An additional 10 mm settlement, or 0.5 percent volumetric strain, developed in the sand during the magnitude 5.8 aftershock that occurred a few weeks later.

Additional illustration and discussion of liquefaction in the Marmara earthquake are given by Bardet, et al. (2000). Further testing and analyses of the observations and conditions at specific sites may provide improved understanding and insights into additional aspects of the practical manifestations of liquefaction during earthquakes.

3.4 Landslides and Subsidence

Extensional tectonic deformations and a "stepover" mechanism wherein faulting jumps between adjacent strike-slip segments are hypothesized by Bardet, et al. (2000) to have been responsible for much subsidence and lateral spreading that developed along the Marmara sea shoreline and along the south shore of Lake Sapanca. Subsidence of more than 2 meters accompanied the fault displacements adjacent to the Ford-Otosan Plant that was under construction just to the east of Gölcük (Figures 2-7 and 3-10). The fault-bounded tectonic subsidence caused a 4-km-long section of the coast near Gölcük to submerge about 2 to 3 m, with considerable flooding of buildings and loss of life by drowning. Landslides may also have contributed to the submergence of shoreline in some areas; however, it is difficult to distinguish local underwater ground failures from tectonic movements.

Mitchell and Martin, 2000

Figure 3-10 Vertical displacement of approximately 2.5 meters due to fault movements adjacent to the Ford-Otosan Plant east of Gölcük

Apart from small rock slides along road cuts and on steep slopes, there were relatively few inland landslides. This can be attributed to the general competence of the slope materials, which undoubtedly was enhanced by the dry conditions of late summer. Bardet, et al. (2000) report the reactivation of a large, deep-seated landslide in Esme, a small town on the north side of Sapanca Lake. They also describe ground movements and landsliding along rural routes between Akyazı and Gölyaka.

3.5 Behavior of Building Foundations

As noted in the preceding sections, fault displacements, subsidence, liquefaction, and lateral spreading were widespread. The movements and loss of foundation support, along with the seismic shaking, were responsible for the settlement, tilting, and collapse of many buildings throughout the earthquake-affected area. No area was more adversely affected by soil liquefaction and ground softening than the city of Adapazarı, so this region has been studied in the greatest detail following the earthquake (Bray and Stewart, 2000).

Most of Adapazarı is located in a sedimentary basin containing Sakarya River floodplain deposits and Holocene and Pleistocene sediments overlying older lakebed sediments that extend to bedrock at depths of 75 to 100 meters in the central part of the city. The soil profile contains interbedded gravels, sands, silts and clays, reflecting the complex history of sedimentation and fluvial action in the basin. Groundwater is shallow, at 1 to 2 meters depth. Gradation test results reported by Bray and Stewart (2000) indicate that sediment boil material brought to the ground surface after liquefaction was non-plastic silty sand with 5 to 40 percent fines.

Most of the structures are 1 to 2 story timber/brick buildings and 3 to 5 story concrete frame buildings. Most are founded on shallow (about 1 meter) mats, owing to the high groundwater level. Buildings in Adapazarı experienced substantial damage in past earthquakes. In the August 17 earthquake, the peak horizontal acceleration, velocity, and displacement were 0.41 g, 81 cm/s, and 220 cm, measured at the Sakarya Station. The shaking was probably greater in the city center. Some 5,078 buildings, or 27 percent of the building stock, were either severely damaged or destroyed.

Bray and Stewart (2000) report and illustrate the results of extensive studies of structural damage in relation to soil conditions and types of shallow foundation deformation and failure. Among the significant findings are:

1. Structural damage was significantly greater among structures founded in the Holocene basin alluvium than among structures founded on bedrock to the west and south.
2. The damage to a structure, as indicated by a "structural damage index," reflecting the extent of cracking and collapse, was compared to a "ground failure index," based on the observed ground movements and ground failure. They mapped 719 structures (about 3.9 percent of the building stock) along three east-west and one north-south lines through the city. The results showed some increase in the severity of structural damage with the severity of ground failure.

3. Shallow foundation movements were associated with three types of soil deformation, in the following decreasing order of frequency:
   - Settlement due to volume change. Settlements of up to about 50 cm were observed, with no evidence of soil bearing failure. Fig. 3-11 is an example of this type of behavior.
   - Bearing failure. Heave of the ground surface was observed in areas around the building or of interior floor slabs. Fig. 3-12 is an example of this type of failure.
   - Lateral movement. This was essentially a rigid body type displacement. The largest observed movement in Bray and Stewart's study, shown in Fig. 3-13, was 44 cm settlement, 50-55 cm laterally to the west (away from the sidewalk) and 100 cm laterally to the south (away from the photographer).

3.6 Performance of Improved Ground and Earth Structures

Six sites where ground improvement had been completed or was underway at the time of the earthquake were investigated. Locations of these sites are shown in Fig. 3-14. Most are industrial sites along İzmit Bay at distances ranging from 0 to 35 km from the earthquake epicenter. At one location, the site of the Arifiye Bridge overcrossing on the Trans European Motorway (TEM) (Site 5 in Fig. 3-14), reinforced earth bridge abutments had been used. With the exception of Derince Port, geotechnical data for each site were available. Descriptions of the soil conditions and ground improvement, and observations and analyses of site behavior during and after the earthquake are given by Mitchell and Martin (2000). A summary of the main findings is given in Table 3-1.

Bray and Stewart, 2000

Figure 3-11 Example of building settlement in Adapazarı due to volume change of liquefied soil. Near vertical settlement of 48 cm was measured at the corner of the building.

Bray and Stewart, 2000

Figure 3-12 Example of settlement in Adapazarı as a result of bearing failure of the foundation soil as evidenced by ground heaving adjacent to the buildings

Bray and Stewart, 2000

Figure 3-13 Building that experienced about 100 cm of lateral displacement

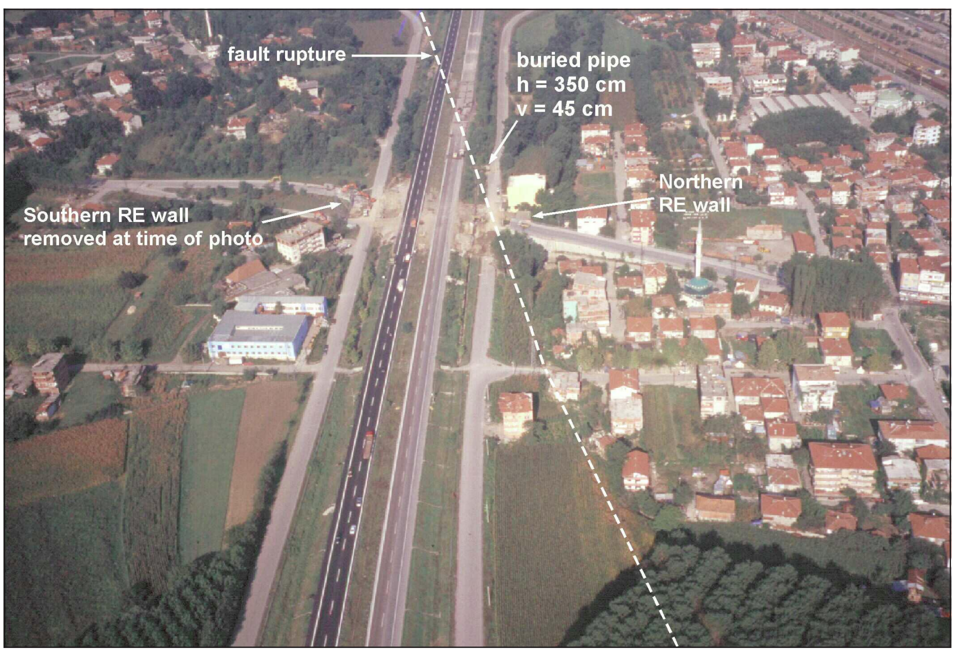
Mitchell and Martin, 2000

Figure 3-14 Ground improvement sites in the region affected by the Marmara earthquake

Methods of ground improvement that had been used for the different projects included preloading, wick drains, jet grouting, stone columns, compacted fills and earth reinforcement. Overall, the ground treatment and soil reinforcement were generally effective in mitigating earthquake-induced damage, especially liquefaction related ground movements. The fault rupture crossed the site of the Arifiye bridge (see Fig. 3-15) producing large displacements, of the order of 3.5 m laterally and 0.45 m vertically, and causing collapse of the four simple spans crossing the TEM. In spite of these large movements, the distorted reinforced earth abutments retained their integrity and did not fail, as may be seen in Fig. 3-16.

Several of the improved ground sites are being analyzed in greater detail, and more definitive results and conclusions are anticipated.

Five large embankment dams (higher than 30 m) are located within 25 km of the fault surface rupture (see Fig. 3-1). Many of these dams are operated for power generation and domestic and irrigation water supplies. As it was late summer at the time of the earthquake, the reservoirs were at low operational water levels. The General Directorate of State Hydraulic Work inspected most of the dams within days after the earthquake, and detailed inspections were completed within two weeks. Either no damage could be observed or there was very limited cracking. In no case was there damage that could cause a public safety risk. Additional discussion of the dams and their response to the earthquake has been prepared by K. O. Çetin and is included in Chapter 7 of the *Earthquake Spectra* special issue (see Mitchell and Martin, 2000).



Mitchell and Martin, 2000

Figure 3-15 Aerial photograph showing surface fault rupture transecting the Arifye Bridge site. The fault displacement caused collapse of the bridge and large deformations of the reinforced earth abutments.

Mitchell and Martin, 2000

Figure 3-16 Reinforced earth wing walls and bridge abutment for the Arifye Bridge overpass. The reinforced earth structure retained its integrity in spite of the large deformations.

3.7 Waterfront Structures

Extensive damage occurred to many of the piers and ports located along İzmit Bay. Geotechnical conditions, waterfront structure designs, construction details, and local ground shaking all contributed to the extent of damage. Settlement of quay wall backfills and lateral spreading resulted in distortion of crane rails, crane derailments, and loss of serviceability. Some pile-supported piers collapsed or were seriously distorted.

Illustrations and descriptions of several pier and port facilities and their behavior in the earthquake are given in Section 6.

3.8 Geotechnical Effects on Transportation Systems

Impacts of the Marmara earthquake on transportation systems in northwestern Turkey are described in some detail by Roblee, et al. (2000) and in Chapter 5 of this report. A few geotechnical observations are relevant, as what the ground did had a direct influence on the performance of transportation structures.

Most of the damaged bridges were founded on geologically young deposits. These materials are often prone to liquefaction and also amplify bedrock motions having intensities of those experienced in the Marmara earthquake. The only total bridge collapse was the four span TEM crossing at Arifye, and this was a direct result of the large fault displacement that passed beneath the structure.

Roblee, et al. (2000) summarize damage to the TEM roadway and embankments from İzmit to about 10 km east of the Sakarya viaduct. Ground deformation, settlement, and

Table 3-1 Performance of Improved Ground Sites in the Marmara Earthquake

Site	Location	Long. - Lat.	Dist. to Energy Release (km)	Est. Peak Accel. (g)	Geologic Environment	Soil Improvement	Liq' ble Soils Present?	Field Observations	Comments
Ford Plant	4 km east of Gölcük	40 42 31 29 54 11	Fault rupture passed along western border of site.		Quatenary marine and alluvial sediments. Very soft clays and loose sands in the upper 5 meters with gravelly sand below.	Jet-grouted and stone columns used across site. Jet-grouted columns installed beneath footing locations. Grid of jet-grouted columns and stone columns provided blanket treatment beneath foundation slabs.	Yes, layers of loose sands present in upper 5 m.	About 2.5 m fairly uniform vertical subsidence of entire site, presumably related to the fault rupture. One building (Body Shop) severely damaged due to 1 m differential vertical movement of foundation, presumably due to nearby fault rupture. No damage at other buildings. Minor sand boils observed in open area where soils were unimproved. No liquefaction at areas where ground was treated. Lateral spreading in the region, but not at the site. Soil treatment appeared to be effective in mitigating earthquake-induced damage.	Data available from original soil investigation report for the site.
Ipekkağit Tissue Factory	Yalova	40 41 06.7 29 33 08.3	3	0.3		Structures at site founded on shallow footings and mats. Jet grouting used under several new buildings and two large water tanks recently built at the factory. Area was treated by jet grouting; prior to jet grouting the soft soil was removed and a 3 m-thick compacted fill was constructed. Older structures at site founded on unimproved soils.	Yes, layers of loose sands at site and surrounding waterfront area.	Minor structural damage occurred in one older building on unimproved ground, as heavy concrete facing elements fell from the exterior. No structural damage occurred at any other location. No ground damage or signs of liquefaction were found at the main plant site or along the waterfront or neighboring sites, all of which contained liquefiable soils. No comparison could be made between the behavior of treated and untreated ground.	Geotechnical data were available from foundation investigations for the addition of recently-added structures.
Borçelik	Gemlik		35	0.1	Quaternary marine deposit with loose sands and marine clays. Bedrock depth is highly variable, ranging from outcropping to deep. Faultline of the southern branch of the North Anatolian Fault passes through site.	Stone columns used across entire site for liquefaction mitigation and foundation support. Pile foundations used beneath some structures and heavy machine foundations.	Yes, deposit of loose marine sands present across much of site.	No structural or ground damage observed at the site or in the general area. Surrounding areas with untreated liquefiable soils also suffered no damage. No distinction in performance between treated and untreated ground could be made.	Geotechnical data available from original site investigation report.

Table 3-1 Performance of Improved Ground Sites in the Marmara Earthquake (cont'd)

Site	Location	Long. - Lat.	Dist. to Energy Release (km)	Est. Peak Accel. (g)	Geologic Environment	Soil Improvement	Liq' ble Soils Present?	Field Observations	Comments
RE Walls for Arifiye Bridge Approach	near Arifiye	40 42 36.1 30 22 55.7	Fault rupture passes between the two reinforced earth walls.	0.3		Approach fills for the Arifiye overpass built using Reinforced Earth (RE). RE walls rested on natural ground, and abutments were founded on piles.	Possibly, in the creek bed underlying the culvert.	Bridge collapsed due to lateral movement of pier supports, along with inadequate beam seat widths. Distortion of the RE wall associated with foundation ground movement due to settlements associated with underlying 4.8 m culvert founded in creek bed. The maximum vertical displacement of the wall (at culvert location) was about 25 cm. Lateral ground movements near the wall were inferred from a buried pipe located near the wall that was displaced laterally 350 cm and 45 cm vertically. Some of the backfill spilled out through the openings between panels. Wall face was 5 cm out of vertical alignment due to the underlying movement. Surprisingly, relatively little damage occurred to the RE walls despite strong ground shaking and large ground displacement. Conventionally-constructed approach embankment about 250 m from RE walls suffered heavy damage with 1 m of fill settlement. RE walls demonstrated impressive performance relative to this embankment.	Surface manifestation of the fault rupture passing near the RE wall (between north abutment and the center pier). Data for the wall were obtained from the Highway Directorate. Wall height was 10 m; backfill was of good quality consisting of compacted sand and gravel; 40 mm x 5 mm ribbed steel strips used for reinforcement.
Derince Port	Derince	40 45 08.7 29 50 14.3	6	0.3	Quaternary marine sediments and artifical sand fills.	Sand fill in some areas of the port was roller-compacted. However, most of the storage area of the port is founded on non-engineered fill.	Yes, very loose fill soil at many areas of port.	Very large (> 1 m) liquefaction-related settlements and lateral movements in unimproved sand fill. Settlements in improved areas with roller-compacted fill were greatly reduced, in the range of 10 cm.	Geotechnical and soil improvement data have been requested from contractor. Data not available at the time of this report. The port consists of several sections built at different times using various construction methods. The seawalls are founded on piles; the areas behind the seawall were filled by several methods, including hydraulic fill, dewatering and excavating weak soil, and roller compaction of sand fill.

Mitchell and Martin, 2000

Table 3-1 Performance of Improved Ground Sites in the Marmara Earthquake (cont'd)

Site	Location	Long. - Lat.	Dist. to Energy Release (km)	Est. Peak Accel. (g)	Geologic Environment	Soil Improvement	Liq'ble Soils Present?	Field Observations	Comments
Carrefour Shopping Center	İzmit		5	0.20	Quaternary marine sediments, consisting of alternating sand and clay strata.	3 m high preloading embankment accompanied with wick drains implemented at some portions of the site. Jet-grouted columns installed beneath isolated footings and mats.	Yes, 2-4 m-thick loose sands across the site at a depth of about 6 m.	Site was under construction at the time of the earthquake. Steel frame for the supermarket building was in place, and the parking facility still was at foundation level. No structural or ground damage observed at the site, with the exception of earthquake-related settlements in an unimproved area of the site, Lot C. Lot C area was not improved with jet-grouting at the time of the earthquake. The area was under preload and the settlements were being monitored with settlement columns.	Data for the geotechnical investigation and soil improvement work were obtained for the site.

Mitchell and Martin, 2000

cracking were observed They provide a data base of minor damage to bridges at 63 locations throughout the area affected by the earthquake. Several instances of approach and roadway fill settlement and cracking were recorded. From the information so far available, it is not known in any case whether the cause was the fill itself, the underlying foundation material, or both.

3.9 Conclusion

Geotechnical effects of the Marmara earthquake were widespread. Significant damage to structures can be attributed to amplification of ground motions at soft soil sites, liquefaction, loss of bearing capacity, and lateral spreading. Ground surface subsidence along İzmit Bay and the south shore of Sapanca Lake were responsible for significant loss of life and property damage. Liquefiable sediments, a high water table and shallow foundations in the city of Adapazarı were responsible for many building foundation failures.

Pre- and post-earthquake measurements at the Carrefour shopping center site near İzmit provide perhaps the first directly documented case of liquefaction-induced settlement of a sand layer wherein the settlement distribution throughout the soil profile is accurately known. Sites where ground improvement and earth reinforcement had been used generally performed better than unimproved sites.

Overall, the geotechnical effects of this earthquake are consistent with those associated with other recent major events impacting areas with soft soils. Given the documentation of ground motions, extensive collection of data on ground and structure failures immediately following the earthquake, availability of data for several affected sites, and the opportunity to make additional studies, it is anticipated that development of better methods for quantification of important geotechnical responses may be possible.

3.10 References

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Much of the information in this section was obtained by members of the Geotechnical Reconnaissance Team supported by the National Science Foundation, Professors Jonathan D. Bray and Jean-Pierre Bardet, Principal Investigators. Dr. Richard S. Olsen reviewed ***Section 3.3, Soil Liquefaction****, and the grain-size analyses therein were made by Michael J. Bennett. Professor Mustafa Erdik, head of the Kandilli Observatory and Earthquake Research Institute, facilitated Tom Holzer's field investigations. Several individuals participated in the gathering of information and analyses reported in* ***Section 3.6, Performance of Improved Ground and Earth Structures****, including Professor James R. Martin and C. Guney Olgun of Virginia Tech and C. Emren Öge, Dr. H.T. Durgunoğlu, and T. Karadayılar of Zetaş Earth Technology Corporation, İstanbul.*

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Section 4
Structural Damage

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Beyond all other considerations, the true tragedy of the Marmara earthquake is that over 17,000 people were killed by the collapse of their homes. The primary function of a building is to shelter its occupants from a potentially harmful environment, whether they be threats due to predators, frequently occurring climate-related inconveniences and dangers, or rare but potentially devastating natural hazards. The collapse of thousands of buildings during an earthquake is, above all, a societal failure to recognize that latter important role of the built environment, a failure that can be attributed to one or more breakdowns in the chain of events needed to provide any community with a satisfactory level of earthquake resilience. That sequence of events requires, among many important steps, acknowledgment of the earthquake risk and the need for earthquake preparedness, implementation and enforcement of a comprehensive earthquake-resistant code for the design and construction of new buildings, identification of the hazards posed by buildings designed and constructed prior to the enactment of effective seismic codes providing an adequate level of protection, and formulation of a fiscally responsible seismic retrofit policy that will be compatible with societal expectations often only best expressed following a major earthquake.

Unfortunately, many of those important steps were not taken in Turkey prior to the August 17, 1999 Marmara earthquake. The latest 1998 Turkish building code, and its earlier 1975 edition to some extent, embody much of the latest knowledge on how to design effective earthquake-resistant buildings. Unfortunately, most existing structures were not built in compliance with these codes, and one may speculate that the extent of structural damage and number of casualties would have been greatly reduced had enforcement been more effective. However, this obviously would not have affected the thousands of buildings constructed prior to the enactment of effective seismic-design regulations, which would have remained seismically vulnerable.

Nonetheless, in spite of the above, some important lessons for North American design practice can be learned from the damage observed during this earthquake.

4.1 Past Earthquake History and Damage

Given Turkey's past seismic history, the extensive damage suffered by reinforced concrete buildings during the Marmara earthquake is neither surprising, nor unexpected. Similar types of damage were observed to a lesser extent in many prior earthquakes throughout Turkey. For example, 30,000 died in Erzincan during the 1939 Richter Magnitude 8 earthquake, further east on the same Anatolian fault responsible for the Marmara earthquake. Following that earthquake, which totally devastated the city, Erzincan was reconstructed a short distance away from the abandoned ruins, further along the fault. Although most of the buildings that collapsed during the 1939 earthquake were of unreinforced masonry, in 1992, a Richter Magnitude 6.8 earthquake struck Erzincan again, with between 500 (official) and 5,000 (non-official) people killed by the collapse of numerous reinforced concrete buildings of similar construction as those damaged by the 1999 Marmara earthquake (Gülkan 1992, Bruneau and Saatçioğlu 1993, EERI 1993, among many). However, because these and many other earthquakes were in more remote, less populated regions of Turkey, the message from earlier reconnaissance visits apparently did not resonate to the same degree.

4.2 Building Characteristics and Building Codes

The predominant structural system used for buildings in urbanized Turkey consists of reinforced concrete frames with unreinforced masonry infills. This structural form is used for all building heights and occupancy, from single-story commercial to multistory residential and office buildings. Frame-shear wall interactive systems are also used in new buildings. Industrial buildings are either reinforced concrete (cast-in-place or pre-cast) or steel frame structures. A typical reinforced concrete frame building in Turkey consists of a regular, symmetric floor plan, with square or rectangular columns and connecting beams. The exterior enclosure as well as interior partitioning is of non-bearing unreinforced hollow clay tile masonry infill walls. These walls contributed significantly to the lateral stiffness of buildings during the earthquake and, in many instances, controlled the lateral drift and resisted seismic forces elastically. This was especially true in low-rise buildings, older buildings where the ratio of wall to floor area was very high, and buildings located on firm soil. Once the masonry infills failed, the lateral strength and stiffness had to be provided by the frames alone, which then experienced significant inelasticity in the critical regions. At this stage, the ability of reinforced concrete columns, beams, and beam-column joints to sustain deformation demands depended on how well the seismic design and detailing requirements were followed, both in design and in construction.

The Turkish building codes and specifications have addressed seismic provisions since 1975. The 1975 provisions have been described extensively by Bruneau and Saatçioğlu (1993), and closely resemble the North American reinforced concrete building codes developed at the time. The provisions in effect at the time of the earthquake (the 1996 edition of the code, enacted in 1998) were available at the web site (*http://www.koeri.boun.edu.tr/earthqk/MP.htm)*. These latter provisions, a substantial improvement over the 1975 code, contain a base shear design equation very similar to that found in the 1988 Uniform Building Code (UBC), with the exception that seismic zone numbering is reversed in the Turkish code, the more severe seismic regions being labeled Zone 1 (instead of Zone 4 in the UBC). Allowing for differences attributable to the Limit States Design format of the Turkish code (compared to the Allowable Stress Design basis of the UBC), both codes have generally similar strength reduction factors, R. The Turkish code also requires that reinforced concrete shear walls be included in non-ductile structural systems.

4.3 Structural Damage

The damage to reinforced concrete buildings from this earthquake can be attributed to one or more of the following factors.

4.3.1 Foundation Failures

Foundation failures were observed for many buildings with large settlements, and in some cases, entire structures overturned. This effect was most pronounced in Adapazarı.

Photographs by M. Bruneau

Figure 4-1 Damage due to foundation failure

An example of severe settlement is shown in Figure 4-1. Taking the distance from balcony to balcony as a reference, one may observe the short-distance left between the second floor balcony and ground level. This provides a qualitative measure of the magnitude of settlement that occurred. Figure 4-2 also shows the extent of ground heave all around the building as the soil under the building is pushed outward during settlement.

Photograph by M. Bruneau

Figure 4-2 Ground heave was extensive all around this building

Examples of overturned buildings are shown in Figures 4-3 and 4-4. In the latter case, force vectors are superimposed on the building to illustrate its significant resistance to lateral loads (Figure 4-4b). As shown in that figure, the resultant weight of the structure, schematically located at the center of gravity of the above-ground portion of the toppled building, can be decomposed into its components perpendicular and parallel to the building's original vertical axis. Calculations indicate that the building, in its new

Photograph by M. Bruneau

Figure 4-3 Overturned building due to foundation failure

leaning "position," resists a statically-applied force approximately equal to 0.9 g perpendicular to its original vertical axis. This resistance is essentially provided by the numerous partition walls that increase lateral strength.

Foundation failures generally occurred as a result of soil liquefaction or bearing pressure failures. Note that geotechnical evaluations of site conditions are apparently often not conducted in Turkey, except for important structures.

4.3.2 Soft Stories

A large number of residential and commercial buildings were built with soft stories at the first-floor level (a soft-story is a floor that is structurally significantly more flexible and weaker than the others). First stories are often used as stores and commercial areas,

(a) (b)

Photographs by M. Bruneau

Figure 4-4 Overturned building due to foundation failure

especially in the central part of cities. These areas are enclosed with glass windows, and sometimes with a single masonry infill at the back. Heavy masonry infills start immediately above the commercial floor.

During the earthquake, the presence of a soft story increases deformation demands very significantly, and puts the entire burden of energy dissipation on the first-story structural elements, as opposed to distributing the burden along the entire height of the building. Many failures and collapses can be attributed to the increased deformation demands caused by soft stories, coupled with lack of deformability of poorly designed columns. Examples of soft-story failures can be seen in Figures 4-5 to 4-9. The timber building shown in Figure 4-5, having a wide obstruction-free ground floor used as a parking garage, has nearly collapsed and clearly illustrates how significant damage can concentrate in the soft-story of such buildings.

Photograph by M. Bruneau

Figure 4-5 Failure of soft first story in a timber building

Soft-story buildings having open street facade and solid back-walls tend to collapse toward the street as a result of the torsional plan eccentricity. Story sway is greater on the more flexible facade side, resulting in greater displacement and ductility demands on the more vulnerable columns on the facade side (Figure 4-8). This was particularly evident on a commercial street where nearly all the buildings collapsed towards the street (Figure 4-9).

Photograph by M. Bruneau

Figure 4-6 Failure of soft first story

Photograph by M. Bruneau

Figure 4-7 Failure of soft first story

Photograph by M. Bruneau

Figure 4-8 Failure of soft first story

Photograph by M. Bruneau

Figure 4-9 Buildings in this commercial area collapsed towards the street due to open facades (soft story) and walls on back side adding torsional eccentricity

Soft-story failures combined with ground failures were also observed along the waterfront in Gölcük. As shown in Figure 4-10, the water of the Marmara Sea submerged parts of the waterfront as a result of ground lateral spreading. Some buildings located along the waterfront (e.g., Figure 4-11) were thus impacted by both geotechnical and structural deficiencies.

Photograph by M. Bruneau

Figure 4-10 Marmara Sea submerged parts of the waterfront as a result of ground lateral spreading

Photograph by M. Bruneau

Figure 4-11 Some waterfront buildings were impacted by both geotechnical and structural failures

4.3.3 Strong Beams and Weak Columns

In most frame structures, the beams were strong and remained elastic, and the columns were weaker and suffered damage and failure in the form of compression crushing, plastic hinging, or shear failure. In many cases, relatively deep beams were used with flexible columns, contributing to a strong-beam weak-column behavior. This undesirable behavior is illustrated in Figure 4-12 and 4-13. In Figure 4-12, for example, the column depths are sizeable along the building alley sides, but they are narrow and thereby less able to resist by flexure the seismically-induced horizontal forces parallel to the front street, particularly when compared to the beam depth and strength at the story above. Not surprisingly, the building collapsed swaying in the direction of weakest column flexural strength.

(a)

(b) (c)

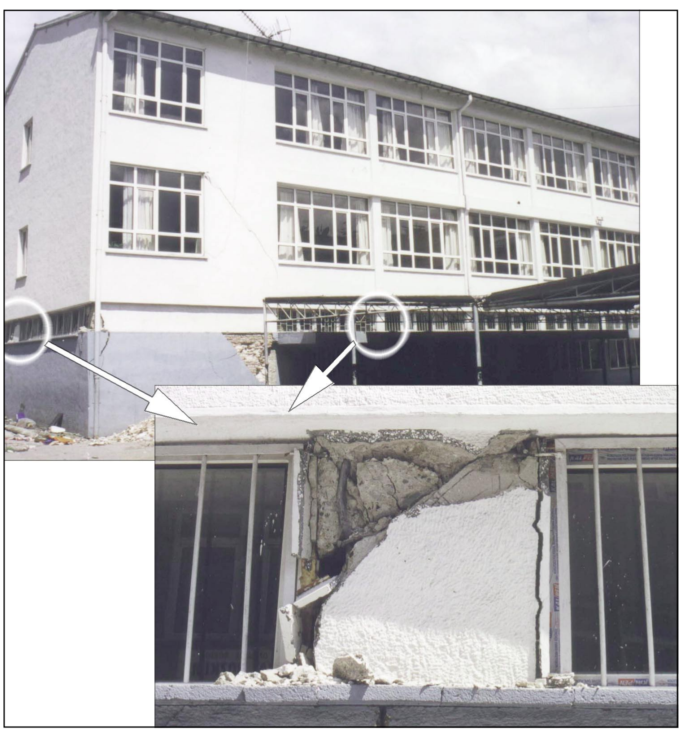
Photographs by M. Bruneau

Figure 4-12 Damage due to strong beams and weak columns

Photograph by M. Bruneau

Figure 4-13 Damage due to strong beams and weak columns

Whenever damage develops in columns without ductile details, strength and stiffness degradation will be further precipitated by the presence of axial forces. Excessive column damage not only means loss of lateral load resistance but also loss of gravity load resistance. Hence, the wisdom of the strong-column weak-beam alternative, promoted by buildings codes.



Photograph by M. Bruneau

Figure 4-14 Damage due to short (trapped) columns

Photograph by M. Bruneau

Figure 4-15 Damage due to flexural failure in non-ductile plastic hinges

Column damage varied as a function of column geometry and detailing. Examples in Figure 4-14 and 4-15 illustrate shear failure in short captive columns "trapped" between partial height infills, and flexural failure in non-ductile reinforced concrete plastic hinges, respectively.

4.3.4 Lack of Column Confinement and Poor Detailing Practice

Most of the structural damage observed in frame buildings was concentrated at column ends. Unfortunately, confinement reinforcement was virtually nonexistent in these members, making them unable to maintain the required ductility. A number of detailing deficiencies were observed in the damaged structures. This included lack of anchorage of beams and columns reinforcement, insufficient splice lengths, use of 90^o hooks, poor concrete quality, less than full height masonry infill partitions, and frequent combinations of many of the above. These errors were often compounded by geometric irregularities such as eccentric beam-to-column connections that induced severe torsion in short perpendicular stub beams (Figure 4-16).

The construction sequence adopted in Turkey's residential buildings is partly responsible for some significant failures due to lack of column reinforcement anchorage. Typically, residential buildings are constructed over a large number of years, one story at the time. Families do not wait for completion of the entire building prior to occupancy, and usually elect to live in the lower completed stories. Additional stories are added as the need arises. Figure 4-17 illustrates a one-story building during construction. Note the column vertical reinforcement extended above the roof line. Infill walls will be added to the first story and residents will move in, and this reinforcement will be left extending above the slab until the day (maybe years ahead) when construction will resume to add another story. As a result of this practice, and because smooth bars are frequently used, anchorage of the column

Photograph by M. Bruneau

Figure 4-16 Damage due to eccentric beam-to-column connections

Photograph by M. Bruneau

Figure 4-17 One-story building during construction with column bars extended above roof slab to accommodate possible construction of other stories in future years

Photograph by M. Bruneau

Figure 4-18 Example of bar pull-out due to deficient anchorage

bars in the slab is often deficient, and may have contributed to many collapses. Figure 4-18 shows an example of such bar pull-out in a building on the verge of collapse.

4.3.5 Miscellaneous

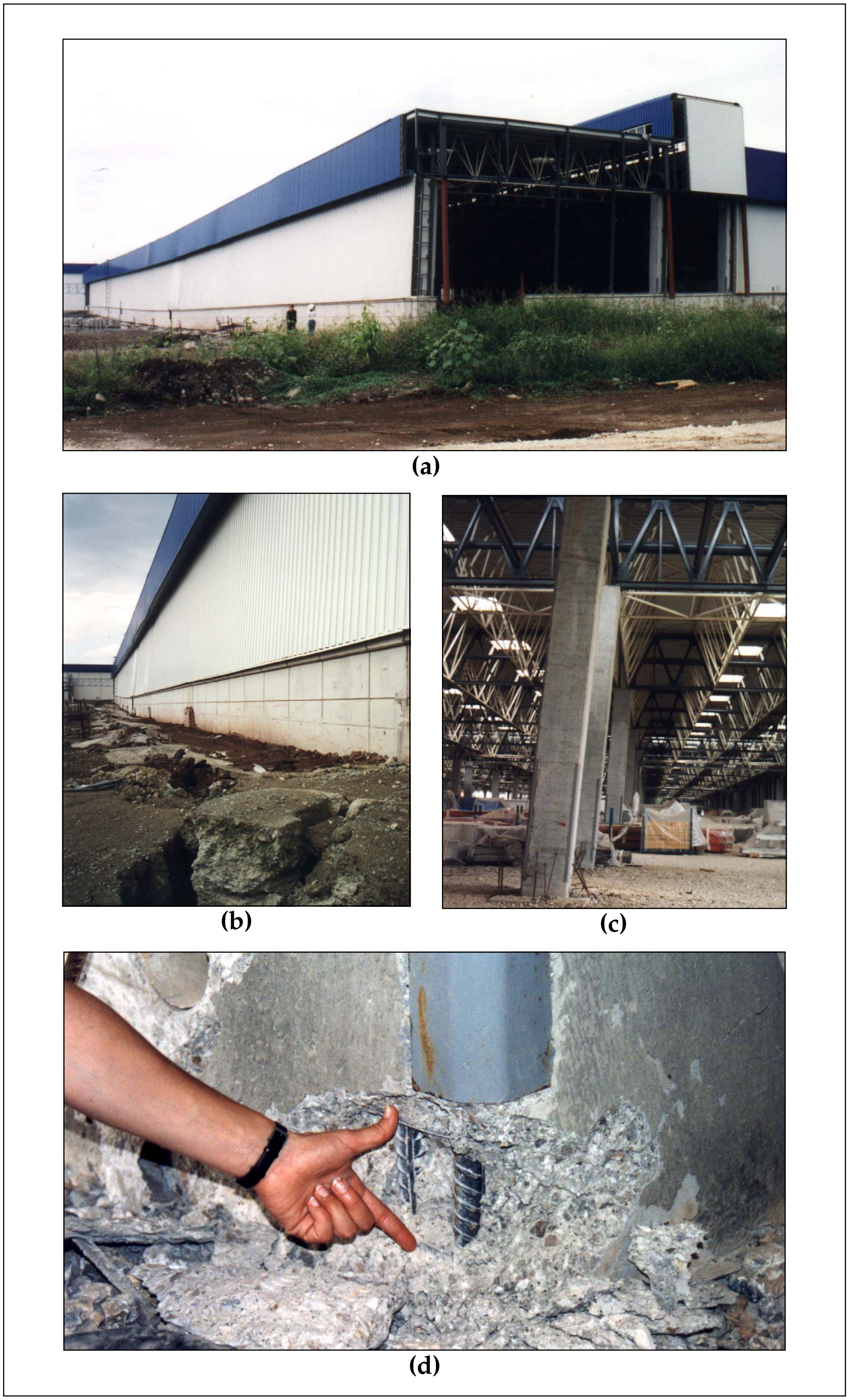
A number of buildings sitting directly on the fault were also destroyed by the relative movements of the fault (Figure 4-19). However, numerous buildings immediately adjacent to the fault survived without structural damage. For residential buildings, this is generally attributable to the additional strength unintentionally provided by the infills, as indicated previously. Industrial buildings similarly located, however, survived on the merit of their explicit design. For example, an industrial complex being constructed 100 feet from the fault had very well confined columns. Extensive ground settlements induced large structural permanent displacements to parts of the structure, but damage was generally limited to minor spalling as the spacing of the column's transverse reinforcement was adequate to ensure ductile behavior (Figure 4-20).

Photograph by C. Scawthorn

Figure 4-19 Collapsed five story building intersected by faulting. Arrows show where fault intersected the building, with attendant differential settlement.

4.4 Damage to Steel Structures

Steel, being by far the most expensive construction material in Turkey, has not been widely used in construction, so that typically only industrial structures rely on steel for their lateral load resistance. Some industrial equipment/structures were damaged by this earthquake, and a few collapsed. Typical causes for collapses include failure of anchor bolts at column bases and structural instability under overturning forces. Other evidence of damage include fracture of brace connections, buckling of braces, and local buckling in concrete filled steel hollow pipes used in wharves. Although the seismic performance of industrial facilities is reviewed separately in Section 6, some comments are appropriate here to illustrate that steel structures also require ductile detailing for superior seismic performance.

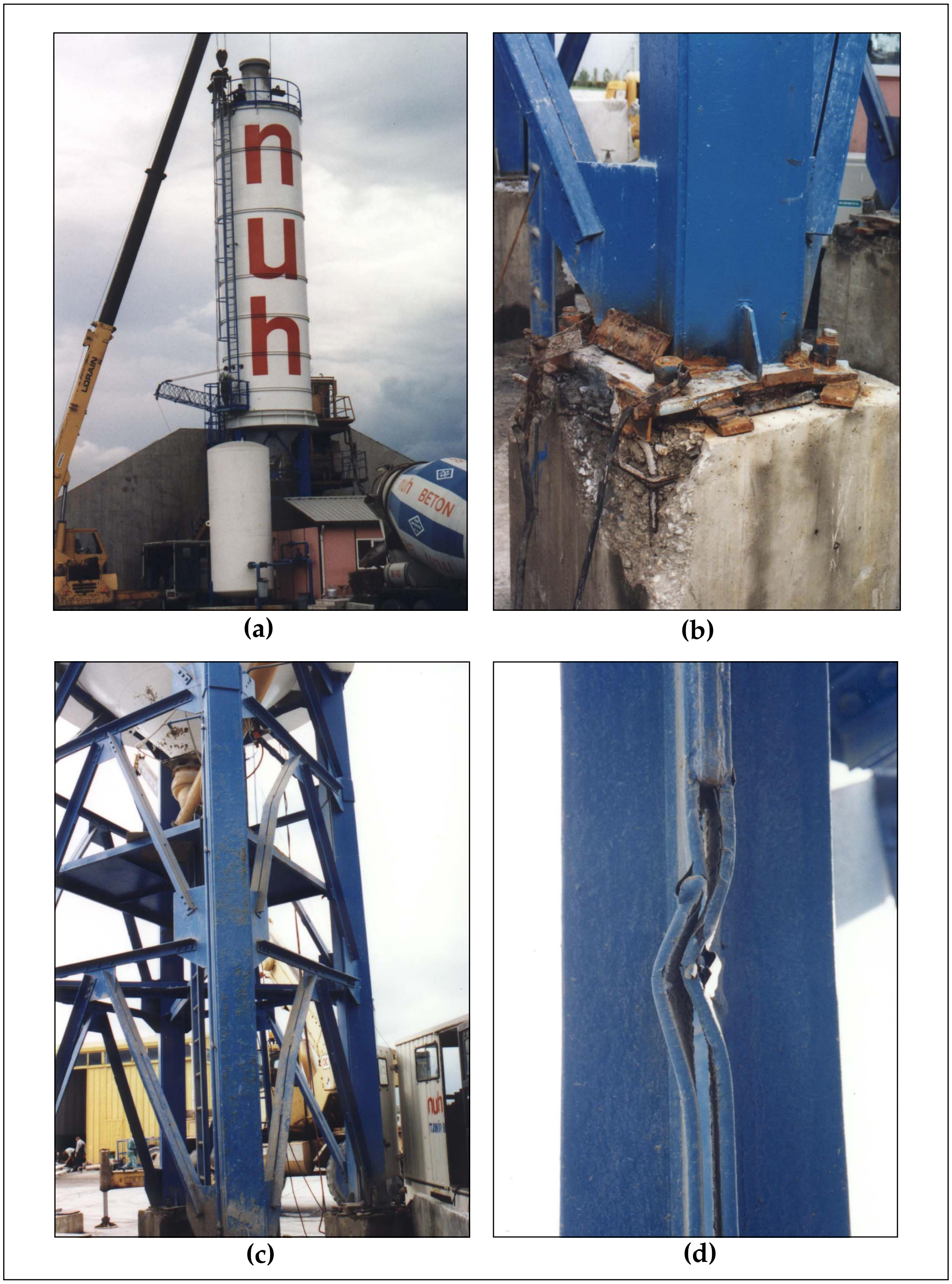


(a) (b) (c) (d)

Photographs by M. Bruneau

Figure 4-20 Industrial facility near the fault: (a-b) Global views of damage due to large ground settlements; (c-d) leaning column with limited damage at base as a result of ductile details (spacing of transverse reinforcement is indicated by thumb and index fingers)

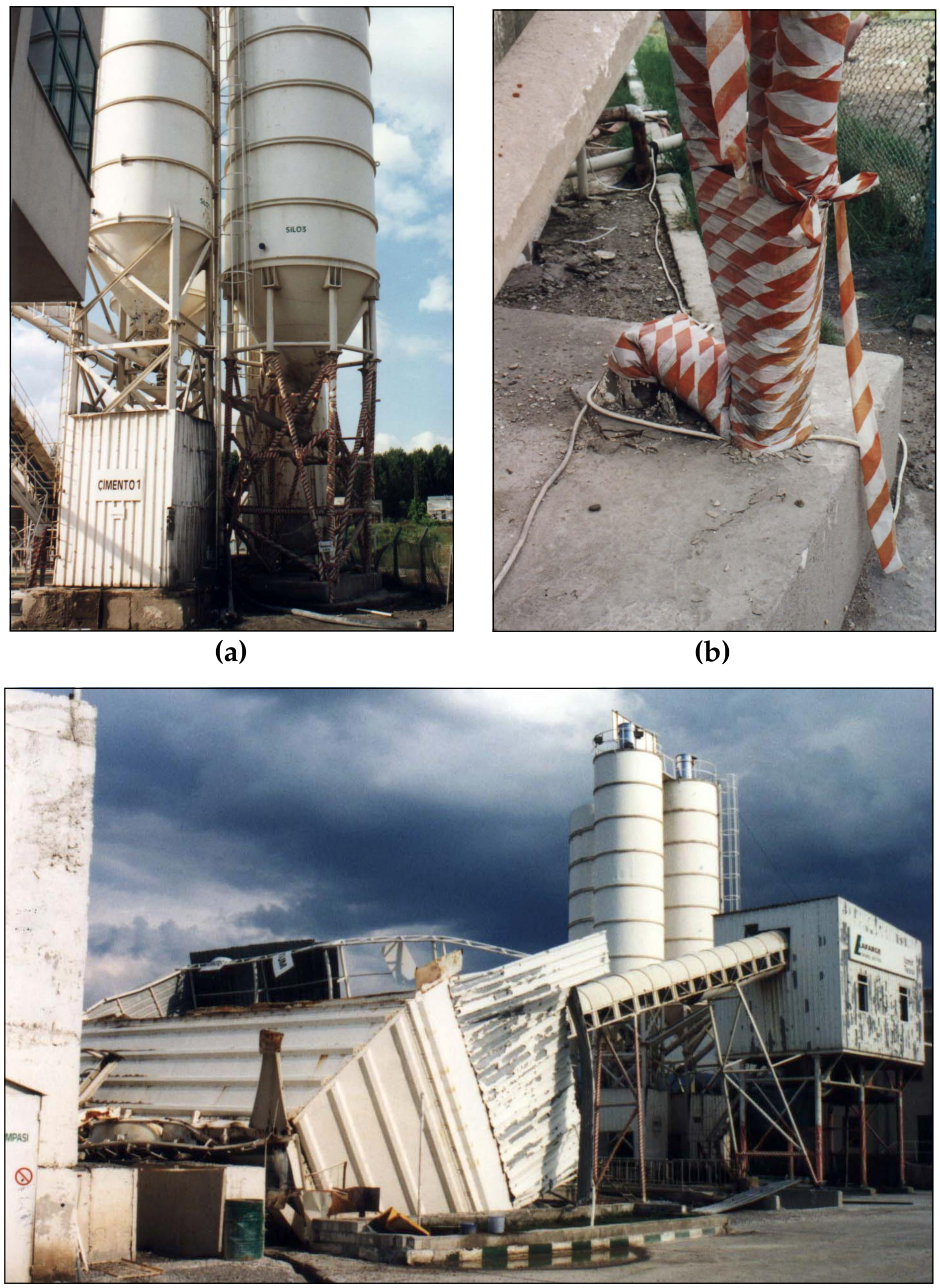
An interesting comparison between ductile and non-ductile steel details for nearly identical structures is shown in Figures 4-21 and 4-22. In Figure 4-21, the anchor bolts of the tank supports of the NUH concrete producing facility yielded in tension, and concrete of the 2.8 m deep pedestals spalled under the compression impact. Although this is not a ductile detail, the braces would be in partial compliance with the AISC seismic design provisions.



Photographs by M. Bruneau

Figure 4-21 Damage to steel structures at NUH concrete plant: (a) global view; (b) spalled pedestal; (c) global buckling of braces; (d) local buckling at brace mid-length

The 2,400 mm long braces are 2L80x80x8 back-to-back 10 mm from each other with batten plates at the 1/3 points, resulting in members having slenderness KL/r of 97 and b/t of 10; note that the AISC limits for ductile concentrically braced frames are 101 and 7.35 respectively for Grade 50 steel, 120 and 8.7 for Grade 36 steel. Connections were also stronger than A_gF_y of the members. Hence, these braces partially met (intentionally or not) the AISC 1997 requirements for ductile concentrically braced frames (DCBF). Inelastic action developed in



(a) (b) (c)

Photograph by M. Bruneau

Figure 4-22 Damage to steel structures at Lafarge concrete plant: (a) global view; (b) buckled leg; (c) overturned sand bin.

the braces, allowing ductile structural response through dissipation of hysteretic energy in a stable manner, with the exception of the deficient anchor bolts detail and somewhat premature local buckling, and the braced frame survived. Global brace buckling, and local buckling at the brace mid-length plastic hinge (Figure 4-21d) illustrate this ductile plastic response. Also typical of braced-frame with Chevron brace configurations, buckling of the diagonal in compression occurred prior to yielding in tension; this led to force redistribution within the structure and resulted in plastic hinging at mid-span of the horizontal member and slight permanent vertical deformations was visible at that point. This typical mechanism of Chevron braced frames is well known and explained in greater detail elsewhere (Bruneau et al., 1997).

By comparison, structures serving the same purpose at the Lafarge concrete plant suffered excessive damage. In this case, all members of the braced towers were hollow structural circular steel members, 150 mm in diameter and approximately 3 mm thick, for a resulting D/t slenderness ratio of 50, greatly in excess of the limit of 26 imposed for Grade 50 steel braces by the aforementioned AISC seismic provisions. However, braces did not buckle in this particular case. Because the lower brace was connected to the tower leg 16" above the base, the tower behaved as a rigid braced structure supported on a 16" tall moment frame, and the tower leg buckled at that location under the combined axial and flexural stresses resulting from this localized severe eccentricity (Figure 4-22). Steel locally fractured in some locations as a result of the large strains induced by this collapse. Note that the most severely damage tower was estimated to be 85-90% full (85 m^3 out of a 110 m^3 capacity) at the time of the earthquake, while the other towers were approximately 65% and 90% full. Incidentally, a gravel and sand bin (approximately 25% full) adjacent to these towers, overturned and collapsed. It was supported on six legs, each tied with a 24 mm diameter bolt to a concrete base. The legs buckled on one side, and the anchor bolts pulled out of the foundation or tore out of the leg as the bin collapsed (Figure 4-22c). Note that damage or collapse of elevated reservoirs was common throughout the affected area (Figure 4-23).

Photograph by M. Bruneau

Figure 4-23 Overturned reservoir

It is noteworthy that some new industrial facilities located in close proximity to the fault survived without structural damage. One such example is the Hyundai plant, designed in 1997 in dual compliance with the latest Turkish and Korean seismic provisions. This structure consists of long span moment resisting frames, with heavily stiffened deep haunches at the end of beams, welded to heavy steel square box-columns built from 1/2" to 1" plates, suggesting that design was accomplished in awareness of the numerous fractures observed following the Northridge problem, and the recommendation that haunches be used to ensure that plastic hinges be located away from the face of the columns. Nonstructural damage was sufficiently extensive to stop production, and the plant manager estimated it would take approximately one month before completion of repair and facility inspection by the Hyundai engineers. Although the author was not allowed to take photos during the visit to this plant, examples of damage included sliding of large 4'-5' diameter 1.6" thick ventilation pipes following rupture of the 12 bolts connection to the floor, and collapse of cable trays in complex configurations unbraced against twisting.

4.5 Other Construction Types, Nonstructural Damage and Seismic Retrofit

Damage to buildings of other construction materials was also observed throughout the affected area. For example, many industrial facilities of pre-cast concrete collapsed as a result of failures at the beam to column connections (Figure 4-24). Damage to unreinforced masonry buildings was also sometimes observed. For example, the building shown in Figure 4-25 suffered severe shear failure of its corner wall, as a result of bi-axial seismic action. The number of such buildings was, however, small in proportion to the overall building inventory.

Photograph by M. Bruneau

Figure 4-24 Damage to a precast concrete building

In the presence of such an overwhelming amount of structural damage and collapse, the seismic hazards ensuing from nonstructural damage tend to be forgotten. These should not be overlooked as they may result in extensive injuries and casualties. For the school build-

Photographs by M. Bruneau

Figure 4-25 Damage to an unreinforced masonry building

ing shown in Figure 4-26a, out-of-plane failure of an unreinforced masonry gable due to inadequate anchorage to its backing could have killed or maimed many children had this earthquake occurred at a time when the school yard was being used. Likewise, failure of the plaster wall finishes inside the corridors of the same school (Figure 4-26b) could also have hurt many small children.

(a) **(b)**

Photographs by M. Bruneau

Figure 4-26 Nonstructural damage to a school building

As noted earlier, at the time of the earthquake, seismic awareness in Turkey had not reached a level that made it possible to focus on the seismic hazard posed by the structures designed without due attention to earthquake-resistant design. This may explain why, to the author's knowledge, only one building in the severely affected region had apparently been seismically retrofitted prior to the earthquake. The Sakarya "province" government building, shown in Figure 4-27, was allegedly retrofitted by the addition of shear walls some years prior to the earthquake. This building was undamaged and fully operational following the earthquake, which is significant considering that it was literally surrounded by collapsed and severely damaged buildings, such as the one shown in Figure 4-28.

4.6 Damage from Aftershocks

It is noteworthy that a number of buildings, weakened by the major initial shock, collapsed during the numerous aftershocks. Because the population was generally left free to re-enter severely damaged buildings to retrieve their personal possessions, these additional collapses added unnecessary casualties and injuries. For example, during the author's earthquake reconnaissance visit, individuals were seen removing miscellaneous furniture (even wood doors) from the dangerously sloping second and third floor of buildings that had completely lost their first story and exterior partition walls.

Furthermore, additional extensive damage, losses and casualties occurred on November 12, 1999, when another earthquake of Richter Magnitude 7.2 struck approximately 115 km east of İzmit, Turkey. This second major earthquake is significant in that it clearly shows that major events may occur closely spaced in time and space to each other (similar to what occurred in the United States during the winter when three earthquakes, each of Richter Magnitude greater than 8, struck the New Madrid area from 1811-1812). The con-

Photograph by M. Bruneau

Figure 4-27 Undamaged Sakarya "province" government building retrofitted with shear walls prior to the earthquake

Photograph by M. Bruneau

Figure 4-28 Typical building adjacent to the retrofitted Sakarya "province" government building

cept of a return period is only true in an average sense, and it would be a major error for the government and population to complacently believe the fallacy that a long period of seismic quiescence inevitably follows a major earthquake. The same urgent need to promptly implement seismic hazard mitigation measures remains following an earthquake, and, if anything, authorities should capitalize on the sudden increase in earthquake awareness and receptiveness to sweeping measures to improve the overall level of earthquake preparedness.

The November earthquake also illustrates the misconception that structures that have survived a first earthquake have thus been "proof-tested" against future earthquakes. First, the same event never repeats itself twice, and a different ground motion "signature," with greater peak-ground-accelerations or velocities, is possible even for a second earthquake of similar magnitude. Second, subsequent earthquakes could be of greater magnitude, or simply have their epicenters located closer to a particular building. Hence, the need to assess the seismic adequacy of existing buildings should not be preempted as a result of prior satisfactory seismic performance, and buildings found to be seismically deficient should still be retrofitted if deemed necessary. However, past seismic performance can be most valuable to calibrate the engineering evaluations of seismic adequacy for those buildings that were instrumented prior to an earthquake and for which response data is available.

4.7 Lessons Learned and Conclusions

The most important lesson with implications for practice in North America is that seismic resistance is not inherent to buildings that are able to resist gravity loads. Explicit consideration of lateral loads, together with ductile detailing, are required to ensure seismic survival and control structural damage. While this may seem obvious to many, the situation still remains that earthquake resistant design is not mandatory in all parts of the United States exposed to a significant earthquake risk, particularly east of the Rockies. The complacent ignorance of the seismic threat that existed in Turkey and that resulted in the poor implementation of existing seismic codes, is not so different from that which impedes efforts to implement seismic codes on the basis of costs or other arguments in parts of the United States. In Turkey, which is a far less litigious society than the United States, the government now finds itself unable to use the Act-of-God argument to defend its past inaction, a position that is now recognized to be indefensible in the United States in light of the extensive knowledge that exists on how to perform earthquake-resistant design of buildings. In that perspective, many non-ductile structures likely to suffer severe damage in future earthquakes exist in Eastern North America, and the potential for enormous losses, in lives and properties, is real.

While there may exist in many buildings infill walls and other such nonstructural elements that may contribute to increase the threshold of damage, consideration of this contribution in terms of strength, ductility, and benefit to seismic response, is currently difficult and, at best, uncertain. The development of reliable models to quantify this impact should be pursued aggressively through future research.

Finally, the importance of a sound geotechnical foundation and the benefits of seismic retrofit have been clearly illustrated by this earthquake. The latter is particularly important to support efforts to formulate seismic retrofit policies to mitigate future earthquake-induced damage and ensure building performance compatible with societal expectations.

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thor is especially grateful for the extensive assistance provided by Nesrin Başöz of K2 Technologies throughout this reconnaissance visit. Special thanks are also extended to Polat Gülkan of the Middle East Technical University. Finally, the author would like to acknowledge the numerous individuals in Turkey who, throughout this turmoil, had the kindness and willingness to freely share information and provide access to damaged facilities.

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Section 5
Damage to the Transportation Infrastructure

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This section describes damage sustained by the transportation infrastructure (highway, railway and port facilities) as a result of the Marmara earthquake in Turkey on August 17, 1999. Figure 5-1 shows a general road map of the area. It will be noted that the prevailing traffic direction is generally east-west with secondary roads to outlying villages running in the north-south direction. Most of the damage was sustained along this east-west corridor. Perhaps this is not surprising as both the highway and railway systems run parallel to the fault rupture.

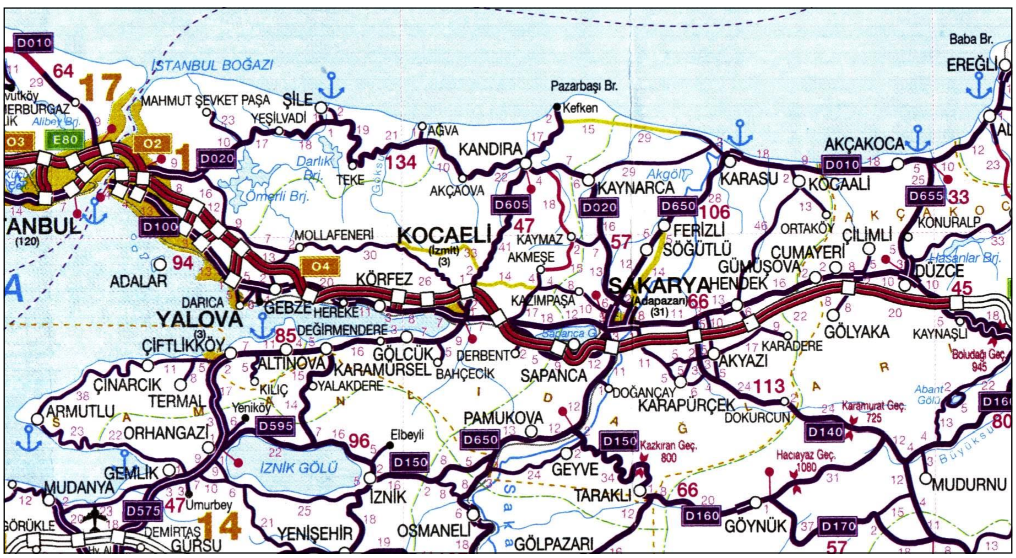


Figure 5-1 Site map. Note earthquake damage extended from the city of Yalova in the west to Düzce in the east. Much of the human fatalities were located in a band from Yalova to Gölcük. Many of the soft soil sites were located in the Sakarya area (Adapazarı).

5.1 Damage to Highway Bridges

This earthquake led to the collapse of only two bridges. It should be emphasized, however, that in both cases, the fault rupture passed directly beneath each bridge.

5.1.1 Collapse of the D650 E-80 Motorway Overpass

Figure 5-2 presents an aerial view of the D650 E-80 Trans European Motorway (TEM) overpass bridge that collapsed. This bridge structure consisted of bathtub style pre-cast concrete box beams with a cast in situ slab, each span being 26.0 m in length. The spans were simply supported for dead load, and as a result of the continuity provided by the deck,

http://www.koeri.boun.edu.tr/earthqk/transportation.htm

Figure 5-2 Collapse of the Motorway overpass that carries the D650 road over the E-80 Trans European Motorway (north abutment at top of photo)

essentially continuous for live load. The piers were skewed 20^{o}. During the earthquake, the fault rupture propagated between the third pier and the northern abutment, as seen in the top left-hand corner of Figure 5-2. As the seat widths for the north span were insufficient to sustain the large (> 1.5 m) right-lateral offset movements, it unseated and fell from its support. In so falling, the fourth span, via deck continuity, also dragged the other three spans off their seats. Direct support to the soffit of the girders (south end of each girder) was lost—the deck slab possessed insufficient strength to carry the tributary weight of the span, and as a result, failed in shear. Consequently, as shown in Figure 5-2, the south end of each span fell off its seat and came to rest on the ground. Unfortunately while falling off the seat, the third span (between piers 2 and 3) collapsed onto a passing bus killing ten people.

It is of interest to comment on the restoration of the highway as a result of the collapse of this bridge. Heavy earthmoving machinery was brought to this site soon after the earthquake occurred and the bridge was cleared away. This was undertaken with several hydraulic excavators, each using concrete breaker attachments. Initially, the central two spans were removed to enable the reopening of the E-80 Motorway. Within four days of the earthquake, practically all of the spans had been demolished and the debris removed. Because the E-80 Motorway is a limited access highway, vehicles that normally use this overpass were required to use a 3 km detour.

For this particular bridge, several measures could have been taken to avoid such a failure. Design improvements that might have been made in this structure would be to ensure full continuity is provided for dead loads as well as live loads. In this way, perhaps only one span would have collapsed with the fault passing directly beneath that span. As an alternative to providing continuity, significantly increased seat width or cable restrainers that have the ability to restrain at least 50% of the weight of a span could be provided. This would stop the span from falling.

5.1.2 Collapsed Local River Bridge Near Akyazı

Approximately 8 km east of the D650 E-80 Motorway overpass bridge was a bridge that collapsed into a river near the town of Akyazı (see Figure 5-3). Little is known about the owner or details of this structure. The bridge was a three-span steel girder with concrete slab deck. The piers consisted of a relatively lightweight steel frame located on both banks of the river. Evidently the piers had insufficient axial capacity to sustain the ground shaking and permanent ground displacement as a result of the fault rupture. Both piers failed by

Photograph by J. Mander

Figure 5-3 A local river crossing near the town of Akyazı

what appears to be axial compression failure of the steel columns in the pier bents. It should be noted that near this facility the critical ground motions were in the order of at least 0.4 g. Although only a minor road, the bridge provided the only access to two small villages. As a result of the bridge collapse, the people in those villages were isolated. It appears that failure of this bridge could have been prevented if the piers were of a more substantial nature and more capable of carrying the higher vertical loads. Nevertheless, it is not surprising that the bridge failed as the fault rupture passed through the northern abutment.

5.1.3 Damage to the E-80 Motorway Bridges over the Sakarya River

Figure 5-4 presents an elevation view of the twin highway bridges carrying the E-80 Motorway across the Sakarya River. These bridges are essentially identical and consist of ten 40.0 m spans. Each span is constructed from four pre-cast, prestressed (bathtub) girders with a reinforced concrete deck slab. The bathtub girders are seated on elastomoeric bearing pads with the deck slab continuous over every second support. In this way, the spans are designed to act as pairs with expansion joints located at every second pier (Figure 5-5). Each girder is seated on two bearing pads and between each bearing pad is a

Photograph by J. Mander

Figure 5-4 A view looking south showing the side elevation of the twin E-80 Motorway bridge over the Sakarya River

Photograph by J. Mander

Figure 5-5 A side elevation of one of the pier of the northbound E-80 Motorway bride over the Sakarya River. Note the concrete rubble located between the span ends and the diaphragm upstand.

shear key that is intended to inhibit transverse movement of the girders relative to the axis of the bridge. The bridge piers consist of rectangular sections that are quite stiff, as shown in Figures 5-5 and 5-7.

As a result of the earthquake, a moderate degree of damage was sustained by these bridges, particularly the northern-most structure that carries the westbound traffic. In several cases, the girders shifted off their seats by some 500 mm as shown in the abutment view of Figure 5-6. The cause of this movement is a result of failure of the shear keys. Site inspection showed that the dowel bars protruding above the pile cap had insufficient height, and movement from the spans loaded to failure in the cover concrete of the shear keys. It appears that the construction of the shear keys was not well controlled, since most of the shear keys in the eastbound bridge survived with little damage.

Figure 5-7 shows an underdeck view of the two bridges and their piers. On the eastbound bridge, the elastomeric bearing pads have started to "walk-out," but were still supporting the spans. However, for the westbound bridge, the spans shifted their seating onto the shear key, many of the bearing pads being nonfunctional.

It is apparent that much of the damage to these bridges could have been avoided by providing stronger shear keys. Perhaps, better still, much of the damage could have been entirely avoided if full continuity between the spans had been provided. Fortunately, the damage sustained by the eastbound bridge was insufficient to warrant closure. Immediately following the earthquake, the westbound traffic was rerouted over the eastbound bridge. The westbound bridge was considered to be sufficiently damaged to warrant closure to enable

Photograph by J. Mander

Figure 5-6 The east abutment of the eastbound E-80 Motorway bridge showing the 500 mm offset of the span with respect to the approach road

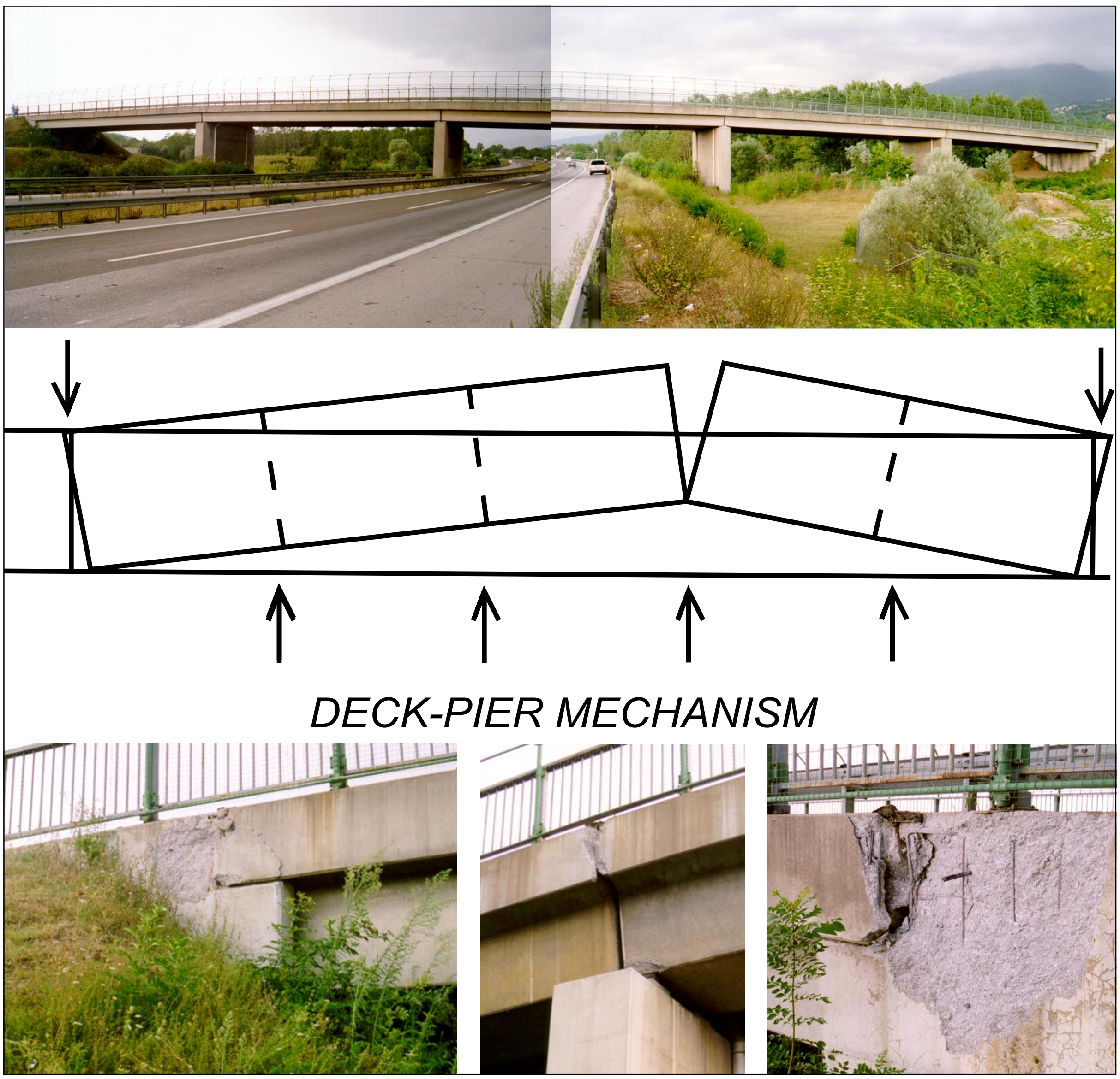
Photograph by J. Mander

Figure 5-7 A longitudinal view of the twin E-80 bridges crossing the Sakarya River. The left bridge is the eastbound structure that showed minimal effect on the bearing seats, whereas the westbound bridge (on the right) showed considerable damage to the shear keys and bearing seats. Note the dislodged bearing and the 500 mm right lateral offset of the girder directly above the right hand pier.

the spans to be reseated. However, due to the significant weight of these spans, this task could not be performed quickly.

5.1.4 Damage to the D310 Overpass that Crosses the E-80 Motorway

This bridge is typical of the overpasses that cross the E-80 Motorway. It consists of five spans, each span having pre-cast, prestressed concrete beams with a cast in situ deck slab. There are expansion joints at each abutment and at the second pier (when viewed from the south abutment). The bridge was located within 500 m of the fault rupture and oriented normal to the fault. It appears that fault-parallel ground shaking caused substantial move-



Photographs by J. Mander

Figure 5-8 The overpass carrying the D31 road across the E-80 Motorway. The upper photograph shows a side elevation of the bridge looking eastward. In the center, a plan view sketch depicts the deck-pier mechanism that formed at the joints that were located at the abutments and the third pier. The lower photograph shows spalled concrete damage located at the deck at these joint connections.

ment of the deck segments resulting in some minor damage to the outside faces of the prestressed concrete girders. It is evident that the ground shaking caused a deck-pier mechanism to occur as shown in Figure 5-8. In addition to this damage resulting from fault parallel shaking, there is some evidence of pier tilting due to foundational settlement of the above-mentioned second pier. It is not clear whether this pier tilting has resulted from fault-normal shaking or is an outcome of the deck pier mechanism. This feature requires further analysis.

5.1.5 Damage to Bridges on the D100 Highway

Some 2 km downstream, in a northerly direction from the above-mentioned twin bridges over the Sakarya River are another two bridges on the D100 highway. One of these bridges is quite old and carries the original two-lanes of this highway, while the other bridge, at the time of the earthquake, was under construction, with construction almost completed. Both of these bridges sustained a minor amount of damage. The older bridge is a reinforced concrete structure continuous over two spans, every second span being a drop-in span. Span supports alternate from fixed to free. Each of the free supports consists of a reinforced concrete bolster that sits on top of the pier that rocks under free thermal expansion. Inspection of this bridge revealed some damage at the support seats in the form of concrete crushing and spalling as shown in Figure 5-9.

Photograph by J. Mander

Figure 5-9 The two bridges crossing the Sakarya River on the D100 Highway. The left hand bridge at the time of the earthquake was a new prestressed concrete bridge still under construction. The right hand bridge is the original reinforced concrete, two-lane highway bridge. The damage can be noticed on the new bridge where the fascia girder is misaligned near the top left hand corner of the photograph. Damage to the old bridge can be seen at the junction of the pier cap to span connection in the mid right portion of the photograph.

Photograph by J. Mander

Figure 5-10 The new two-lane bridge for the D100 Highway over the Sakarya River looking east. Notice the 50 mm offset of the fascia girders. The pouring of the construction joints was incomplete at the time of the earthquake.

The new bridge, which is currently under construction, consists of closely-spaced prestressed concrete I-girders. These girders typically moved 50 mm on their bearing seats resulting in some misalignment of each of the spans. This is evident in Figure 5-10. However, as traffic was not interrupted, the damage to both of these bridges could be regarded as "slight."

5.2 Damage to Roads

When traveling east, the E-80 Motorway passes near the southern shores of Lake Sapanca. In this vicinity and some 30 km east, there was substantial damage to the roadway. Much of this was a result of the close proximity to the fault rupture. Indeed, in many instances the fault rupture traversed the road itself causing substantial damage to the pavement. There were numerous instances of damage to the road surface and a typical example is shown in Figure 5-11. This damage led to several vehicles careering off the road and also resulted in temporary closure of the Motorway. As shown in Figure 5-12, the damage was quickly repaired and the Motorway brought back into service soon after the earthquake. Within one week, most of the surface damage was repaired and the Motorway was operating at its usual 120 km/h speed limit.

Another major problem associated with the E-80 Motorway, particularly when it runs immediately adjacent to Lake Sapanca, was related to substantial settlements sustained by the embankments. Embankment settlements of 500 mm were commonplace. This resulted in two problems. First, the roadway was left in a substantially wavy nature, and secondly, there were serious bump-onto-the-bridge problems at both culverts and single-span bridges, as shown in Figure 5-13. Immediately following the earthquake and after the major highway debris had been cleared, asphalt was brought in and used to provide ramps onto and off the bridges at those locations where the bumps were very abrupt. Then within one week of the earthquake, major repairs were commenced. Where the bridges sat up high with respect to the surrounding roadway, the asphalt roadway was removed and the road was repaved and reprofiled to enable vehicles to travel at the regular full speed.

Photograph by J. Mander

Figure 5-11 Distress to the pavement due to the fault rupture on the E-80 Motorway

Photograph by J. Mander

Figure 5-12 A view of the E-80 Motorway taken from an overpass near Akyazı showing the restored roadway that had been severely damaged by the fault rupture

Photograph by J. Mander

Figure 5-13 One of the numerous bridges on the E-80 Motorway that is some 500 mm above the road surface. The severe shaking caused bearing capacity settlements of the road embankment leading to classic bump-onto-the-bridge problems.

It is difficult to speculate whether this damage was a result of a bearing capacity failure, or settlement due to liquefaction, or a combination of the two. Although the surrounding soils appeared to be quite damp over to the crossing proximity at the lake, it is considered that the cause of failure was mostly due to the former rather than the latter. It is considered that liquefaction was unlikely as there was little evidence of sand boils in this vicinity.

It is also of interest to mention the structural damage that led to partial closure of the Trans European Motorway. A toll plaza at one of the entrances of the Motorway collapsed, as shown in Figure 5-14, completely closing the entrance to the Motorway. This heavy reinforced concrete canopy structure was supported on small columns with inadequate detailing to sustain the large lateral sidesway. Following the earthquake, the collapsed structure

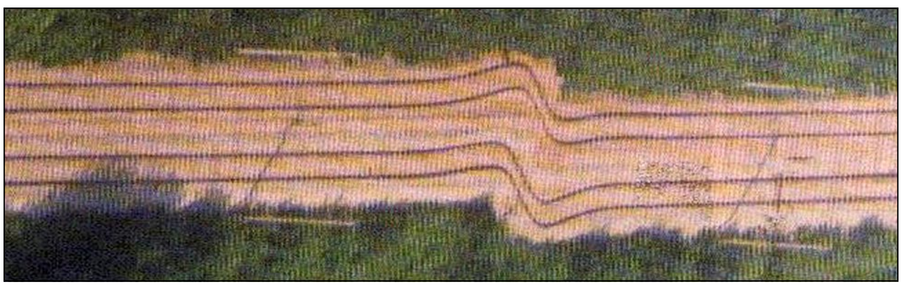
Photograph by Hamdi Aydin

Figure 5-14 Collapse of the toll plaza at an entrance to the E-80 Motorway

was removed. Early reopening of this portion of the highway was essential to permit emergency access of response and recovery teams. Because of the demand for the use of this motorway, the government decreed that the payment of tolls would not be necessary due to the state of emergency.

5.3 Damage to Railways

Like the E-80 Motorway, the main railway system is dual track and runs in a general east-west direction. In the Sapanca area, it runs adjacent to the E-80 Motorway. In this location, the fault rupture transverses both the highway and the railway with the damage shown by the aerial view in Figure 5-15. From this photograph, it is evident that the magnitude of the right lateral offset on the fault is about 1.5 m—this is roughly equal to the track gauge. Although the damage to the tracks is substantial as shown from the ground view in Figure 5-16, repairs were implemented rather quickly. However, in one nearby branch line near Adapazarı, an electric traction pole was brought down from the track requiring the restringing of the overhead traction wires. Such repairs to the electric



http://www.koeri.boun.edu.tr/earthqk/transportation.htm

Figure 5-15 An aerial view of the railway track buckling in the Sapanca area. Note there is a right lateral offset on the fault roughly equal to the track gauge of 1.5 m.

http://www.koeri.boun.edu.tr/earthqk/transportation.htm

Figure 5-16 A view of the fault passing through the railway embankment showing the substantial (2 m) right lateral offset

traction system are generally more problematic than reopening the track itself, and until the traction system is operational, the use of diesel locomotives is necessary. The railway system appeared to be fully operational within three days after the earthquake.

5.4 Damage to Port Facilities

The eastern end of the Marmara Sea is a major port terminus. To the north of İzmit bay there is a concentration of industrial facilities near Kocaeli (İzmit) port where cement, petrochemical plants and oil refineries abound. To the south of the bay at Gölcük, is the main Turkish naval facility. The main fault rupture zone passed through this naval port including the dock and wharf facilities, causing much damage to buildings and barracks as well. Figure 5-17 shows damage to the concrete quay wall due to the close proximity of the fault rupture. This quay wall, which was initially straight, has been both tilted and displaced approximately 1 m due to a combination of permanent ground displacement as well as shaking effects. The extent of the damage resulting from the fault rupture is more clearly seen in Figure 5-18. The wharf structure, which spanned between the land and the quay wall, collapsed in several places.

Photograph by J. Mander

Figure 5-17 The Naval Port at Gölcük looking east. Notice the bow of the quay wall resulting from proximity to the fault rupture.

It is worth emphasizing the important role that the military was expected to play as part of civil defense following a natural disaster. Due to the collapse of the buildings on the naval compound, as well as the failure of the wharf structures, many of the ships that were tied up (as seen in Figures 5-17 and 5-18) had a full complement of personnel aboard, who could not be gainfully employed on post-earthquake clean-up activities. Clearly such facilities are critical and essential to the response and recovery requirements of natural disasters.

Photograph by J. Mander

Figure 5-18 Failure of the wharf structure at the naval port at Gölcük

5.5 Conclusion

Although few completely new lessons were learned from this earthquake, several points can be emphasized:

- Engineered structures, by and large, performed very well. This included the transportation structures as well as engineered buildings. This is in stark contrast with non-engineered structures such as domestic housing, that performed quite badly and led to considerable loss of life and limb.
- In spite of the good performance of the transportation infrastructure, there is a need to classify and prioritize seismic retrofit needs for existing structural systems and facilities. Important structures should be held to a higher standard of performance. The traditional life-safety paradigm is insufficient for most public assets such as roads, highways, bridges and railways. There is a need to develop performance-based engineering standards that emphasize post-earthquake serviceability, damage avoidance (wherever possible) and rapid repairability if damage does indeed occur.
- The Marmara earthquake of August 17, 1999 demonstrated the importance of correctly characterizing soils and foundation problems. Structures and other facilities such as roads and highways on very soft soils did not perform particularly well. Moreover, non-engineered structures (housing and buildings) fared badly when located in soft-soil zones.
- This earthquake demonstrated the need for assessing the propensity for surface fault rupture. Inevitably, wherever the surface fault rupture passed, mayhem and destruction was left in its trail. Admittedly, it is generally difficult to ascertain the precise location of a fault rupture, but wherever possible, this should be identified by microzonation mapping.

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Section 6
Performance of Industrial Facilities

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University of California, Berkeley

The epicentral area includes about 40% of Turkey's heavy industry. There are several concentrated areas of industry surrounding the Marmara Sea and İzmit Bay, extending to Adapazarı. Substantial damage to industrial facilities was observed over a large geographic area. Many of these facilities face extended down time.

More than 25 companies from various industries in the İzmit and Adapazarı areas were surveyed in the days immediately following the earthquake. The performance of these industrial facilities is relevant to other areas of the world, since Turkey has many modern, engineered facilities, in many cases owned by multinational companies. The industrial facilities visited generally were constructed with much higher quality control than observed in the residential structures. This section summarizes observations relevant to the seismic performance of industrial facilities, both in terms of damage and operational impact.

6.1 Types of Industry

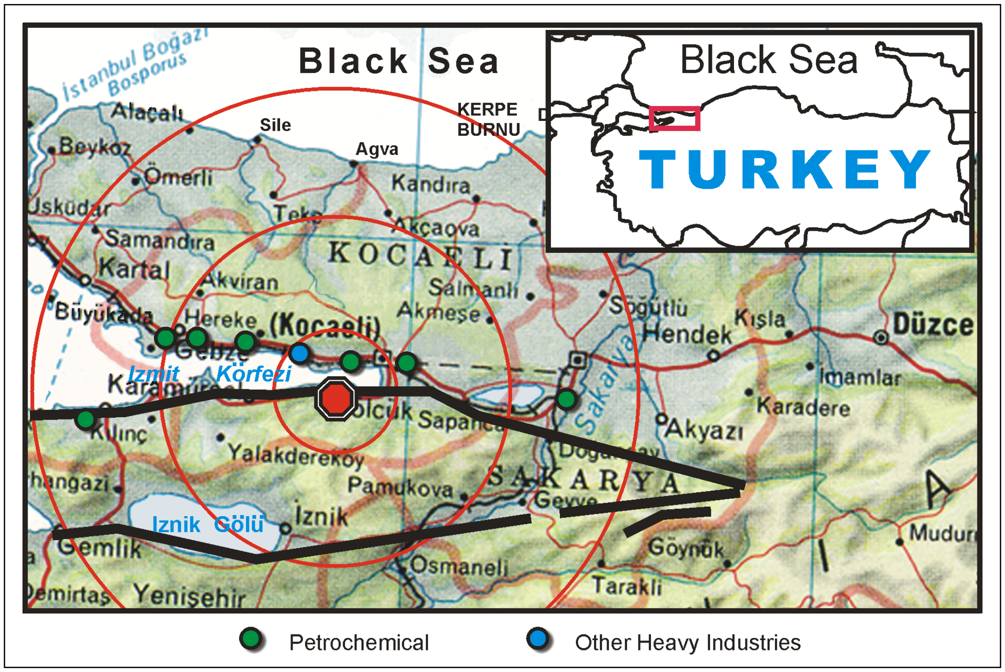
Figure 6-1 shows the locations of major industrial facilities relative to the epicenter. Facilities surveyed included the following industries:

- Petrochemical
- Automobile
- Tires
- Paper mills
- Pharmaceutical
- Cement
- Steel pipes
- Power plants
- Other manufacturing

6.1.1 Petrochemical Industry

The petrochemical industry performance is of special interest because of the damage observed and the location of these plants relative to the epicenter. There is a heavy concentration of petrochemical plants near Körfez, on the northern side of İzmit Bay, within about 10 km of the epicenter. Among the plants located there are the state-owned Tüpraş refinery and Petkim petrochemical plants, the İGSAŞ fertilizer plant, and approximately 20 Liquefied Petroleum Gas (LPG) terminals and storage facilities.

The Tüpraş refinery is the largest refinery in Turkey, producing over 220,000 barrels per day. This is about one-third of Turkey's total production, almost all for domestic consumption. The Petkim petrochemical plant is an important supplier of raw materials to the region's extensive tire industry. Damage to these plants will have long lasting impacts on industries throughout the region.



Adapted from *http://www.koeri.boun.edu.tr/earthqk/earthquake.htm*

Figure 6-1 Map showing location of industrial facilities relevant to epicenter

Performance of these facilities is also important because this is the first time in many years that large refineries and chemical plants have been so close to the epicenter of a major earthquake, and may be the largest concentration of petrochemical facilities to ever experience such a shake.

Most of these plants experienced peak accelerations on the order of 0.32 g, based on an instrument located at the Petkim petrochemical plant. The response spectra for that instrument indicate a large long-period response, with a duration of strong shaking of about 45 seconds.

Damage observed in these facilities, described in more detail in the following sections, includes complete collapses of stacks and cooling towers, structural damage to buildings, tank collapses, major fires, oil spills, and gas leaks.

6.1.2 Automobile Industry

The automobile and tire manufacturing industries are also especially prominent throughout this area. A wide variation of multinational industrial companies such as Pirelli Tires, Goodyear, and Hyundai are located within a few miles of each other in the Köseköy region, just to the east of İzmit (Figure 6-2). The Sabancı company has joint venture facilities with several companies in the area. The partnership with Bridgestone of Japan that manufactures rubber goods and tires is called BriSA. In the same complex are several other companies that supply this industry, including DuSA (Du Pont and Sabancı), BekSA (Bekaert, a Belgium company, and Sabancı), KordSA (steel belts for tires), and EnerjiSA (power for all of these plants). Sabancı also owns 50% of the Toyota car manufacturing plant in Adapazarı. Ford is building a new plant, which was damaged by fault movement, in Gölcük. Honda, Isuzu, and Renault also have plants in the area around the Marmara Sea.

Photograph by G. Johnson

Figure 6-2 Signs indicate a number of automotive and tire related facilities in the immediate area of Köseköy, just east of İzmit

6.2 Summary of Damage and Business Interruption

Table 6-1 summarizes the performance of major industrial facilities surveyed after the earthquake. Estimated downtime is generally based on opinions of the facility management immediately following the earthquake.

As shown in the table, one of the notable lessons from this earthquake is the extensive business interruption at many facilities. Of the more than 25 facilities surveyed within 10 days of the earthquake, only one was operating. On the order of a half dozen were expecting to be out of operation anywhere from two to six months or more. The reasons for large downtime estimates range from severe structural damage to inability to use undamaged critical equipment because of its location in a damaged building.

Many of the industrial facilities affected by this earthquake are important because they impact the local, regional, and in some cases, global economies, as major employers, major producers, and major suppliers. In the months following the earthquake, many facilities may discover that production is limited because of difficulties with "just-in-time" delivery, or due to a lack of geographical dispersion of suppliers.

Further discussion on specific instances of damage at these facilities is presented in the following sections.

6.3 Tüpraş Refinery Damage

The most widely publicized and spectacular damage to any industrial facility occurred at the large petroleum refinery near Körfez, owned by the state-owned oil company, Tüpraş.

Table 6-1 Summary of Industrial Facility Performance

Name	Facility Type	Year Built	No. Employees	Est. Downtime	Damage Description
Tüpraş	Refinery	1960s		6 months - 1 year	• Tank farm fires • Water supply line breaks • Tank collapses • "Sinking" of floating roofs • Pile damage at port • Pipeway collapse • Cooling tower collapse • Stack collapse • Oil spill
Petkim	Petrochemical	1967-1975	2,500	2 months	• Cooling tower collapse • Pipeway collapse • Port failure • Water supply line breaks
İGSAŞ	Fertilizer	1977		2 - 6 months	• Cranes off rails • Pipeway damage • Building damage • Reactor support structure damage
British Petroleum	Gas Terminal	1980s (?)		< 1 week	• Buckling of tank roofs • Damage to tank walkways
British Petroleum	Gas Tanker Filling Plant	1974		< 1 week	• Minor vessel movement
Hyundai	Car Manufacturing	1997		1 - 2 months	• Lost connection bolts on steel frame • Air handler duct failure • Unzipped cable tray runs
Toyota	Car Manufacturing	1994		2 weeks	• Collapsed storage racks • Transformer jumped • Movement of cars on line and unanchored items
Ford	Car Manufacturing	1999 (under construction)		Not operational	• Large building displacement • Building damage
Pirelli	Tire Manufacturing	1960s		Several weeks (partial)	• Building collapse
Goodyear	Tire Manufacturing	1963	500	2 - 3 weeks	• Fire protection lines broken • Minor structural damage
BriSA	Tire Manufacturing	1976 1989		2 - 3 weeks (partial)	• Severe structural damage (walls fallen) • Transformer damage • Control room damage
KordSA	Steel Cord (for tires)	1976	1,100	Few weeks	• Building damage
DuSA	Tire Cord Fabric	1987		6 months - 1 year	• Severe building damage • Process equipment moved • Pipes "blocked" • Instrument cables cut

Table 6-1 Summary of Industrial Facility Performance (cont'd)

Name	Facility Type	Year Built	No. Employees	Est. Downtime	Damage Description
EnerjiSA	Power	1997	50	Few days/weeks	• Boiler moved • Structural damage to HRSG • Transformer bushings broke
BekSA	Steel Cord (for tires)	1987	240	Few weeks (partial)	• Building collapse • Windows broke
NUH	Cement Plant	1968-1973		Few days (partial)	• Minor structural damage and movement • Falling monitors in control room • Settlement at port
Mannes-mann Boru	Steel Pipe Factory	1955	200	Few weeks	• Building damage • Crane collapse
SEKA	Paper Mill	1936-1960		2 weeks - 2 months (maybe longer due to port)	• Water supply line breaks • Complete collapse of port structure • Multiple partial roof collapses • Silo collapse • Transformer damage
Pakmaya	Food Processing	1976	300	2 months	• Shifting of reactor vessels • Vessel piping and support damage • Steel frame structural collapse • Fallen walls • Steel frame building damage
Philips	Incandescent Bulb Factory	1964	77	1 - 2 weeks	• Minor structural damage to buildings • Cracked water tower base • Minor movement of items
Habaş	Liquified Gas Plant	1995 (tanks)		Few weeks (partial)	• Collapsed liquid oxygen tanks
Citi	Glass Vial Manufacturing			Few weeks	• Minor structural damage • Minor equipment movement
Toprak İlaç	Pharmaceutical	1990	240	2 months	• Storage rack collapse
Toprak Sağlik	Paper Products	1993	170	Few months	• Unanchored cabinet stand air tanks fell • Product fell • Some structural damage to building
Çamlica	Soft Drinks	1999 (under construction)		Not operational	• Partial roof and wall failures
Çap	Textiles	1997	650	May be permanently shut down	• Building collapse

The Tüpraş refinery experienced fires, oil spills, and severe structural damage that will likely require 6 to 12 months to repair before the plant can become operational.

The refinery received international media attention because of the tank farm fires that burned out of control for several days. The first fire was initiated in a floating roof naptha tank. Naptha is a highly volatile material with a low flashpoint, and is easily ignited. The most common hypothesis is that the sloshing of naptha in the tank caused the floating roof to breach its seal, allowing naptha to spill. The naptha was likely ignited by sparks or friction between the oscillating steel roof and the tank wall.

The refinery receives its entire water supply through a dedicated pipeline from Lake Sapanca, some 45 km to the east. Due to multiple breaks in the pipeline, the refinery quickly lost all water and all fire-fighting capabilities. As the fire spread to additional tanks, aircraft attempted to douse the fires by dropping foam. After a few days, the refinery used diesel pumps to draw water directly from İzmit Bay to fight the fire, along with the aerial foam attack. The fires were finally declared under control on Sunday, some five days after the earthquake.

While the fire was burning out of control, an area within 2 to 3 miles of the refinery was evacuated, including some areas where search and rescue operations were taking place in collapsed buildings. Train service was disrupted in the area because of the fire. Strangely, personnel in neighboring facilities report that they were not allowed to leave their facilities during the evacuation period, because nobody was allowed in or out of the area.

The fire and heat eventually damaged numerous tanks in the tank farm. It was reported that at least 17 tanks were considered to be total losses. These tanks were generally buckled by the intense heat, with one tank expanding as if ready to explode (Figures 6-3 to 6-5).

Photograph by G. Johnson

Figure 6-3 Collapsed tank due to fire at Tüpraş refinery

Photograph by G. Johnson

Figure 6-4 Collapsed tanks due to fire at Tüpraş refinery

Photograph by G. Johnson

Figure 6-5 "Expanded" tank due to fire at Tüpraş refinery

In addition to the tanks directly damaged by fire and heat, several tanks appeared to be damaged by sloshing of fluid (Figure 6-6). A few had ruptured walls near their tops and clear evidence of loss of material down the tank wall.

A large number of tanks (on the order of 50) were reported to have had floating roofs "sink." The sloshing of fluid in the tanks apparently caused damage to seals and allowed fluid on top of the floating roofs. The extra weight then caused the roofs to sink into the tank. Each of these tanks must be drained, and the roofs decontaminated and often repaired or replaced. Sloshing is a long period response, and the amount of damage was likely amplified by the long duration of shaking.

Photograph by G. Johnson

Figure 6-6 Failure at top of tank due to sloshing of fluid at Tüpraş refinery

No evidence of piping rupture was observed. This is primarily attributed to the typical configuration of running piping in a flexible manner down central pipe runs between the tanks (Figure 6-7). Some leakage was reported in piping in the area of burned tanks.

One tank that burned was observed to have a classic "elephant's foot" bulge on one side (Figure 6-8). The other side appears to have damage that has led to draining of the tank, and

Photograph by G. Johnson

Figure 6-7 Pipes between tanks in Tüpraş tank farm typically run above ground

spreading of the fire to this tank and an adjacent tank. We understand that these two tanks were the last to burn, after the fire spread over or through a berm, skipping over a few tanks in the process.

The main process units are located just beyond another berm from the tank farm. Four cooling towers, one concrete and three wood, are located at the berm. One of the wooden cooling towers was burned completely by the fire. A second cooling tower, some 50 meters away was shaken down completely, while the adjacent tower remained standing. A concrete tower on the other side of the burned tower appeared to be undamaged (Figures 6-9 to 6-11).

Photograph by G. Johnson

Figure 6-8 Elephant's foot buckling at tank that collapsed due to fire at Tüpraş refinery

Photograph by G. Johnson

Figure 6-9 Burned out cooling tower just over berm from Tüpraş tank farm

Photograph by G. Johnson

Figure 6-10 Collapsed cooling tower next to Tüpraş tank farm

Photograph by G. Johnson

Figure 6-11 Location of burned out and collapsed cooling towers next to Tüpraş tank farm

Piping runs into the units between the burned and collapsed cooling towers (Figure 6-12). It is not difficult to believe that the fire came close to burning down the entire facility, an estimated $3.5 billion investment.

6.3.1 Crude Unit and Stack Collapse

The other area of severe and spectacular damage in the Tüpraş refinery occurred in one of their three crude units, when a 90-meter high reinforced concrete heater stack collapsed. The break appeared to occur at about the height of a penetration of the stack for a large

Photograph by G. Johnson

Figure 6-12 Piping between Tüpraş tank farm and process units runs between cooling towers

diameter heater duct. The cause of the failure was not immediately obvious from sifting through the rubble of the stack (Figures 6-13 to 6-15).

The top of the stack fell into the unit, destroying the heater, while the bottom portion fell into a pipeway running around the perimeter of the unit. The destroyed pipeway was

Photograph by G. Johnson

Figure 6-13 View from a distance at 90 m high stack collapse in Tüpraş crude unit

Photograph by G. Johnson

Figure 6-14 Collapsed stack in background was attached to furnace in foreground by a large duct

heavily congested with piping from all over the refinery. It is likely to take several months to identify, isolate, and repair damaged piping in this area (Figures 6-16 to 6-17).

One of the pipes broken by the stack collapse was a naptha line from the original burning naptha tank in the tank farm. A fire started when the collapse occurred, and although it was extinguished relatively quickly, it flared up several times because of the new fuel from the broken pipe. The supply could not be stopped because the two block valves were at the tank, inaccessible because of the fire, and downstream from the crude unit.

Photograph by G. Johnson

Figure 6-15 Top of stack collapsed into unit, severely damaging heater unit. Top of stack is in foreground of photo.

Photograph by G. Johnson

Figure 6-16 Bottom portion of stack fell backwards into pipeway

Photograph by G. Johnson

Figure 6-17 View showing congestion of piping in destroyed pipeway

6.3.2 Port Damage and Oil Spill

The Tüpraş refinery has its own private port facility. Water depth is approximately 15 meters. The wharf structure reportedly had several sheared piles at the waterline. This was attributed to a combination of earthquake loads and existing heavy corrosion.

There was evidence of ground failure at the approach to the wharf. A steel frame pipeway on the wharf structure extending out from the shore partially collapsed, with broken frame connections and severely bent members (Figures 6-18 and 6-19). Damage was reported to supply and return lines due to this support damage.

Photograph by G. Johnson

Figure 6-18 Pipeways collapsed and leaning on wharf approach to shore

Photograph by G. Johnson

Figure 6-19 Pipe supports bent and broke at welded connections

The loading jetty is a separate structure oriented parallel to the shore. It separated from the wharf structure, as evidenced by dropping of connecting grating into the water below. Other nonstructural damage at the wharf included a fallen light standard (Figure 6-20).

An oil spill occurred at the port. When the earthquake occurred during transfer operations, a vessel pilot moved his vessel away from the dock, ripping the transfer hose

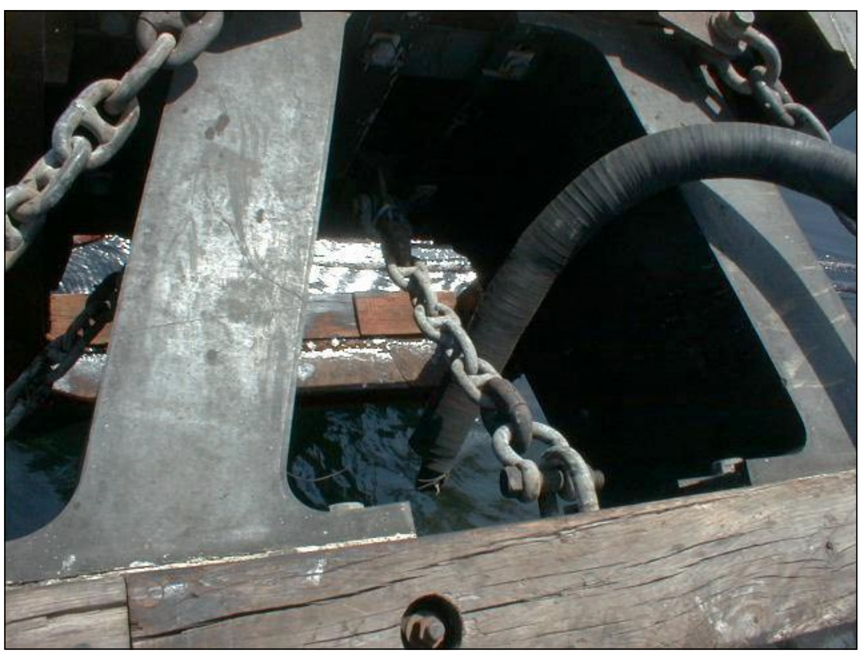
Photograph by G. Johnson

Figure 6-20 Fallen light standard at Tüpraş port

before the manual valve could be shut down (Figures 6-21 and 6-22). The damaged piping on the wharf also contributed to the oil spill, as well as overflow of the drainage system for the tank farm, made worse by emulsion from the fire fighting efforts.

Photograph by G. Johnson

Figure 6-21 Hoses used for transfer operations at port



Photograph by G. Johnson

Figure 6-22 Hose reportedly broke when vessel pilot pulled away during earthquake without disconnecting. Caused oil spill at Tüpraş port.

Photograph by H. Sezen

Figure 6-23 One of two identical buildings at Çap textile plant

6.4 Building Performance at Industrial Facilities

Many of the industrial buildings, especially warehouse structures, are constructed of precast concrete frames. These buildings generally performed better than residential concrete construction. This would be expected, because of generally better quality control and inspection likely to be found in industrial facilities.

One site with particularly poor performance of these structures was the Çap textile plant. This plant had one building completely collapse, and another experienced significant permanent drift, causing partial collapse of the roof (Figures 6-23 to 6-25).

Photograph by H. Sezen

Figure 6-24 One building at Çap textile plant completely collapsed.

Collapse or partial collapse of roof diaphragms was observed at other industrial facilities also. At the SEKA paper mill in İzmit, several buildings lost sections of reinforced concrete plank roofs (Figure 6-26). Roof damage was also noted at the İGSAŞ fertilizer plant and other facilities (Figures 6-27 and 6-28).

Photograph by H. Sezen

Figure 6-25 One building at Çap textile plant had hinging of columns, large permanent drift, collapsed walls, and fallen roof panels

Photograph by G. Johnson

Figure 6-26 Precast concrete roof planks fell in several SEKA buildings

Photograph by G. Johnson

Figure 6-27 Warehouse roof collapse at İGSAŞ

Photograph by H. Sezen

Figure 6-28 Collapsed roof in storage structure at KordSA

One other complete building failure was at the Pirelli tire factory in İzmit. One of the older buildings at the plant, constructed in the 1960s, totally collapsed, killing one worker and injuring twenty (Figures 6-29 and 6-30).

Numerous office buildings were damaged (Figures 6-31 to 6-33). The İGSAŞ fertilizer plant had severe damage to one of their four-story office buildings, with a collapse of the entire first story. According to facility staff, the building was identical to an adjacent building, which appeared to be undamaged. They indicated that the building did not contain

Photograph by G. Johnson

Figure 6-29 Collapsed building at Pirelli tire plant

Photograph by G. Johnson

Figure 6-30 Severe damage to building adjacent to collapsed building at Pirelli. This building houses critical equipment and cannot be used because of the building damage.

car ports, large openings, or other features to suggest a soft story or weak story collapse mechanism (Figure 6-34).

Damage was observed at several buildings at the Mannesmann Boru steel pipe factory, often associated with reinforced concrete frame structures with partial height masonry infill. "Short column" damage was especially noticeable on two buildings, a production

Photograph by G. Johnson

Figure 6-31 Other buildings at Pirelli did not collapse but had significant damage

Photograph by H. Sezen

Figure 6-32 Collapsed portion of main plant at DuSA

Photograph by G. Johnson

Figure 6-33 View of buildings at SEKA paper mill. Wall panels have fallen on upper floors of building to left.

Photograph by G. Johnson

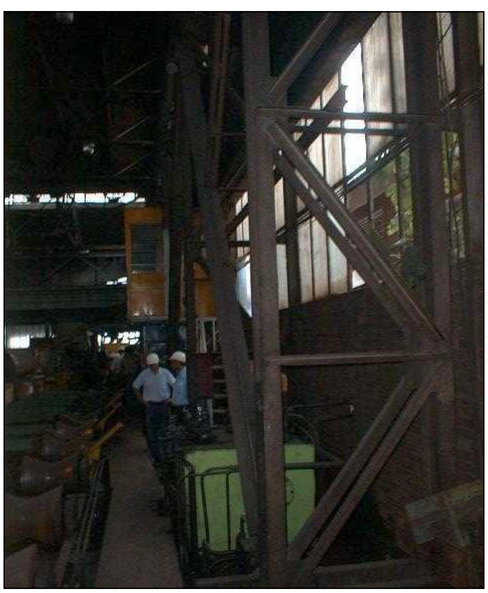
Figure 6-34 Failed first floor in İGSAŞ office building

building and a warehouse, where adjacent building sections had very different window opening heights (Figure 6-35). The shorter columns experienced much more severe damage than the adjacent taller columns.

One steel frame production building at the Mannesmann Boru large pipe area uses steel moment resisting frames. Anchor bolts on these columns stretched and fractured. It was noted that some torsional effects may have added to the column response in the longitudinal direction due to inclusion of diagonal braces on only one truss face. This 100 m wide by 600 m long main plant had two steel moment frames in the longer direction and several shorter frames in the other direction. Since shorter frames were not placed symmetrically, they also apparently caused some damage due to torsional effects (Figures 6-36 and 6-37).

Photograph by G. Johnson

Figure 6-35 Short columns failed in bays next to longer columns at Mannesmann Boru steel pipe factory



Photograph by G. Johnson

Figure 6-36 Steel frame building at Mannesmann Boru large pipe factory. Eccentric load paths led to shearing of bolts.

Photograph by G. Johnson

Figure 6-37 Sheared bolts at base of column at Mannesmann Boru large pipe factory

The administration building experienced some building separation and infill damage. Similar effects were observed at another warehouse building. An elevated skylight along the length of one warehouse building collapsed.

At other facilities, several buildings of reinforced concrete frame construction were also reported to have cracking of infill walls and damage at building separations. These were noted at the Tüpraş refinery main office building and at the Petkim petrochemical PVC plant.

Steel frame buildings generally performed well, with some exceptions. The Toyota plant in Adapazarı used very heavy steel construction and had no damage. That plant had columns with flange thicknesses of up to 5 inches. The Hyundai plant in İzmit used heavy steel bolted frames, and reported numerous failures of connection bolts in the steel frames.

One failure of a steel frame structure took place at the Pakmaya food processing plant in İzmit, very close to the failed Pirelli tire building. At Pakmaya, a two-story steel frame with masonry infill was built on the roof of a concrete frame structure. The two story steel frame was severely damaged, with columns hinging at top and bottom. The failure appeared to only be attributable to inertial loads, as the tanks housed in the building do not penetrate to the upper floor and could not have knocked down the structure (Figures 6-38 to 6-40).

Photograph by G. Johnson

Figure 6-38 Fallen walls and damaged steel penthouse building at Pakmaya food processing plant

Photograph by H. Sezen

Figure 6-39 View of large displacements on steel penthouse at Pakmaya

Photograph by H. Sezen

Figure 6-40 Columns on steel structure at Pakmaya hinged top and bottom causing several feet of interstory drift

6.5 Performance of Non-Building Structures

In addition to the damage previously described at the Tüpraş refinery, there were numerous other instances of damage to non-building structures.

Wood cooling towers collapsed at the Petkim petrochemical plant as well as the Tüpraş refinery (Figure 6-41). These failures are unusual in that the towers shook down completely. It is believed that the duration of ground shaking contributed to the severity of this damage.

Photograph by G. Johnson

Figure 6-41 Collapsed cooling tower at Petkim

In past earthquakes, heavy damage to wood cooling towers has primarily been caused by the poor condition of the wood prior to the earthquake. According to management, that was not the case for these cooling towers.

A concrete cooling tower at Petkim was also severely damaged due to short column effects. Every exterior column around the entire perimeter of the tower hinged at the base. Examination of the interior columns revealed no damage. This is likely attribut-

Photograph by G. Johnson

Figure 6-42 Severely damaged concrete cooling tower at Petkim

Photograph by G. Johnson

Figure 6-43 All columns on perimeter are "short" columns and hinged. Interior columns are longer and were undamaged.

Photograph by G. Johnson

Figure 6-44 The approach to the port at the SEKA paper mill is completely unusable

Photograph by G. Johnson

Figure 6-45 SEKA port support structure has collapsed single reinforced concrete columns

able to the length of the interior columns, not supported on shear walls. It is likely that the shorter, stiffer exterior columns attracted more load (Figures 6-42 and 6-43).

Numerous ports in the area were damaged, either structurally or by ground settlement or spreading. The port at the SEKA paper mill was severely damaged by the total failure of the approach bridge. The approachway was supported on single reinforced concrete piers that failed along the entire length of roadway (Figures 6-44 and 6-45). A second wharf there was also severely damaged (Figures 6-46 and 6-47).

Photograph by G. Johnson

Figure 6-46 One section dropped a foot or more relative to other sections on the second wharf structure at SEKA

Photograph by G. Johnson

Figure 6-47 Pipelines did not appear to be damaged, but second port structure at SEKA is also unusable

Photograph by H. Sezen

Figure 6-48 Damage battered piles at Petkim port

The wharf structure at Petkim had severe damage to 10 battered piles. Every pile was also severely damaged on both dolphins (Figures 6-48 and 6-49).

Petkim also had severe damage to pipeways at the wharf. Fractured cantilever supports dropped over 100 meters of fire protection pipe onto the deck, although the pipe itself was undamaged (Figures 6-50 and 6-51).

Photograph by H. Sezen

Figure 6-49 All piles severely damaged on dolphins at Petkim port

Photograph by G. Johnson

Figure 6-50 Fallen fire protection line at Petkim port. Piping was not damaged.

Photograph by G. Johnson

Figure 6-51 Pipe support failure that led to falling of fire protection pipeline at Petkim port

The port at the Gölcük naval base was heavily damaged by fault rupture throughout the wharf area. A crane jumped off its base at this location also. Cranes also jumped off their rails at Petkim. Two identical cranes collapsed at the Mannesmann Boru pipe factory (Figures 6-52 and 6-53).

Photograph by G. Johnson

Figure 6-52 Collapsed crane at Mannesmann Boru large pipe factory yard

Photograph by G. Johnson

Figure 6-53 Box section of crane leg buckled Mannesmann Boru. A second crane experienced an identical leg failure but did not fall.

Storage racks collapsed at the Toprak pharmaceutical plant and the Toyota factory, both in Adapazarı (Figures 6-54 and 6-55).

6.6 Tank Damage

The most severe tank damage occurred at the Tüpraş refinery, as described earlier. Much of the damage was caused by fire, with some evidence of elephant's foot buckling. Sloshing of fluid was also a major cause of damage.

Roofs of fixed tanks were also damaged at the British Petroleum gas terminal immediately adjacent to Tüpraş. The damage consisted of local buckling of the roof skin due to

Photograph by G. Johnson

Figure 6-54 Collapse of storage racks at Toprak İlaç pharmaceutical plant in Adapazarı

Photograph by H. Sezen

Figure 6-55 Collapsed storage racks at Toyota plant

Photograph by G. Johnson

Figure 6-56 Three identical tanks at Habaş. Tanks to left were full of liquid oxygen. Third tank to right was apparently 1/4 full of liquid nitrogen and did not collapse.

sloshing of fluid. No containment was lost. In addition, damage to interconnecting walkways at the roof levels of tanks occurred in a few locations.

The Habaş plant in İzmit provides liquefied gases to commercial plants and medical facilities. The major damage observed at Habaş was the collapse of two out of three large storage tanks (Figures 6-56 and 6-57). Three identical 48 foot diameter tanks were built in

Photograph by H. Sezen

Figure 6-57 Tanks at Habaş collapsed due to failure of reinforced concrete columns and support base. Support structure was built in 1995.

1995 and consisted of stainless steel shells with an interior diameter of 42 feet. The tanks were each supported on a 42 inch deep reinforced concrete platform, with sixteen 20-inch diameter reinforced concrete columns, 100 inches tall. Two of the three tanks were filled with liquid oxygen at the time of the earthquake. Their column supports were not strong enough to resist lateral loads induced by the earthquake under high axial load leading to collapse of the entire support frame in a brittle manner. An identical third tank is immediately adjacent to the collapsed tanks. This tank was reportedly 1/4 full of liquid nitrogen and had no apparent damage.

6.7 Equipment Damage

Most of the equipment damage observed was to unanchored equipment. Examples include the electrical equipment and small tanks at the Toprak facilities in Adapazarı (Figure 6-58).

Transformers were damaged in several locations, including the SEKA paper mill, Toyota car factory, EnerjiSA power plant, Adapazarı substation, and Ambarlı power plant (Figures 6-59 to 6-61).

Damage observed at the Hyundai plant in İzmit included severe separation of a large air handling unit, with the duct offset by more than one foot. In addition, a cable tray system unzipped and fell to the floor. A poor overhead connection detail that is easily subject to prying action from tray movement is the likely reason for the failure.

Photograph by G. Johnson

Figure 6-58 Unanchored electrical cabinets fell at Toprak Sağlik's paper products plant in Adapazarı

Photograph by G. Johnson

Figure 6-59 Damaged transformer at SEKA plant 4 will cause the plant to be shut down for two months

Damage to a regulator valve for the gas furnace at the Bastas fluorescent bulb factory caused damage to the glass furnace itself. Staff reported that due to the heat problems after failure of that valve, a special "tube" deformed and became unusable. A replacement must be ordered from Holland, and was expected to cause a shutdown of 6 to 8 weeks.

An elevated reactor vessel at the İGSAŞ fertilizer plant had broken steel braces hanging from the vessel near the top of its concrete frame support structure. Because of the Tüpraş

Photograph by H. Sezen

Figure 6-60 Transformers at EnerjiSA. End transformer rolled and tipped.

Photograph by H. Sezen

Figure 6-61 Transformer at EnerjiSA rolled several feet and tipped on its end

fire, İGSAŞ had not yet had the opportunity to inspect the structure and vessel at the time of the site visit. The concrete support frame itself was reported to be severely damaged (Figure 6-62).

Pakmaya had numerous bioreactor vessels, unanchored on pedestals in their process building. Several of these vessels appeared to have shifted many inches on their supports, buckling skid beams and shifting supports (Figure 6-63). Piping was reportedly damaged due to shifting of the vessels.

The Petkim petrochemical plant reported internal damage to a reactor vessel.

Photograph by G. Johnson

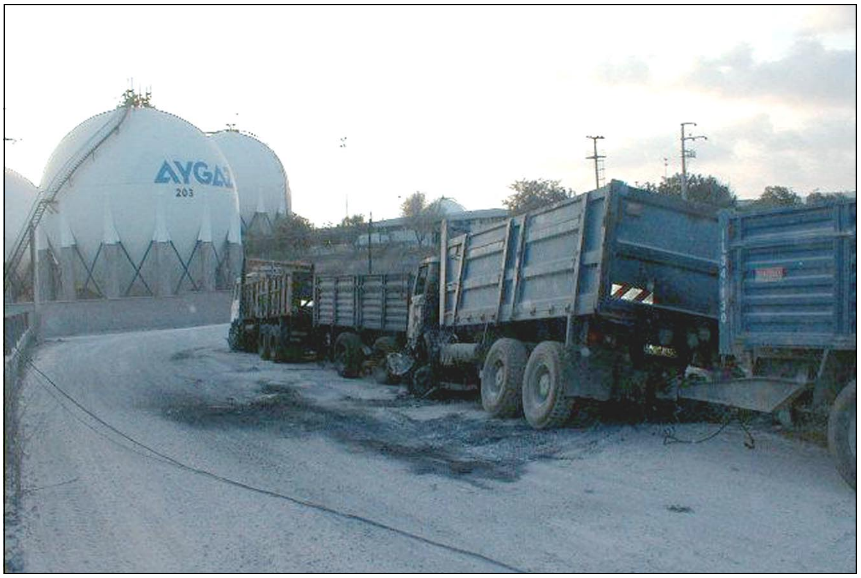
Figure 6-62 Severely damaged reinforced concrete reactor support structure at İGSAŞ. Braces near top of reactor are hanging disconnected after earthquake.

Photograph by G. Johnson

Figure 6-63 Skid beams buckled and shifted due to displacement of large bioreactors at Pakmaya food processing plant

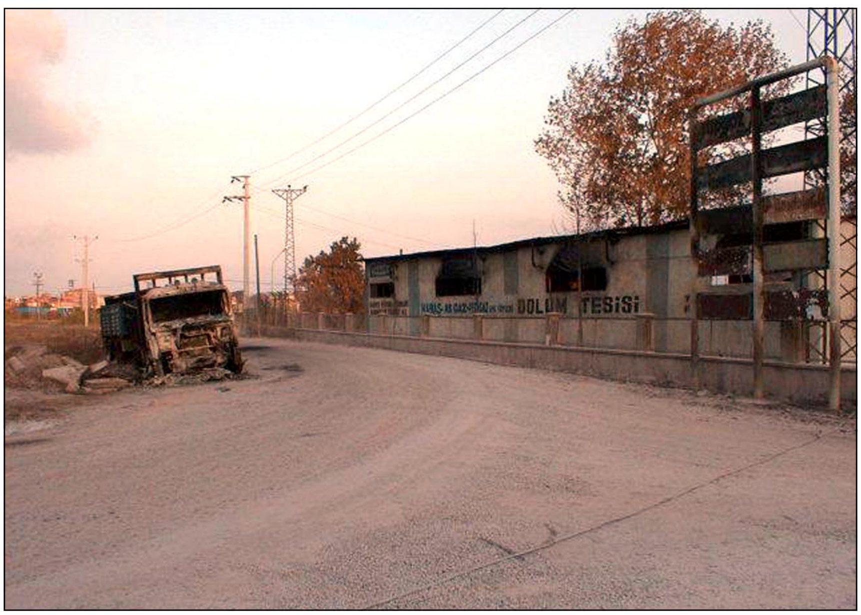
6.8 Other Fires

Although no major structural damage was observed at LPG plants in the epicentral area, two truck drivers were killed in a fire ignited by driving through a gas leak from one of the facilities. Security cameras at one facility captured the drivers leaving the facility across the street, beginning to run down the road on foot, changing their minds and returning to their trucks, and driving away. The remains of their burned out trucks and a burned out building in the facility could be found less than a mile down the road (Figures 6-64 and 6-65).



Photograph by G. Johnson

Figure 6-64 Burned out trucks drove through gas cloud leaking from facility



Photograph by G. Johnson

Figure 6-65 Fire from trucks burned down building at facility (to right) and killed drivers

6.9 Summary

The epicentral area contains a high percentage of Turkey's industry. As might be expected, the industrial facilities in the region generally had higher levels of engineering and much better construction quality control than the residential and commercial construction.

However, damage was much more severe and extensive than seen in earthquakes with similar peak ground acceleration levels, with numerous examples of extended business interruption. Based on the type of structures damaged and the nature of the damage, it is likely that the long period motion and duration of the earthquake were major contributors to the extent of damage.

This earthquake has pointed out many situations that might be encountered and hazards that might be faced during earthquakes of this magnitude in other regions, such as emergency response, human response, fires, oil spills, and toxic releases, in addition to fundamental issues of structural and nonstructural damage.

As additional information is gathered and studied from these facilities, we expect that lessons learned will be directly applicable to industrial facilities in other seismic regions of the world, including the United States.

The authors would like to acknowledge the assistance of Mr. Rafael Alaluf of YESA, İstanbul and Mr. Marin Jordanov of EQE International in Sofia, Bulgaria for their assistance. We would also like to acknowledge the tremendous access and cooperation provided by nearly all of the affected industrial facilities affected by the earthquake and visited during our investigation.

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Section 7
Lifeline Performance

Charles Scawthorn
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This section reports on impacts of the August 17, 1999 earthquake on water, power and gas utilities, based on field surveys conducted on August 24-25, 1999. Because services such as water and power are vital for the function of an urban region, they are referred to as *lifelines*. Transportation lifelines, such as highways and railroads, are covered in Section 5, Transportation. Lifelines such as water, power and gas have a similar topology, consisting of:

- *sources* (e.g., reservoirs, electric power plants or gas wells),
- *transmission* (large pipes or extra high voltage lines),
- *nodes* (e.g., electric substations, water treatment plants, or pump or compressor stations), and
- *distribution* (typically, a dense highly interconnected complex in the urban region, operated at lower pressures or voltages when compared with the transmission system).

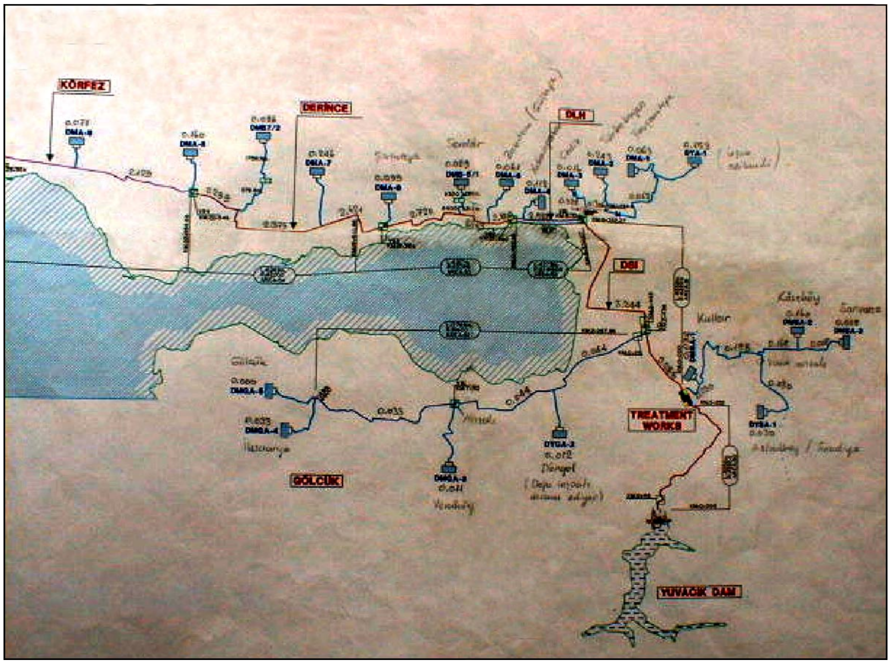
The lifelines in the affected region had this structure to varying degrees.

In general, lifelines performed well in this earthquake, especially the source and transmission elements. Distribution systems, however, were more severely damaged, especially the underground water system piping in the high intensity areas. Typical of many earthquakes, this damage was due to large permanent ground deformations, due either to fault displacement (e.g., Gölcük), lateral slumping (in the bayside areas of Gölcük), or liquefaction (especially in Adapazarı).

7.1 Water Systems

The main source of water for much of the affected area is the recently constructed İzmit Water Project, built and operated by Thames Water. It is the largest privatized water project in the world as of this writing, and replaces a variety of low quality sources for the various municipalities in the area. Figure 7-1 shows the general layout of the wholesale system, which begins in the hills south of Yuvacik at a 60 million cu meter reservoir impounded by a 40 m high clay core earthen dam, constructed in the early 1990's (Figure 7-2). The dam is uninstrumented, and reportedly experienced only very minor settlements, although the reservoir is reported to have experienced a 2 m amplitude seiche. Water is conveyed approximately 4 km from the dam to a water treatment plant, via a steel pipe of 2.2 m diameter.

The water treatment plant is 440 million liter/day capacity (110 mgd) and employs a standard treatment process of aeration, flocculation/sedimentation, sand filtration and chlorination. Buildings, in-ground concrete balancing reservoir and equipment were



İzmit Water Project

Figure 7-1 Wholesale water system for affected region

City of İzmit

Figure 7-2 İzmit Water Project Dam

undamaged (see Figure 7-3) with the exception of fiberglass piping in the clarifiers, which are cantilevered downward approximately 3 m. In basins which were not in use at the time, and empty, these 'trident' pipes cracked and/or broke at their upper (base) end. However, sufficient capacity remained for the plant to operate. Daily demand at the time of the earthquake is 2,500 l/s but, following the earthquake, demand increased to 3,200 l/s, which was attributed to leakage along the transmission line. Downstream of the plant, water is conveyed to retail customers via a 2.2 m spiral-welded steel pipe, which was

Photograph by C. Scawthorn

Figure 7-3 İzmit Water Project

reportedly undamaged except at clean-out connections at low points, where flanged fittings appear to have cracked at perhaps a dozen locations. The transmission line was being scheduled for a one day outage for Aug. 26 (i.e, nine days after the earthquake) for repair of these leaks.

Approximately one km downstream of the plant, the steel transmission line crosses the fault trace. This location was inspected and found to have approximately a 2 m right lateral offset but, while some water flowing to the surface was observed (it was raining at the time, however), the pipe was reportedly undamaged at this location[1] (see Figure 7-4).

Impacts of the earthquake on water retailers and urban distribution pipe networks were not available in detail at the time of the field survey. The distribution system in İzmit was reported to have relatively little damage, while the distribution system in Adapazarı was reported to be very severely damaged, due to the significant permanent ground displacement occurring there. It was known that the retailers in general were able to store water in their local distribution reservoirs (shown in Figure 7-1), but were unable to distribute it due to numerous breaks in the distribution system. Potable water needs were being served by tanker trucks supplied from the İzmit water treatment plant and from several naval vessels in the Bay, and by bottled water (see Figure 7-5).

[1] Subsequent to the author's field visit, it has been reported that this pipe was excavated and found to have sustained some damage, which was repaired.

Photographs by C. Scawthorn

Figure 7-4 Top photo was taken looking north along pipeline alignment. The two men are at the location of the pipe-fault intersection, showing the approximately 2 m fault offset. Bottom photo taken looking east along the fault, with the pipeline alignment in foreground. The man is leaping across fault scarp, to east of pipeline. Note that the scarp appears to alter alignment northwards right at pipe (in foreground).

Photographs by C. Scawthorn

Figure 7-5 Potable water supply via tanker truck and bottled water, Adapazarı

City of İzmit

Figure 7-6 İzmit Wastewater Treatment Plant

7.2 Wastewater

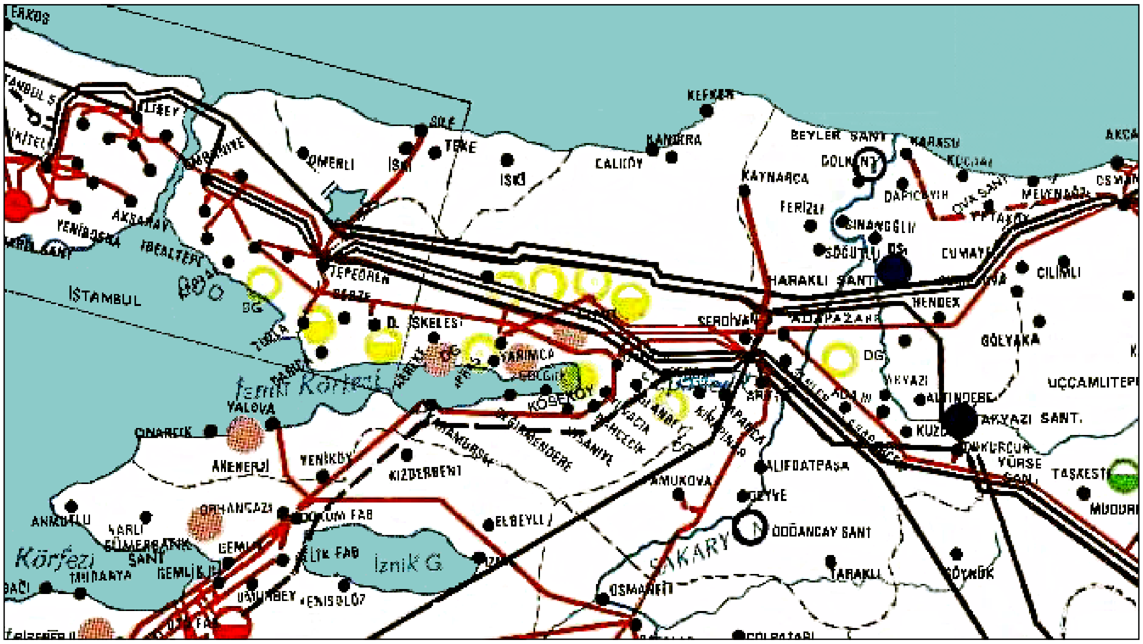
No information was available during the field survey, except that the city of İzmit reported no damage to their wastewater treatment plant (see Figure 7-6).

7.3 Electric System

The electric power generation and transmission system in Turkey is owned and operated by the Turkish Electricity Generation Transmission Company (TEAŞ), which operates about 13,000 km of transmission lines at 380 kV, 27,000 km at 154 kV. Figure 7-7 is a portion of the system map, for the earthquake-affected area.

As can be seen in Figure 7-7, TEAŞ has no generation in the immediate high intensity area, although there are several cogeneration plants in the area. No major damage was reported to any generation units. As also can be seen in Figure 7-7, there are six 380 kV circuits passing through the high intensity area, as well as several 154 kV circuits. The only 380 kV substation in the area is located at Adapazarı, and it sustained porcelain breakage as seen in past earthquakes. Four of the six 380 kV circuits pass through the Adapazarı substation, while two by-pass it.

Power failed within minutes of the earthquake due to damage at Adapazarı substation as well as power plants tripping off, which resulted in a nation-wide blackout. Power was generally restored to all parts of Turkey except the high intensity area by early afternoon of the day of the earthquake (e.g., about 12 hours later) although aftershocks complicated this process.



ENERJİ TESİSLERİ
TRANSMISSION LINES AND POWER PLANTS

	380 kV	154 kV	66 kV
HATLAR Power Transmission Lines			
TESİSİ TAMAMLANMIŞ VE İŞLETMEDEKİ TESİSLER Completed and In Operation	——— (black)	——— (red)	——— (blue)
İNŞA HALİNDE VE İNŞAASI PROGRAMA ALINMIŞ TESİSLER Under Construction or Programmed	— — — (black)	— — — (red)	— — — (blue)

TEAŞ

İşletmedeki TEAŞ Hidrolik Santralları (Sistemle Paralel çalışanlar) TEAŞ HYDRAULIC Power Plants in Operation (in Parallel)	**Sistemle Paralel Çalışan Otoprodüktör Santrallar (HİDROLİK)** Autoproducers Connected to the System in Parallel (HYDRAULIC)
İnşaatı Devam eden Hidrolik Santrallar HYDRAULIC Power Plants Under Construction	**İşletmedeki üretim Şirket Santralları (HİDROLİK)** Power Companies Power Plants in Operation (HYDRAULIC)
Planlanan Önemli Hidrolik Santrallar Major Hydraulic Power Plants in Planning	**ETKB'ca Tesis Sözleşmesi Yapılan Üretim Şirketlerine ait Hidrolik Santrallar** Hydraulic P.P. which Belong to Power Corp. and Their Agreement Made with MENR
İşletmedeki TEAŞ Termik Santrallar TEAŞ Thermal Power Plants in Operation	**İşletmedeki Görevli Şirket Santralları (HİDROLİK)** Power Utilities Power Plants in Operation (HYDRAULIC)
İnşaatı Devam Eden TEAŞ Termik Santrallar TEAŞ Thermal Power Plants Under Construction	**İşletmedeki Görevli Şirket Santralları (TERMİK)** Power Utilities Power Plants in Operation (THERMAL)
Planlanan TEAŞ Termik Santrallar TEAŞ Thermal Power Plants in Planning	**Mevcut Y.İ Santralları** Existing Power Plants Under BO MODEL
Sistemle Paralel Çalışan Otoprodüktör Santrallar (TERMİK) Autoproducers Connected to the System in Parallel (THERMAL)	**İnşaatı Devam Eden Y.İ Santralları** Under Construction Power Plants Under BO MODEL
	Planlanan Y.İ Santralları Planned Power Plants Under BO MODEL

TRANSFORMATÖR İSTASYONLARI/SUBSTATIONS

İŞLETMEDE IN OPERATION	●	**İNŞA HALİNDE VEYA PLANLANMIŞ** PLANNED OR UNDER CONSTRUCTION	○

Figure 7-7 TEAŞ system map (partial)

Photograph by C. Scawthorn

Figure 7-8 Electric transmission tower pulled to left (north) due to conductors being put in tension due to right lateral fault displacement (fault is to north, or left, of the tower)

Transmission lines and towers did not appear to be damaged, except where the lines crossed the fault. Figure 7-8 shows a tower leaning over due to the conductors being put in tension at the fault crossing. Distribution within the high intensity shaken area was heavily damaged, due to building collapse and other damage.

7.4 Gas System

Propane has traditionally been the primary source of heating and cooking gas in Turkey. In the 1990's, underground distribution systems have been installed in İstanbul, İzmit and some other large cities. In the high intensity shaken area, the only natural gas distribution system was İzmit. The system contains about 400 km of gas distribution piping, mostly polyethylene (PE).

The system performed extremely well, with no reported damage to pipelines and main regulators aside from that due to building collapse and related damage.

7.5 Summary and Lessons Learned

With the exception of water distribution system damage in Adapazarı, lifelines performed relatively well in this event. The modern İzmit Water Project and İzmit gas facilities were relatively undamaged. The TEAŞ electric power grid lost power nationwide for about 12 hours following the earthquake, due to protective tripping of generation plants, but was generally restored by the afternoon of the day of the earthquake.

The performance of lifelines in this earthquake offers a number of lessons, and opportunities for research, including:

- modern engineered facilities, including the İzmit Water Project, İzmit Gas facilities (and transportation structures discussed in Chapter 5) all performed well, demonstrating the value of appropriate investment in engineering design.
- older distribution systems in areas of poor soils were devastated, due to permanent ground deformations (for underground utilities), and building damage (i.e., collapse) damaging above-ground utilities. The restoration of these distribution systems is a time-consuming, expensive process, which can be improved via pre-event retrofitting or replacement, division of distribution systems into blocks which can be easily isolated, and planning for restoration.
- Electric power is vital for emergency response and recovery. The TEAŞ power grid failed, causing loss of power and communications, and confusion, throughout Turkey (this also occurred in the 21 September 1999 ChiChi earthquake, in Taiwan). Electric power was restored within about 12 hours for most of the country, but took much longer for the heavily damaged area, impeding recovery processes. Damage to the electric power infrastructure followed the pattern seen in many other earthquakes: generation was undamaged, higher voltage substations sustained significant porcelain damage, unanchored equipment was damaged, low voltage poletop transformers in the distribution system were widely damaged in areas of high ground shaking, and redundancy in the transmission system permitted bypassing of damaged nodes and enhanced system recovery.
- The İzmit Water Project 2.2 m diameter steel transmission line crossed the main trace of the fault, sustaining about 2 m of lateral offset, yet not catastrophically failing. That a pipe could sustain such large offsets and not fail is remarkable, and the detailed strains in the repaired pipe, and site soil properties, require detailed study to understand the specifics of this situation (which offers important lessons for other fault crossing situations).
- Polyethylene (PE) pipe performed extremely well in the İzmit gas system, and selected portions of water systems. It appears to be a highly seismic resistant piping material, so that its use for new systems and, more importantly, its potential for rehabilitating older underground utility systems, needs to be further explored and encouraged.

The widespread damage to underground utilities in Adapazarı, combined with the significant permanent ground deformations, provides an ideal situation for detailed data collection and development of a database which can be statistically explored. This should proceed as soon as possible.

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The author received assistance and data from a number of individuals, for which he is grateful. Special gratitude is due to Mr. Kadri Veziroğlu, Vice Mayor of the City of İzmit; Mr. Mike Price, Operations Manager, İzmit Water Project; Mr. Fakir Erdoğan, Turkish Electricity Generation-Transmission Corporation; Mr. Bariş Öztek, Birikim DA; and Mr. Atilla Özdikmen, Alter Uluslararası. The author is also grateful for support received from MCEER.

Section 8
Social, Political and Emergency Response

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Baylor University

The Richter magnitude 7.4 earthquake covered a very large area of about 5,000 square miles in northwest Turkey. This economically prosperous region contains a large urban population (about 15 million people in the affected area) and is highly industrialized. Fatalities of over 17,000 men, women and children, with about 44,000 injured, were coupled with a vast number of destroyed and damaged homes and businesses, which presented a very difficult challenge for search and rescue efforts.

The dimensions of this tragedy are further emphasized when it is realized that, in just about 45 seconds, thousands were missing, about 250,000 people became homeless, the economy was devastated, and the state now needed many billions of U.S. dollars to recover losses.

8.1 Search and Rescue (Initial Response)

The emergency management and response effort got off to a slow start for the first several days. The survivors, public and media were unusually outspoken, critical of the government and military for their initial search and rescue performance.

Command and control at all levels was severely limited during the first day. It was widely reported that President Demirel and Prime Minister Ecevit were unable to communicate with Ankara from İstanbul for up to four hours. Evidently, there was no operational communications back-up. The sheer size of the disaster—covering a very large, heavily populated urban and industrial area—combined with the initially limited national and local institutional and organizational response, detracted from a more efficient timely start for the emergency phase of search and rescue management.

The initial search and rescue was unorganized and mostly performed by the earthquake survivors themselves, who frantically tried to rescue family members and neighbors tangled or covered by the debris (see Figure 8-1). These volunteers were not trained emergency personnel, and their efforts were limited. Scarce or unavailable heavy lifting equipment, no search dogs, and physical and mental exhaustion exacerbated Turkey's most costly natural disaster.

A national volunteer search and rescue team (AKUT) began working in İstanbul within 24 hours of the event, and continued to work after all foreign teams had departed.

Foreign search and rescue teams came from Algeria, Austria, Azerbaijan, Belgium, Bulgaria, Canada, Denmark, Finland, France, Germany, Greece, Hungary, Israel, Italy, Japan, Kuwait, Norway, Poland, Russia, Spain, Sweden, Switzerland, United Kingdom, and the USA, with several arriving on Day 1. A reported 50,000 Turkish soldiers were assisting in the search and rescue by Friday, August 20. Intensive rescue efforts lasted through Day 4.

Photograph by W. Mitchell

Figure 8-1 Search and rescue team members in Yalova on August 25, 1999

Media reports estimated that 1,000 foreign search and rescue people were in Turkey within the first 48 hours. Several teams had technical equipment and dogs—but many did not. Successful rescues included:

- An AKUT team rescued two victims on August 18
- An Israeli team rescued two military survivors on 18 August
- A French team rescued a 16 year old girl and a man in Yalova on August 19
- A Swiss team rescued a 16 year old girl and a man in Yalova on August 19
- A Hungarian team rescued a 3 year old girl in İzmit on August 20
- An Israeli team rescued a 10 year old girl in Çınarcık on August 21
- A team rescued a 95 year old woman near Çınarcık on August 21
- A French team rescued 19 and 10 year old sisters in Gölcük and a 23 year old man in Yalova on August 21
- A Turkish team rescued a 45 year old woman in Gölcük on August 22 and a 25 year old man in Körfez on August 23

The last rescued victim was a 4-year-old boy recovered by an Israeli and Turkish assisted team on August 24, one week after the earthquake. Most of the foreign teams had departed by August 24. The press reported that all foreign teams were to leave Turkey by Wednesday, August 25.

Based on a variety of news reports, it appears clear that the approximately 1,000 foreign search and rescue team members and staff (some with dogs and highly technical listening devices), along with 50,000 Turkish soldiers, and dozens of AKUT volunteers saved 17 people. This small number of rescued victims contrasts with Turkish television, which reported on August 29 that 65 foreign rescue teams, made up of 2,700 specialists and 109 dogs, saved 621 lives. Even more controversial were the media reports on August 29 which announced that the Army had rescued 40,646 victims "from the rubble."

Law enforcement, particularly for crowd and traffic control, was reportedly lacking during the first day or two. The heavy traffic into and out of the damaged areas, along with the loud noise from horns and generators, added to the overall confusion on the partially blocked and heavily congested roads.

Evacuation of victims was by private automobiles, tractors, taxis, trucks, ambulances, ferry boats, hydrofoil boats, private boats, and helicopters.

Heavy equipment for debris removal was on the scene in some towns by Day 3. The national government ordered removal and lifting equipment into the area based on degree of estimated damages by provincial governors. Equipment was mostly from the affected region, but some was delivered from cities over 600 kilometers (e.g., Adana) from the disaster area.

The Minister of Health, Mr. Osman Durmuş, called for terminating all foreign assistance and stated "we don't need any help" during a widely viewed and published press conference on August 22. His comments were strongly criticized by the Turkish people who were expressing their gratitude to the international and national rescue teams.

8.2 Brief Overview of Emergency Response

The government of Turkey has implemented disaster response plans during past earthquake disasters. In this case, the prime minister's crisis action center was reportedly activated within hours of the event, but no on-scene response from the national or provincial public agencies occurred for an excessive period (reports vary from 1 to 4 days). Many survivors stated they had waited all day before receiving even minimal assistance, while others waited up to 4 days before receiving help. This lack of organized planning for the distribution of food and water resulted in large amounts of perishable food (bread) being dumped on the ground (and uneaten). The public officials, from local to provincial to national, were severely criticized by angry and emotional survivors.

As in past search and rescue attempts by international teams, there was friction between those who were trying to hear sounds from possible survivors buried under the concrete and debris, and the heavy equipment operators who wanted to bulldoze, load and carry off the damaged buildings (see Figure 8-2).

The government did request international assistance for emergency aid, fire fighting equipment, and for longer term restoration and reconstruction support.

8.3 Casualties and Injuries

Deaths and injuries occurred when apartments collapsed (see Figures 8-3 and 8-4). Injuries were mostly orthopedic, neurological, and cuts, scratches, and bruising. Obviously, emotional trauma and shock were noted. Victims were taken to hospitals and medical clinics by ambulances, private cars, trucks, buses, taxis, boats, and helicopters. First aid was slow to be organized, but within 48 hours, it was available to many. Field hospitals were set up in the city soccer stadiums at Yalova, Adapazarı, İzmit, and Avcılar.

Casualty figures steadily climbed, reaching 3,789 deaths and 16,000 injuries on August 19. These figures reached 10,009 deaths on August 21. By August 23, the government re-

Photograph by W. Mitchell

Figure 8-2 Foreign search and rescue team preparing to continue searching

ported that 12,000 bodies had been recovered, with 38,000 injuries. Deaths were widely reported at 18,000 on August 25. Then on August 26, the government revised the death toll from 18,000 to 13,009. Injury reports were revised to 26,630. On September 1, the reports stated more than 14,000 deaths and 25,376 injuries, with thousands missing. As of October 13, 17,118 were reported dead and more than 40,000 injured ("Turkey Quake Death Toll: 17, 118," Agence France-Presse, 14 October 1999).

Many injuries in İstanbul were leg and arm fractures from people jumping out of their apartment windows.

The deceased were stored in makeshift morgues. The İzmit Ice Rink was used for storage, but electricity was not reliable. Greece offered a large refrigerator ship but the Minister of Health reportedly refused to use it. Victims not immediately identifiable were photographed for later identification. Listings of known dead were published in newspapers, on official buildings, and broadcast on TV around the clock for several days.

Mass burials were conducted after Day 3 and continued through Day 5. Islam tradition requires burial within 24 hours, if possible. Given the sheer volume and inaccessibility of the deceased, this was not possible in many cases. Nevertheless, the religious procedure of washing the deceased body, covering it with a shroud, and performing religious services before burial was accommodated as much as possible.

All mass burials, and many smaller services, were conducted under extensive television, newspaper, and radio coverage.

8.4 Medical Facilities

Some medical facilities were damaged or destroyed by the earthquake. The İzmit Social Insurance Hospital and the Düzce State Hospital (Düzce's Faculty of Medicine was de-

Photograph by W. Mitchell

Figure 8-3 Totally destroyed apartment building near Karamursel

Photograph by W. Mitchell

Figure 8-4 Collapsed apartments in Gölcük

stroyed) were heavily damaged by the earthquake, but were able to begin serving patients on August 28. Düzce's private, five story Ömür Hastanesi was destroyed and suffered nine doctor fatalities, along with additional injuries to nurses and staff. The Sakarya State Hospital was moderately damaged but it continued to provide emergency care outside in its garden area and inside in the undamaged wing. The Kocaeli University Arslanbey campus was destroyed, however the University Hospital, although destroyed, was serving victims outside the ruins, with 250 doctors working around the clock. During the first

24 hours, 700 injured victims were brought to the hospital (130 deceased). At Gölcük, the hospital remained open, without electricity, with its 100 beds moved outside.

Twenty mobile and 16 permanent hospitals were in service by August 29. In addition, on 29 August, Israel, USA, Belgium, Spain, and Canada had established emergency field hospitals. On September 1, the Ministry of Health announced that within the earthquake area 20 mobile hospitals, 20 Ministry of Health hospitals, 25 Social Insurance Hospitals, and 50 health clinics were serving patients.

During the emergency response, the 102 doctors and medical personnel in the 120 bed Israeli Field Hospital in Adapazarı treated 1,250 patients in critical condition, performed 80 operations, and delivered 14 babies by cesarean section. The Israelis turned their field hospital over to Turkish medical officials and departed on September 1.

There were reports that people in İzmit broke into drug stores for medical supplies. At the same time, calls for blood donors were sent throughout the nation. A strong criticism was that some private hospitals increased their customer charges by 100 percent ("Earthquake Toll May Surpass 10,000," Turkish Daily News, August 19, 1999).

8.5 Mental Health Services

Limited emergency mental health services were available at the major hospitals in İstanbul and in some hospitals in the damaged areas. A nationwide plea for psychologists and psychiatrists, and social counselors, was broadcast within days of the event. The National Association of Psychologists called for all of its members to report to the disaster site as soon as possible.

Non-acceptance, anger, and shock of the human loss and devastation consumed those interviewed by the author. Nevertheless, the author was continually offered food, help, and assistance from the survivors. The kind, selfless concern for the author, as a foreign visitor, was overwhelming.

In Avcılar, three suicide attempts were reported. Mental health activities were focused on children survivors. Members of many private clubs, including athletic, visited the children and often played games with them.

Frequent aftershocks created additional stress and depression for many.

8.6 Displaced Persons

Most of the 15 million people in the vast earthquake area remained outdoors, even if suffering no physical damage, during the night of August 17. Many continued, because of aftershock fear, living outside of their undamaged homes for weeks (see Figure 8-5).

Initial reports were 200,000 people homeless. The government increased this to 500,000 homeless on August 27. A projected 100,000 to 120,000 new homes needed to be built (based on five people per household, this results in 500,000 displaced people).

Residents in İzmir and Ankara, hundreds of miles away, felt the quake, and many of them stayed outside during the first and second nights.

Photograph by W. Mitchell

Figure 8-5 Improvised temporary shelter for survivors

It appeared that 62,000 families were living in 62 tent sites throughout the earthquake zone. The government reported that 95,582 tents with a total capacity of 370,328 were available on August 30, and that 50,000 prefabricated homes would be built by the end of November.

The U.S. Navy (Marines) set up 2,300 tents near Gölcük. These tents had floors and were waterproof. Japan promised to build 60,000 prefabricated homes, 1,000 of which would be built in Adapazarı.

The Prime Minister promised to have all survivors in permanent homes by the summer of 2000.

Many residents are leaving the area, particularly those who have migrated from the East and Black Sea area. At least 30,000 gave official notice of their moves, but many did not bother with this administrative formality.

Press reports indicated that there were some problems in transporting people to some tent cities, and that some sites were perceived as too remote.

On September 6, 1999, the press reported that 600,000 are homeless, 200,000 are living on the streets, and the government is seeking 40,000 more prefabricated homes before winter (see Figures 8-6 through 8-8). As of September 18,121 tent cities containing 103,013 tents were still housing the homeless ("Aftermath of the Quake," Turkish Daily News, 18 September 1999).

Many of the displaced persons who moved back to the East were migrant laborers who moved to this highly industrialized zone because of employment opportunities offered by large companies such as Pirelli, Ford-Koç, Toyota, and the pharmaceutical, paper and pulp processing, rubber, and chemical processing industries. Other victims who relocated from the area are the upper class who can afford a temporary home in vacation

Photograph by W. Mitchell

Figure 8-6 Temporary shelter near Yalova

Photograph by W. Mitchell

Figure 8-7 Temporary shelter near İzmit

spots along the Aegean, or in other large cities. There was an obvious attempt to leave the disaster site, at least temporarily.

8.7 Turkish Red Crescent (Kızılay) and Other Organizational Response

The Red Crescent (Kızılay)was slow in establishing field kitchens on site. By Day 7, Kızılay feeding facilitates were noticed throughout the area. Many large businesses and holdings, along with private clubs and organizations, brought food to the survivors. Bottled water was donated by water bottling companies. Sanitation was a problem for days. Portable toilets were not available for several days.

Photograph by W. Mitchell

Figure 8-8 Turkish Army setting up a "tent city"

The Turkish Red Crescent (Kızılay) was harshly criticized for its slow response, and for the quality of its floorless, canvas tents (see Figure 8-9). It was also criticized for selling burial shrouds for the deceased. Perhaps the strongest criticism was of the leader of the Red Crescent, Mr. Kemal Demir, who was frequently referred to as a "dinosaur" because of his age and slow response, while reportedly living in a five-star hotel in Ankara ("Quake Provides Reminder of Turkey's Split Identity," Turkish Daily News, 26 August 1999).

Many national and international organizations responded to the disaster. The International Red Cross began an appeal for $7 million ("What about Disasters TV Crews Miss?," The Christian Science Monitor, 26 August 1999). The European Union (EU) contributed

Photograph by W. Mitchell

Figure 8-9 Canvas Red Crescent tents without floors

$2 million in emergency aid ("Devastating Turkish Quake Raises Hopes for Improved Relations with the West," Turkish Daily News, 27 August 1999), and Algeria, Jordan, Pakistan, Egypt and Japan were delivering aid at the İstanbul Atatürk International Airport by Day 3. Other foreign fundraising organizations, such as the American Jewish World Services, Baptist World Aid, Doctors of the World, Direct Relief International, Greece Red Cross, Mercy Corps, Food for the Hungry, Lutheran International, United Methodist Committee on Relief, World Relief, Catholic Relief Services, UNICEF and others, responded with financial, medical, or material assistance, or began fund drives. The European Command of the United States army sent medical supplies by air on August 24. On 25 August, the EU promised grant aid of $26 million. This was followed by the European Investment Bank announcing a $1 million grant in emergency assistance in the form of tents, blanket, medical supplies, water purification equipment, mobile kitchens and other emergency gear. The World Bank and the International Monetary Fund (IMF) announced that they would study the disaster and announce their aid programs in September ("A Worldwide Rush to Help Turkey," The Christian Science Monitor, 20 August 1999; "Quake Shatters Already Struggling Ecomony," USA Today, 24 August 1999; and "Digging Out and Moving On," US News and World Report, 6 September 1999).

The Gulf Cooperation Council member countries decided on September 10-11 to launch a project with the aim of providing humanitarian aid. A statement released by the Turkish Foreign Ministry said the project established a $400 million fund, which will be used to finance reconstruction ("The Aftermath of the Quake," Turkey Daily News, 18 September 1999).

The Turkish military was directly effected by the devastation of its Naval Headquarters at Gölcük. Casualties, including many senior or field grade officers, were high. The fault ran through the naval base.

8.8 Media Response

The press, television, and radio coverage was different from past earthquake disasters in Turkey. The coverage was continued around the clock by Turkey's private and government stations for about a week (TV5, Kanal 6, Kanal D, Star, NTV, Show TV, Flash TV, ATV, Kral, TRT 1 and TRT 3). Some regular programming started back on August 24 and most private channels had resumed regular programming by August 27. The government Turkish Radio and Television (TRT) stations continued with frequent earthquake specials and updates well into September.

On scene, live broadcasting exceeded, in volume and duration, any previous natural disaster in Turkey. Multiple television stations and newspapers strongly criticized the government for slow response in search and rescue and recovery assistance. Live broadcast scenes of victims frantically trying to lift heavy debris with their bare hands, human bodies partly protruding from the rubble, survivors pleading for help, and chaos in general, resulted in the government's Supreme Board of Television and Radio (RTUK) charging private Kanal 6 with "provoking hatred among the public towards the state" and "demoralizing the public," resulting in an order for a one week station closure. The station did not shut down during our reconnaissance, and it did appeal the closure.

The print media was even more critical of the government and military. The Turkish Daily News (TDN), a highly reputable English paper, devoted most of its coverage to the earthquake, either as related events, features, or articles. From Day 2, the TDN critically reported problems with Turkey's slow search and rescue response, the unsanitary conditions faced by the survivors, the problem with hasty and shoddy construction of apartment buildings for the influx of workers from the East, the slow response of the military, the lack of declaring martial law in the damaged region, and the Red Crescent's lack of timely response.

On the positive side, the TDN started a national media fund drive for the victims and by August 28 the newspaper had received donations nearing one-half million dollars. Before this, the TDN was apparently reprimanded by the state for its August 19 editorial addressing public unhappiness with rescue efforts, and commentary on government inability to address a type of disaster it has long experienced in the past. August 20 headlines "Total Fiasco: Public Anger Grows," in addition to reports on "Widespread Public Anger and Accusations of Criminal Negligence by the Government," followed by reports and headlines on August 21 such as "Total Fiasco Forces Administrative Shake-up" and "Frustration of Foreign Search and Rescue Teams with Lack of Government Coordination of Rescue Operations," and further reports criticizing the lack of military involvement, combined with additional stories and headlines such as "Rebellion Erupts Against the State," "First Earthquake, then the State Struck," resulted in the TDN running AP reports on the earthquake, with the following note of explanation: "Dear readers, in view of the complaint by the authorities that the Turkish press has been misleading everyone about Turkish public anger on the way they handled the quake, we have decided to use the AP wire service report as our main story" ("This is the Time to Heal the Wounds," TDN August 23, 1999).

Even with the apparent "slap on the wrist" by Ankara, the TDN continued with criticism about "how encompassing the government has become and yet it took 48 hours for it to take appropriate action after the earthquake." The August 25 headline "Rage Grows Against State, Army, after Quake Disaster" was carefully noted as an AP story. On 25 August the TDN reported that "Taxes anger people, experts warn of cover-up" in reference to the government proposed earthquake-tax on tobacco and alcohol products and further criticized the permission for contractors to remove damaged buildings before owners could have professional assessments completed. The TDN had extensive coverage on construction practices, property developers, and how improper construction killed innocent people.

The Turkish newspapers were particularly relentless on finding blame for the casualties and damages. The Hurriyet on August 18 carried headlines "Murderers" in reference to the construction contractors and developers, while the Radikal published headlines "We Have Collapsed" (August 19). The fires at the Tüpraş oil refinery received wide coverage along with the 30-kilometer traffic jam near Gölcük on Day 1 and 2. The Milliyet headlined "Ignorance in Rescue Work" and described how bulldozers were used indiscriminately while search and rescue teams were nearby (August 18). The media were very cordial and sympathetic toward the foreign assistance and aid, but exceptionally critical of the Turkish government and those condoning shoddy construction, particularly those becoming wealthy from the building industry. In Turkey, there are laws of sensitivities preventing criticism of the government leaders and its institutions. These were overtly ignored by much of the press.

8.9 Human Impact of the Destruction and Damage

Early assessments indicated that one-half of the buildings in Sakarya were damaged, many destroyed. City officials in Gölcük (population 131,935) estimated that one-third of its apartment buildings collapsed (see Figure 8-10). In İzmit (population 441,263), 42,391 buildings were reported destroyed. Total estimates ranged from 60-115,000 buildings destroyed, including 550 of the 600 buildings constructed by a single contractor.

Photograph by W. Mitchell

Figure 8-10 Ferry boat used as temporary shelter near Yalova

On August 30, the Ankara prime minister's crisis action center announced that 17,199 buildings were completely destroyed, and 25,651 were severely damaged (most were multi-storied apartment building).

As of September 18, 63,403 residences and 10,506 places of work were heavily damaged. 136,495 residences and 18,889 places of work had sustained some damage ("The Aftermath of the Quake," Turkish Daily News, 18 September 1999).

Officials from the Ministry of Disaster Works and from the Ministry of Public Works and Housing were responsible for assessing each residence and business for damage. Homes were identified and marked as either destroyed, heavily or medium damaged, or lightly damaged. From August 21 through August 26, officials were observed surveying for damages.

Photograph by W. Mitchell

Figure 8-11 Temporary banking facilities

Damage estimates ranged widely, from 7 to 35 billion dollars. Turkey's *Financial Forum* estimated the cost at 25 billion dollars. The International Herald Times estimated 20-40 billion dollars. Industrial insurance claims reported by Aksigorta are "about 2 billion dollars." The Middle East Technical University estimated replacement housing for the survivors at 10 billion dollars. The UN (as of 30 August, see "Quake Delays Tender on Turkish High Speed Train," Agence France-Presse, 31 August 1999) estimated a loss of about 10 billion dollars (see Figure 8-11).

Unemployment is a serious problem, for both the survivors and the national economy. Turkey is suffering serious inflation, and is undergoing economic measures to correct its balance of payments. The cost of rebuilding, along with the lost production and migration of workers, present a tremendous additional burden on a struggling economy.

8.10 Recommendations for Further Study

The following topics, issues, and questions should be further studied for international applicability:

- Create and practice a national quick response program for search and rescue.
- Create and practice exercising a plan for mass casualties.
- Create crisis action centers at several administrative levels (with back up communications).
- Why was there a delayed response by the well trained and equipped military?
- Is "fatalism" (*kismet*) no longer acceptable by the public? (Does God kill, or does improper construction kill?)
- Rework the entire civil defense system. What role should the Jandarma (Gendarme) have in national disasters?

- Would government implementation of Art. 119 of the Turkish constitution have helped? ("The President may direct economic and emergency rule for six months")
- How can several thousand portable toilets be provided within 24 hours?
- The impact of apparently improved international relations with Greece.
- The impact of improved relations with the European Union.
- Could the government learn from the Koç and Sabanacı Crisis Action Centers?
- What can İstanbul learn from Athen's 1981 earthquake-resistance retrofitting program?
- Will this disaster make Turkey a more liberal democracy?
- How to best train and provide all provincial centers with high-tech, dog supported emergency search teams?
- How extensive were inflated prices and theft occurrences in the disaster area (soldiers caught some thieves, rent doubled for some "safe" apartments, and some burial shrouds were reportedly sold by the Red Crescent)?
- How significant was mental illness as a result of the disaster trauma?
- What is the effect of disaster on the children (many orphaned)?
- How to best implement safe construction practices and quality control the construction?

Turkey, the United States, and other countries know that another powerful earthquake will strike again—maybe next year, maybe in 20 years. We cannot offer a precise date, but since we know more are coming, we can act now to minimize risk. The Marmara earthquake taught, confirmed, or suggested that:

- All megacities need their own search and rescue teams, trained and well equipped with state-of-the art technology;
- States can benefit by studying the retrofitting program introduced by Athens after its 1981 earthquake;
- Repeated emergency management mistakes may lead to more liberalization in unitary states;
- Most effective emergency management delegates and encourages action at all levels of administrative organizations;
- The media play a major role in changing the attitude of "fatalism;" and
- Improper and illegal construction practices—Turkey's weak chain in sustainable hazard mitigation —must be addressed and corrected.

8.11 Conclusions

Earthquakes are not new to Turkey. Six earthquake disasters since 1970 have resulted in thousands of people dying, thousands more being injured, thousands of buildings collapsing, and thousands of cattle, goats and sheep being killed, along with enormous economic losses.

The August 17, 1999 earthquake was unique in several ways. First, it covered a very large area, which included seven provinces. The total earthquake area is estimated at 5,000 sq. mi. and contains about 15 million people. Second, victims were not mostly rural villagers, but were the educated urban elite, including many of Turkey's intellectuals, wealthy businessmen, teachers, and other professionals. Third, it was located in Turkey's industrial and population heartland. Fourth, it generated an atypical outpouring of criticism by the elite and middle class against the government and military response to the disaster. Even more public anger was directed toward construction leaders and land developers. Many Turks stated they are no longer satisfied with accepting "fatalism" as an excuse, and that improper and cheap construction—not God, not earthquakes— kill people.

This preliminary survey reinforces the natural disaster literature with further evidence that poorly built, unreinforced structures, constructed on improper sites, with disregard for geology and seismology, particularly near and/or on the North Anatolian fault zone, collapse in severe or major earthquakes, with large numbers of casualties.

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Section 9
Restoration Activities

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By any standard or definition, the earthquake that struck northwestern Turkey on August 17, 1999 was a major disaster. Measuring 7.4 on the Richter scale, the earthquake was centered near the cities of İzmit, Gölcük, and Adapazarı. It damaged or destroyed over 200,000 buildings, left hundreds of thousands of people homeless, and, according to official estimates, resulted in the deaths of nearly 17,000 people. As previous sections of this report indicated, the earthquake also had a major impact on large industrial facilities in the region, and estimates of its economic impacts vary between 5 billion and 10 billion U.S. dollars. While preliminary estimates of the economic costs associated with the earthquake vary widely, actual costs will likely be substantial given the sheer magnitude of the event. Because the earthquake occurred in a largely urban and industrialized area, it resulted in widespread physical damage and severe social and economic disruptions.

This section describes activities that were initiated to restore social routines to the impacted region. Section 8 dealt with social aspects of the immediate response period, while this section focuses on the early recovery phase. Beyond their potential for physical destruction, a defining characteristic of disasters is their potential for disrupting routine social functioning. Basic social functions (e.g., transportation, lifeline systems, health care, education, and economic production, distribution, and consumption) are often disrupted when major disaster events occur. Disasters differ, however, in the degree to which they cause social disruptions. For example, some disasters may result in only brief power outages and minimal damage to structures, allowing the impacted community to resume normal functioning fairly quickly. In other cases, a community or one of its segments may go for days or even weeks without electricity, and a significant proportion of its building stock may be badly damaged or destroyed. As a result, the amount of time needed to restore daily routines increases.

Regardless of its scale, communities faced with a disaster are also faced with the challenge of restoring social routines and practices that have been disrupted. The amount of time, effort, and resources needed to restore normalcy, however, will largely depend on the scope and magnitude of the event. Figure 9-1, which depicts a scene on a busy street in Gölcük, nicely illustrates the restoration of daily routines approximately five weeks after the earthquake. As shown in the photograph, many businesses had resumed operations by that time and public transportation services had been restored. In terms of restoration activities following the earthquake, this section focuses on three basic social functions: (1) housing, (2) education, and (3) health care.

Following such a large earthquake, it is not surprising that housing is a prominent issue, and it will likely remain a major issue throughout winter and beyond. The first part of this section describes some of the major housing issues that arose following the earth-

Photograph by G. Webb

Figure 9-1 Restoration of daily activities in Gölcük (October 1, 1999)

quake, including difficulties associated with estimating the number of homeless, the establishment of large "tent cities" to house those displaced from their homes, and problems associated with tracking the numerous tent cities. The ways in which residents of these massive tent cities are adjusting to their new living arrangements is also described. In the second part of this section, the issue of restoring education in the most heavily impacted areas is discussed in some detail. Following the earthquake, officials, particularly those in the city of Gölcük, were faced with the challenge of determining when it was appropriate to resume school and deciding how best to do that. The third part of the section describes how some hospitals in the region were impacted by the earthquake and how they responded to it. Because some hospitals in the region sustained extensive physical damage, they were forced to alter their routines for delivering medical services. Those changes are described in the third section. The final part of this section presents a series of recommendations for future research on the social aspects of the earthquake in Turkey. These recommendations are aimed at gleaning lessons from this event that can be used to reduce the impacts of future disasters or improve societal responses to them.

9.1 Housing and the Earthquake

During the MCEER team's trip to Turkey (September 28 to October 5, about six weeks after the earthquake occurred), the most prominent and salient social aspect of the event was housing. Because the earthquake was so physically destructive, it displaced an enormous number of people from their homes, all of whom needed alternative living arrangements. As will be discussed below, however, for various reasons it is difficult to know exactly how many people were left without homes in the earthquake's aftermath.

Following major disasters like the one in Turkey, the provision of temporary sheltering and housing is typically a priority in early attempts to restore normal social functioning. While in the first few hours and days after a major event the focus is likely to be on immediate response activities such as search and rescue and the delivery of emergency medical services (as discussed in Section 8) the sheltering and housing process also typically begins fairly quickly. In terms of characterizing the social aspects of disasters, housing is a crucial component of the entire process.

For the most part, social scientists tend to view disasters as involving four phases or periods: preparedness, response, recovery, and mitigation (Drabek 1986). Preparedness activities are simply those things that individuals, households, organizations, and communities do to get ready for a disaster. For example, an organization may develop a disaster plan and stockpile food, water, and supplies to ready itself for a disaster event. The response phase involves the enactment of behaviors and mobilization of resources in response to an actual event. During this phase, which is also referred to as the emergency period or the crisis period, families assemble themselves, informal groups of neighborhood volunteers launch search and rescue activities, formal emergency organizations dispatch personnel and resources, and lifeline organizations attempt to restore crucial services as quickly as possible. During the recovery phase, communities begin to restore basic social functions and resume daily routines. Typically, this phase involves both short-term (up to six months after an event) restoration activities and long-term (beyond six months) recovery processes. Finally, mitigation activities are community-wide measures taken to reduce the impacts of future disasters. For example, a city may enact stricter land-use ordinances or stronger building provisions.

Clearly, the four disaster phases do not necessarily occur distinctly or sequentially; rather, they usually overlap in important ways (Neal 1997; Quarantelli 1998). For example, a household or organization may decide to develop preparedness plans only after an actual event occurs, or a community may implement a mitigation measure while recovering from an event that has already occurred. Thus, the four phase model is best viewed as a conceptual tool used to describe human social response to disaster as a process. In this context, the housing process can be seen as both a response and recovery activity. On the one hand, the provision of immediate temporary sheltering to survivors is clearly a response activity that ensures safety and provides a means of accounting for people. On the other hand, the transition of displaced people from temporary to more permanent living arrangements is clearly a sign of early recovery. In the case of the Turkey earthquake, six weeks after the event, the establishment of numerous tent cities can be viewed as an early restoration activity. Some residents had begun returning to work, and, as discussed below, these emergent living arrangements evolved into fairly complex social systems that provide many of the essential services that are typically provided by local governments.

9.1.1 Estimating the Number of Homeless

The task of estimating the number of tent cities that exist and the number of people living in them is extremely challenging. Some estimates suggest that the earthquake destroyed or badly damaged 120,000 housing units, leaving as many as 600,000 people without homes. Other estimates suggest that approximately 120,000 people are living in 200 tent cities throughout the region. In either case, the number of people left homeless in this disaster is very large, and it will be important to generate more accurate estimates as plans are developed for more permanent living arrangements.

The need for more accurate estimates is heightened due to the fact that winter can be bitter in the impacted region. Because most of the tents in which people were living at the time of the team's visit were not adequate for extreme winter weather, plans were being discussed to bring in stronger winter tents and some pre-fabricated buildings. Therefore, as officials began making housing arrangements, they could have benefited from an accurate estimate of the number of people living in tent cities.

In many U.S. disasters, it is not uncommon for officials to drastically over-estimate public housing needs because they sometimes do not recognize that many of those who are displaced go to live with friends or relatives whose homes were not destroyed. It is likely that similar patterns occurred in response to the Turkey earthquake and that these patterns may have complicated census-taking efforts. For example, in the mountains surrounding Gölcük and Adapazarı, two cities that were very heavily damaged, there are many small villages from which people migrated to live in the larger cities. And many people from other parts of the country that may be much further away have migrated to these more urbanized and industrialized cities to find work. Following the earthquake, it was not known how many people returned to their places of origin to live with friends or relatives and exactly how many people remained in the two cities. It may have been easier for people from the surrounding mountain villages to return home, whereas people from more distant places in Turkey may have been less likely to leave the area after the earthquake.

In either case, officials do know that there has been some migration, but they do not know how much. For example, a health official in Adapazarı indicated that prior to the earthquake, approximately 200,000 people lived in the center of the city. After the earthquake, this official estimated that only about 50,000 to 70,000 remained in the city. Similarly, an official in Gölcük, which had a population of about 75,000 prior to the earthquake, indicated that about half that many remained in the city after the earthquake.

In addition to internal migration patterns and survivors' reliance on existing social networks of support, there are other reasons why it is difficult to officially estimate the number of people left homeless by the earthquake. For example, another major impediment to obtaining an accurate census is that many people (exactly how many is not known) whose homes were not badly damaged are nevertheless reluctant to reenter their buildings. Since the earthquake occurred, there have been several major aftershocks that have instilled hesitancy on the part of survivors.

Additionally, some officials indicated that although several groups and organizations are developing counts for various purposes, they are not coordinating those efforts closely enough. For example, some groups are taking counts in order to make arrangements for the delivery of mental health services, and others may be trying to order appropriate amounts of certain supplies. With so much activity going on, however, it is very difficult for these various groups to collaborate with each other and coordinate their efforts. The result, then, is that various groups and organizations are taking counts for their own purposes, and these numbers are not being shared.

In most disaster situations, research has shown that both inter- and intra-organizational coordination are often difficult to achieve because circumstances change rapidly and because numerous organizations (many of which have no mandate or responsibility for emergencies) become involved in the overall community response (Dynes 1970). In situations where various organizations are not familiar with one another and lack established patterns of interaction and coordination, it is not uncommon for these kinds of problems and issues to arise.

9.1.2 Three Types of Tent Cities

Although it was not possible at the time of the team's visit to know exactly how many tent cities existed and how many people were living in them, it was possible to describe the tent cities and how residents adjusted to living in them. Basically, displaced people in the impacted area who have not sought shelter in other locations were living in three different types of tent cities: (1) those organized by the military, (2) those organized by non-government organizations and private corporations, and (3) those that are informally organized. In reality, it is difficult to classify individual tent cities because there is some overlap among these general types. For example, a tent city organized and run by the military may also offer some services to residents that are performed by a voluntary or non-government organization. Similarly, a tent city organized by a private corporation may integrate non-government organizations into its service delivery system and rely on military personnel to provide security. In a very general sense, however, it is useful to organize the numerous tent cities into these three general types.

In terms of size, the largest tent cities seem to be those that are organized either by the military or by private corporations or non-government organizations. At one of the military-run tent cities in Gölcük, for example, 3,000 people are living in tents that cover a large land area (shown in Figure 9-2). Another tent city in Gölcük set up by a large manufacturer in the area houses approximately 3,700 people. Informal tent cities, which are comprised mainly of neighborhood groups living outside in tents near their homes (which may or may not be badly damaged), are scattered throughout the region and tend to be

Photograph by G. Webb

Figure 9-2 A military-run tent city in Gölcük

Photograph by G. Webb

Figure 9-3 An informal tent city

comparatively small (see Figure 9-3). It was difficult at the time of the visit to ascertain the proportion of people living in the various types of tent cities for the same reasons discussed above. For example, the crisis response center in Gölcük reported the existence of 12 tent cities in Gölcük, but one administrator knew of at least 21 different tent cities. A more accurate count may improve the efficiency and effectiveness of the delivery of needed supplies, and it may ultimately help in the arrangement of adequate provisions for the future, particularly for winter.

A more accurate census of tent cities and people living in them would also make it possible to compare the different types along several dimensions. For example, on the one hand, a clear benefit of the informally organized tent cities is that they allow primary social groups (i.e., families, extended families, and close friends) to live near each other and rely on each other for social support. While administrators of the other two types of tent cities have tried to keep these groupings intact, they are less able to do so as these tent cities increase dramatically in size and as space becomes less plentiful in them. On the other hand, the larger military- and volunteer-run tent cities may be able to offer a wider range of services to residents, including large kitchens, pharmacies, counseling services, entertainment, and kindergarten for small children. For example, at one of the large military-run tent cities in Gölcük, a civic group from İstanbul (which had no prior involvement in disasters) established a kindergarten for young people.

This involvement of non-emergency organizations in providing services after the earthquake is similar to what occurs in many U.S. disasters, and, as will be discussed in the concluding remarks section, it is an issue that should be explored further through cross-cultural and cross-societal comparisons of disaster responses. If there are important differences in the type and quality of services offered at the various types of tent cities, and if there are certain benefits and limitations to each of them, they should be used as lessons for future disasters when mass numbers of people must be temporarily relocated.

9.1.3 Adjusting to Daily Living in the Tent Cities

Following major disasters like the one in Turkey, the establishment of tent cities serves several important functions: it provides necessary shelter from the elements; it re-establishes and reaffirms community and collective solidarity; and it begins to provide a stable base from which people can start to restore their daily routines. In some of the large military- and volunteer-run tent cities, for example, meals are served at certain times each day, residents engage in routine religious rituals and perform basic routines like doing laundry, young people play soccer and attend kindergarten, and some adults leave each morning to go to work. Just across the street from one of the tent cities, a market has emerged that provides residents a place to go to purchase basic items. And local bus companies have altered their routes to provide transportation from the tent cities to various points throughout the city. All of these examples illustrate the point that when social routines are severely disrupted, individuals, groups, and organizations improvise and adapt in creative ways as they attempt to restore normalcy to the social order (Bosworth and Kreps 1986; Kreps and Bosworth 1993; Quarantelli 1996; Webb 1998).

One of the most important issues that individuals and families face under these circumstances is the challenge of making a temporary living arrangement into a home that provides all its members with safety and comfort. In a social psychological sense, this means rebuilding or re-establishing an attachment to place that provides security and stability in daily interactions. When a major disaster disrupts a group's attachment to place, its members interact to develop a new definition of the situation that gives meaning to their experiences and guides them through their interactions with others.

One of the most noticeable things about life in a large tent city is that residents have almost no privacy. In this kind of living arrangement, virtually every aspect of an individual's life is on public display. To minimize or alleviate that problem, residents often adapt in some very creative ways. For example, occupants of a tent will make additions that divide it into two separate spheres: a front area where they can sit and talk with others, and a back area where they sleep and prepare for the day. Figure 9-4 nicely illustrates how this

Photograph by G. Webb

Figure 9-4 A "renovated tent"

Photograph by G. Webb

Figure 9-5 A tent under construction

is accomplished. In Figure 9-5, a tent is shown that is "under construction," and Figure 9-6 shows a finished product that actually resembles a small house.

In a sociological sense, these innovations are very meaningful because, although there are important cultural differences, the separation of public and private spheres is a crucial component of social life. In their interactions with others, individuals make decisions about what things to openly present in the front stage region and what things to display only in the back stage region (Goffman 1959). In a very basic sense, for example, housing units in many cultures are designed with a living area intended to be on display to guests and a sleeping area that is typically not openly displayed. By making these kinds of additions to their tents, many of which are fairly elaborate, residents of the tent cities are redefining a fundamental aspect of their social lives.

Residents are also engaged in the process of building new social relationships and a sense of community. For example, as shown in Figure 9-7, the residents of a particular row of

Photograph by G. Webb

Figure 9-6 A finished product

Photograph by G. Webb

Figure 9-7 A "street sign" in a tent city

Photograph by G. Webb

Figure 9-8 Graffiti in Gölcük

tents in a very large tent city in Gölcük gave themselves a street name and erected a sign bearing the words "Save Me Street" (translated). This example nicely illustrates how under conditions of extreme stress people rely on each other and the relationships they have to give meaning to their experiences. Similarly, in other cases, community members often spray paint graffiti after disasters to express either messages of hope and collective solidarity, discontent with the official response, or simply convey basic information. As shown in Figure 9-8, residents of one tent city stretched large white banners across a fence surrounding a playground and painted various things on them, including the slogan "Let's not Forget Gölcük."

These expressions of solidarity and hope may account for some of the debate about the delivery of mental health services following major disasters (Quarantelli 1985). In many U.S. disasters it is often assumed that these services will be widely needed, but in many cases survivors do not seek out that kind of assistance. At some of the tent cities in Turkey, there have also been some concerns that residents are not utilizing mental health services to the degree that they should. There may be two reasons why disaster survivors do not always seek mental health services after a major event: first, they may find comfort and support in their interactions with significant others who have also experienced the event; and second, some of the mental health consequences may not necessarily be negative. As some of the examples above show, when a community has been severely disrupted, its members rely on existing social relationships and newly formed ones in coping with the emergency and beginning to restore normalcy to their lives. Sometimes disasters may enhance, if only temporarily, the collective solidarity felt by members of a community because they all share a common experience. Clearly, there is a need for more research on the mental health consequences of disasters, and the earthquake in Turkey provides a setting where important cross-cultural and cross-societal comparisons can be made.

9.2 Restoration of Education After the Earthquake

Another basic social institution that is often disrupted in a disaster and that must be restored, is education. In addition to providing young people knowledge they need to become adult members of a society, schools also serve the crucial function of keeping a substantial portion of a population occupied and on a rigorous daily schedule. When that schedule is interrupted, a certain amount of ambiguity and confusion is created, so officials typically try to resume school as quickly as possible. Their concern is often not only to get students back in school for learning purposes, but also to give structure and meaning to young people's lives in a period of confusion and disruption. The restoration of daily activities, including school for children, is a crucial part of community response to and recovery from a disaster.

The earthquake in Turkey occurred almost one month before schools across the country were originally scheduled to begin on September 15. Schools in many areas did begin as scheduled, but when a major aftershock occurred on that same day, all school openings were indefinitely postponed. Ultimately, schools in areas such as İstanbul that did not sustain heavy damage began operations on Monday, October 4. Even that caused some controversy because many parents in those areas did not understand why their children were being held out of school for so long. In more heavily damaged regions, such as Gölcük, it was hoped that school could begin in early November, significantly later than originally planned.

There are several reasons why the opening of schools in Gölcük was delayed for such a lengthy period of time. First, some of the school buildings themselves sustained heavy damage, so pre-fabricated structures or large tents would be needed to conduct classes. Second, many teachers, students, and parents expressed major concerns about reentering even those school buildings that had not been badly damaged in the earthquake. Finally, in Gölcük it was not known how many students in the area would be returning to school. As was discussed above in relation to housing issues, migration patterns strongly affected the population of students in the most severely impacted areas, and that made it difficult to estimate the number of returning students for whom plans should be made. Many students were believed to have returned with their families to either villages in the surrounding mountains from which they came or to more distant parts of the country to live with relatives or close friends. A school official in Gölcük, for example, estimated that only 10,000 of the area's 28,000 students would return to school.

To facilitate the opening of schools in the most heavily damaged regions, the Turkish government commissioned one of the major universities to become involved. According to some of those involved in the project, the commission has two major goals: first, to get an accurate estimate of the number of students who will be returning to school; and, second, to conduct focus groups with teachers, students, and parents to better understand their anxiety about reentering school buildings that were not damaged.

Some school officials, however, indicated that this approach may not be the most efficient and effective way to go about restoring school to the most badly damaged areas. For example, one official suggested that it may be more productive to establish schools throughout the region in large tents and see how many students report. If the demand were to exceed the number of tent schools established, then additional ones could be set up. This case illustrates that a major disaster can disrupt even the most basic social institutions and that key participants often have differing perspectives on how to respond. In some disasters, such as the recent earthquake in Taiwan, schools resume fairly quickly, but there are certainly times when a prompt restoration is not possible. Thus, there are important lessons to be learned from the recent earthquakes in terms of understanding barriers to the restoration of basic social institutions and identifying strategies that are particularly effective.

9.3 Health Care Facilities and the Earthquake

Another basic social function that is sometimes disrupted in major disasters is health care. These disruptions occur either because the number of fatalities and injuries exceeds the health care system's capacity to respond or the health care system itself sustains physical damage which affects its ability to deliver services. In either case, this is another area in which the social system often becomes very flexible and adaptive in meeting heightened emergency demands.

In both İzmit and Adapazarı, several hospital buildings experienced major physical damage during the earthquake. At a hospital in İzmit, for example, two buildings and the pedestrian walkway connecting them sustained serious damage from the shaking. Immediately after the earthquake, medical staff were forced to evacuate the building and move existing patients outside. As people began bringing the injured to the hospital's emergency department, it quickly became congested and overcrowded. To alleviate the crowding, hospital staff began assembling the injured in a school yard across the street, sorting and tagging them by severity of injury, and transporting them to other regional facilities. Similarly, existing patients who could not simply be discharged early were also transferred to other facilities.

What is most interesting about this particular hospital is that even five weeks after the earthquake, staff still had not yet reentered the buildings. On two occasions they tried to reenter, but when major aftershocks occurred, they returned outside. Because they were forced to set up operations in tents in the parking lot (shown in Figure 9-9), the hospital

Photograph by G. Webb

Figure 9-9 A hospital in İzmit

has been unable to resume its normal functioning. For example, minor injuries are treated, basic exams are conducted, and medications are dispensed, but it is not possible to perform major medical procedures. This case shows that even emergency relevant organizations such as hospitals can themselves be impacted by disasters, and, when they are, they must become flexible and adaptive under the circumstances.

Similarly, a major hospital in Adapazarı sustained extensive physical damage to its buildings. In particular, two of the facilities five buildings were damaged, forcing staff members to move existing patients outside. As was the case in the previous example, existing patients and new arrivals were assembled outside, sorted and tagged by severity of injury, and transferred to other regional hospitals or field hospitals set up by international relief organizations. According to one official, this process created some confusion at the hospital because staff members were not able to document all of the victims who were seen and transferred. The receiving hospitals later created detailed lists and sent them back to this facility, but the delay in that process created some confusion as concerned people came to the hospital looking for their friends or relatives. This official also indicated that for a short period of time there was a shortage of trained medical staff in the immediate aftermath of the earthquake. That problem was resolved, however, as volunteers quickly began arriving. The same official pointed out that this staff shortage existed in Adapazarı even before the earthquake.

While staff members have reentered the facility in Adapazarı, the hospital still had not resumed its normal functioning at the time the research team visited. For example, major medical procedures still were not being performed at the hospital, and staff from other cities who came to volunteer were still living in tents in the parking lot. At the time the team visited, the hospital in Adapazarı had focused its activities on providing broader public health services. For example, officials began producing and distributing brochures and pamphlets that describe how to treat water, prepare food, and avoid bacterial diseases. In addition, local health officials have been involved in monitoring the city's supply of clean water, much of which was being hauled in by tankers from a nearby lake. One official gladly reported that there have been no major outbreaks of bacterial diseases in the region, in large part because of the activities undertaken by staff members at the hospital.

These examples of hospitals in Turkey highlight two important points. First, they clearly show that health care facilities, which are usually assumed to be operational in mass emergency situations, can sometimes experience physical impacts themselves. And, second, when hospitals are impacted by disasters, their basic structures and functions are often altered to meet heightened demands created by the emergency. Although these alterations and innovations are often functional and adaptive, they may sometimes be dysfunctional and maladaptive. In either case, it cannot be assumed that hospitals will always be operational in the aftermath of a major disaster event. In fact, surprisingly little research has been done that documents exactly how prepared hospitals are for disasters and how they actually function when disasters do occur. Clearly, this is an area where much more research is needed, and the earthquake in Turkey provides a situation where cross-cultural and cross-societal comparisons can be made in describing and understanding how hospitals function under stress.

9.4 Concluding Remarks and Future Research Needs

This section described some of the early restoration activities following the earthquake in Turkey. In particular, it focused on three essential social functions: housing, education, and health care. In terms of housing, the section described the difficulties associated with estimating the number of people left homeless by the earthquake, three different types of tent cities that have been established to meet housing needs resulting from the earthquake, and various ways in which people are adapting and adjusting to daily life in the tent cities. The section on education highlighted the importance of restoring education in providing daily routines for young people, discussed several reasons for the delay in resuming schools in the most heavily damaged areas, and described various strategies proposed for restoring education in those areas. Finally, the section on health care facilities focused on two hospitals in İzmit and Adapazarı, describing how they were impacted by the earthquake, how they functioned during the immediate response period, and how they were functioning at the time of the team's visit.

In all three areas, it was shown that disasters have a strong potential for disrupting even the most basic social functions and that the process of restoring those functions can be very difficult and challenging. It was also shown, however, that even under the most stressful circumstances, individuals, groups, and organizations can be very creative and adaptive in responding to major social disruptions. Although it can be a long and sometimes controversial process, most communities do recover from even the most devastating disasters, which underscores the resilience of human social systems under stress (Fritz 1961). Clearly, the topics addressed herein point to only the early stages of recovery, and the entire process will likely take a significant amount of time, effort, and resources.

This last section draws out some of the future research needs that were mentioned in the previous sections and presents others that were not explicitly stated. There are several areas in which the earthquake in Turkey provides a setting in which interesting cross-cultural and cross-societal comparisons can be made along several dimensions. First, at a very basic and descriptive level, it would be useful to do further research on the various organizations that have become involved in the response to and recovery from the earthquake. As was described in the previous sections, various organizations, many of which have no defined disaster responsibilities, have become involved, and many of those that do have disaster responsibilities, such as hospitals, have significantly altered their basic structures and functions. This kind of organizational innovation and adaptation has often been documented in studies of U.S. disasters, so there is a unique opportunity to make comparisons with the situation in Turkey. These studies can either document how specific types of organizations, such as hospitals, responded to the earthquake or focus on the issue of inter-organizational coordination between various types of organizations. This kind of research can be readily translated into lessons learned and ultimately usefully integrated into the practice of emergency management.

The broader issue of social recovery is another area in which important cross-cultural comparisons can be made. Several studies have looked at the process of household (Bolin 1994) and business recovery (Dahlhamer and Tierney 1998; Tierney and Dahlhamer 1998; Webb, Tierney and Dahlhamer forthcoming) in the U.S., so the earthquake in Turkey presents an opportunity for comparative research. There are several important areas in which the earthquake in Turkey can improve our broader understanding of community recovery as a social process (Nigg 1995). For example, future studies might document the impact of this event on the collective memory of the people who experienced it and assess the degree to which it may or may not affect subsequent mitigation decisions aimed at reducing the impacts of future disasters. Along those same lines, it will be interesting to measure the local, regional, national, and international economic impacts of the earthquake and monitor the progress of economic recovery. As one example of this, officials in Gölcük have already expressed differing views of how best to promote economic recovery—some want to rebuild the existing downtown business district, while others want to relocate it away from the sea and closer to the mountains. These kinds of perspectives and debates will likely intensify in the coming months, and that process should be studied.

In addition to studying the process of economic recovery, there is a tremendous amount to be learned from studying the transition of earthquake survivors from temporary to permanent housing. On a practical level, there are valuable lessons to be learned from this case as officials try to place tens or even hundreds of thousands of people in more permanent living arrangements. And, on a conceptual level, it will be important to understand how individuals, families, and groups construct meaning in their daily lives in the tent cities and beyond and how they re-establish their attachment to place under conditions of such extreme uncertainty.

Future research should also be done to explore the many political implications of the earthquake (Sylves 1998). For example, some commentators have suggested that the earthquake has promoted a certain critical sentiment among Turkish citizens and that for the first time they are speaking out against their government and criticizing its response to the disaster. Others have suggested that the sympathetic outpouring of international relief reflects improved relations between Turkey and other nations. Whether these changes were induced by the earthquake or simply accelerated by it, the political dimensions of this disaster will also be important to consider.

Finally, as some of the other sections in this volume demonstrate, the recent earthquake in Turkey also provides a setting in which to assess the applicability and utility of advanced damage assessment technologies and loss estimation methodologies. Moreover, there is a need for research that describes what technologies have been employed in responding to and recovering from the earthquake, assesses their utility, and identifies areas in which technologies can be improved to enhance response capabilities.

As shown in this section, there are numerous research needs stemming from the earthquake in Turkey. Whether the knowledge gained from that research is used to promote disaster preparedness, enhance emergency response, facilitate social recovery, or suggest certain mitigation measures, there is a tremendous amount to be learned from this event. Ultimately, the lessons learned from this earthquake should be translated into measures that either reduce the impacts of future disasters or improve societal responses to them.

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Section 10
The Marmara Earthquake: A View from Space

Ronald T. Eguchi and Charles K. Huyck
EQE International, Inc.

Bijan Houshmand
Jet Propulsion Laboratory and the University of California at Los Angeles

Babak Mansouri and M. Shinozuka
University of Southern California

Fumio Yamazaki and Masashi Matsuoka
Earthquake Disaster Mitigation Research Center

Suha Ülgen
Interactive Media and Geographic Information Systems (IMAGINS), Inc.

The Marmara earthquake occurred during a time of unprecedented technological development. Post-disaster information and data that once took months to generate were developed within a matter of days in this event. Furthermore, the ability to comprehensively understand the meaning of these data was significantly enhanced because of the use of sophisticated database management programs and geographical relational algorithms, e.g., geographic information systems, (GIS). In the most general sense, we were able to literally map the effects of the earthquake in "real time."

One area that has benefited immensely from this technology explosion is earth observation and mapping. From over a dozen different platforms, we are able to view and quantify with surprising precision the different properties of the earth's surface. Topographic features are clearly seen from low earth-orbiting optical satellites. Urban areas are also visible in these images. In addition, using an analysis technique called "interferometry," it is possible to detect minute changes in the earth's surface by comparing a series of radar images taken at different times. It is from the perspective of testing the use of advanced technologies for post-earthquake reconnaissance that we provide our analysis of the Marmara earthquake.

The following discussion offers a preliminary report on a joint reconnaissance effort between MCEER and the Earthquake Disaster Mitigation (EDM) Research Center in Miki, Japan. This reconnaissance took place approximately one and a half months – between September 28th through October 4th - after the disastrous main shock of the Marmara earthquake. The team leaders were Ronald T. Eguchi of EQE International, who led the MCEER team and Professor Fumio Yamazaki of Tokyo University, who led the EDM team. The following sections discuss the purpose of the trip and the meetings that were held, the new technologies that were used during this reconnaissance trip, a "thumbnail" sketch of specific in-field studies that were conducted, and finally, the usefulness of these advanced technologies in assessing damage from this devastating event.

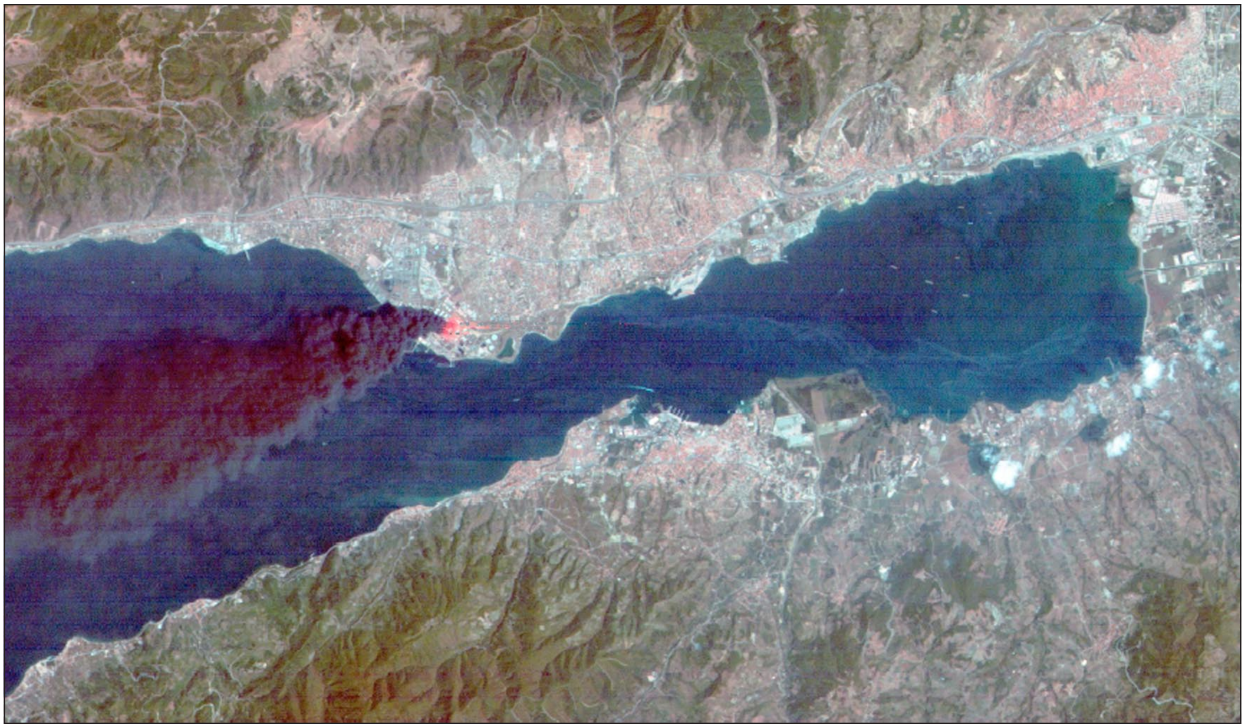


Image provided to EQE International by the European Space Agency under a cooperative research agreement established for this earthquake. Image details: RGB mapping of 721, replacing the red band with the far infrared band. A Gaussian filter was applied to maximize visibility of the smoke.

Figure 10-1 Landsat 5 Image of İzmit Bay taken on August 19, 1999. Note the fire and smoke plume originating from the Tüpraş Refinery, seen at the center of the figure.

10.1 Purpose of the Trip

This reconnaissance trip had three main objectives:

1. To conduct high level reconnaissance using satellite imagery, Differential Global Positioning Systems (GPS), and in-field GPS-GIS interfaces
2. To validate damage information contained in early U.S. State Department Damage Maps
3. To reinforce the collaborative activities between MCEER and EDM.

The collaboration with EDM has been ongoing since the 1994 Northridge earthquake in the U.S. and the Kobe earthquake in Japan (1995). Both Centers have committed substantial resources to explore the use of advanced technologies for natural disaster management. The investigation of the Marmara earthquake represents the latest collaboration between these two organizations.

The investigation team consisted of seven researchers. Owing to the diverse research interests of the two centers, the investigation team was multidisciplinary and focused on various aspects of the earthquake. The team is listed below for each center:

MCEER:

1. Ronald T. Eguchi, EQE International (Team Leader)
2. Charles K. Huyck, EQE International (GIS)

3. Bijan Houshmand, Jet Propulsion Laboratory and the University of California at Los Angeles (Remote Sensing)
4. Babak Mansouri, the University of Southern California (Radar Imagery)
5. Gary Webb, the Disaster Research Center at the University of Delaware (Social Impacts)

EDM:

1. Fumio Yamazaki, Tokyo University and the Earthquake Disaster Mitigation Research Center (Team Leader)
2. Mashashi Matsuoka, EDM (Remote Sensing)

In addition to this research team, several Turkish companies provided invaluable support.

Collaborators in Turkey:

1. Suha Ülgens, Interactive Media and Geographic Information Systems (IMAGINS)
2. Serkan Bozkurt, IMAGINS
3. Turgay Türker, Türker Engineering (Structural Engineering)

10.2 Itinerary

The itinerary for the trip was established several weeks before departing for Turkey. The trip consisted of meetings with Turkish researchers and investigators, and brief field visits to several of the hardest hit areas. The details of the field visits are discussed in more detail later in this section. Provided below are brief summaries of the meetings that were held during the first two days of this trip. Table 10-1 summarizes the itinerary for this trip.

Table 10-1 Itinerary

Date	Meeting/Visit
9/30/99	• Mustafa Erdik, Kandilli Observatory and Earthquake Research Institute, Boğaziçi University • Field Visit to Avcılar
10/1/99	• TÜBİTAK Marmara Research Center: Earth Sciences Research Institute • TÜBİTAK Marmara Research Center: Space Technologies Group • Field Visit to Seymen • Field Visit to Gölcük
10/2/99	• Field Visit to Adapazarı
10/3/99	• Field Visit to Seymen • Field Visit to Gölcük

During our visit with Professor Mustafa Erdik at the Kandilli Observatory and Earthquake Research Center of Boğaziçi University, the research team was able to ask general questions about the extent of damage to western Turkey. We found that although the earthquake was initially named after one of the cities closest to the main shock (i.e., İzmit), damage in this area was not as severe as other areas further away from the epicenter. We were told that Gölcük (located on the southern side of İzmit Bay and roughly 80 kilometers east of İstanbul) and Adapazarı (located roughly 125 kilometers east of İstanbul) had experienced far more damage than the town of İzmit.

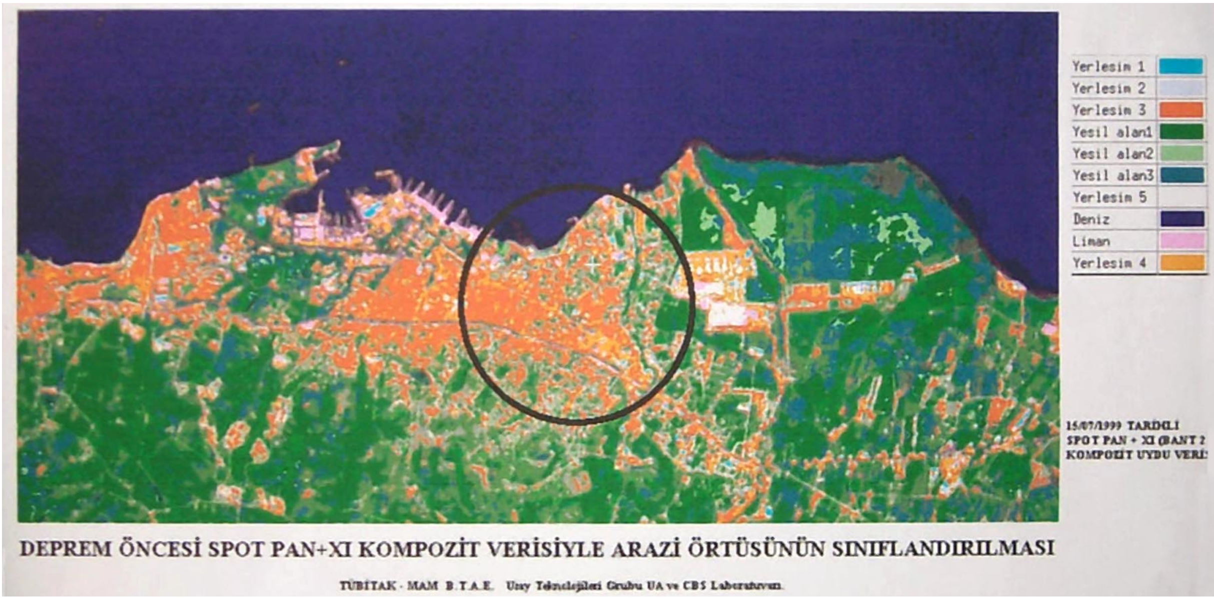
We were also shown preliminary ground motion records from this event, learning that the peak ground acceleration in Adapazarı reached about 40 percent g. At the time of our visit, a number of portable instruments were being installed in order to record ground motions from large aftershocks. Before leaving this facility, the MCEER/EDM team was given a tour of the Kandilli Observatory Laboratory where we viewed other ground motion data that was being collected.

At TÜBİTAK (Turkish Scientific and Technical Research Institute) Marmara Research Center, several different meetings were held. The first meeting was with the Earth Sciences Research Institute where the team met with Dr. M. Namık Yalçın, the Director of the Earth Sciences Institute at TÜBİTAK Marmara Research Center, and Dr. Semih Ergintav, a member of the Earth Sciences Research Institute. The purpose of this meeting was to determine the availability of GPS information for the earthquake. The team was particularly interested in collecting data on post-earthquake displacements for towns that were hardest hit by this earthquake. This information would be used to compare permanent ground displacements calculated using Synthetic Aperture Radar (SAR) with those derived from the continuous GPS network. We understood that a continuous GPS system was in place at the time of the earthquake and that displacements at several sites were being monitored. We also understood that the primary interest in these data was to map the co-seismic slip of the fault, and not the relative tectonic movement of the region. The results of this work were presented at the Annual American Geophysical Union meeting that was held in San Francisco in December 1999.

The second meeting was held with the Space Technologies Group at TÜBİTAK. The investigation team met with Dr. Hülya Yıldırım, the Director of Remote Sensing and Geographic Information Systems at the Marmara Research Center. Before the earthquake, this group was involved with numerous environmental and agricultural studies. One study involved the preparation of watershed maps for the five provinces surrounding İzmit, which is in the province of Kocaeli. After the August 1999 earthquake, this group was assigned the responsibility of producing GIS maps that documented damage in the İzmit area. While lacking any prior earthquake experience, this group immediately began integrating available GIS maps with satellite imagery to identify those urban regions that were most affected by this event.

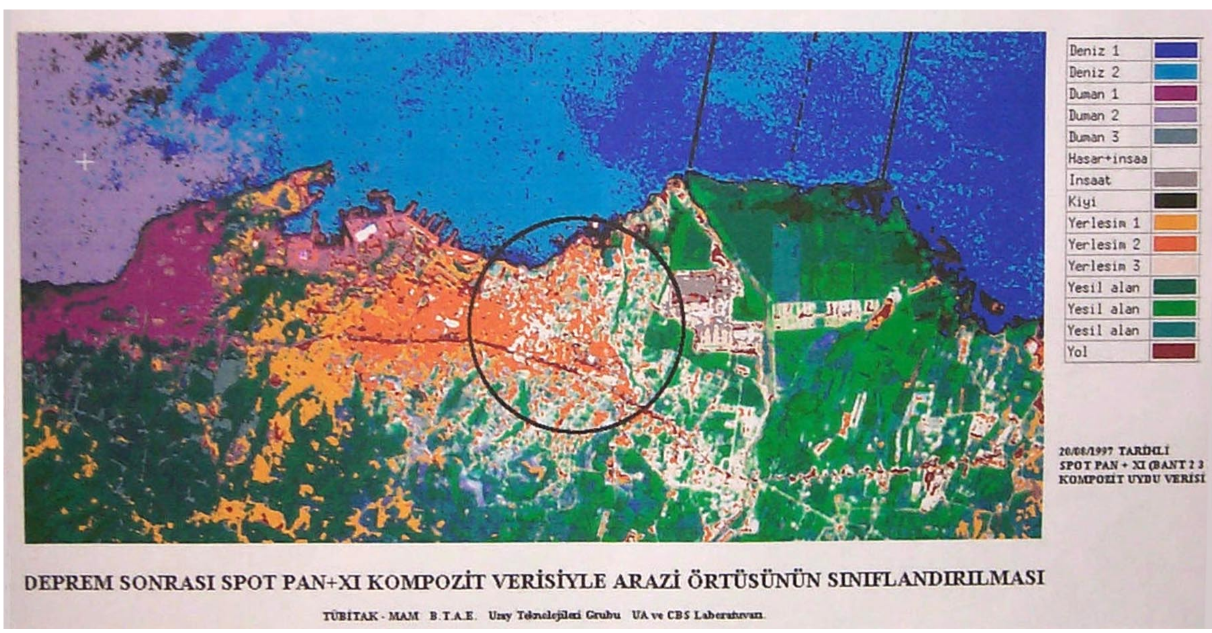
One analysis, which was based on a comparison of pre- and post-earthquake SPOT[1] images, showed large areas in Gölcük that were clearly affected by the earthquake. Several of these images are shown in Figures 10-2 and 10-3. In addition, other satellite-derived images showed extensive areas along the shore near Gölcük that were inundated as a result of ground subsidence caused by liquefaction. Figure 10-4 shows an aerial view of the inundation area.

[1] SPOT is a French company that provides satellite imagery data throughout the world. SPOT stands for Satellite Pour l'Observation de la Terra.



Source: TÜBİTAK

Figure 10-2 Landuse Map developed from SPOT image after earthquake (July 7, 1999). The different colors/shades represent various levels of development or open areas. The circle surrounds the town of Gölcük. Note that the harbor is located just to the left of the circle.



Source: TÜBİTAK

Figure 10-3 Image of Gölcük created after the earthquake. (SPOT image taken on 8/20/99). Note that the white or light areas identify city blocks where significant damage to buildings occurred.

Photograph by D. Andrews

Figure 10-4 Aerial view of earthquake damage in Gölcük. This area was affected by ground subsidence caused by liquefaction.

10.3 Field Investigations

During this trip, the MCEER/EDM team was able to survey earthquake damage in four areas: Avcılar, Seymen, Gölcük and Adapazarı. Where possible, we applied GPS technology linked with GIS systems to record damage information. In addition, satellite imagery and aerial photographs were available for some areas. The following sections discuss the data that were collected, the technologies that were used in recording this information, and the analyses that have been performed – since our return – to interpret the effects of this earthquake. Before discussing these field investigations, we discuss very briefly the technologies that were used on this trip.

10.3.1 New Technologies

Radar Images. The MCEER/EDM team was fortunate to obtain numerous satellite images of the İzmit area prior to its departure. Through a cooperative research agreement with the European Space Agency (ESA), EQE International received a series of radar images, both before and after the earthquake, via the ERS-1 and ERS-2 satellites. A tabulation of these data is listed in Table 10-2. As will be discussed later, several of these scenes (i.e., images) are being used to create interferograms that will hopefully identify areas of significant damage.

The project team also received post-earthquake Radarsat images of western Turkey. These, however, were received after the team returned from Turkey. We have yet to process this information.

Optical Satellite Images. In addition to the radar data, ESA also provided Landsat 5 images taken several days after the earthquake. Figure 10-1 shows a Landsat 5 image of

Table 10-2 ESA Synthetic Aperture Radar (SAR) Data and Images

Date (mm/dd/yy)	Track	Frame	Orbit	Product
06/07/95	336	2781	20364	RAW or SLC
06/08/95	336	2781	00691	RAW or SLC
10/15/98	336	2781	18226	RAW or SLC
12/24/98	336	2781	19228	RAW or SLC
03/04/99	336	2781	20230	RAW or SLC or PRI
03/20/99	064	2781	20459	RAW or SLC
04/05/99	293	2781+2 nodes	20688	PRI
04/24/99*	064	2781	20960	RAW or SLC
08/12/99	157	819-4 nodes	42229	RAW or SLC or PRI
08/13/99	157	819-4 nodes	22556	RAW or SLC or PRI
08/17/99	**EARTHQUAKE**			
08/23/99	293	2781+2 nodes	22692	PRI
08/25/99	336	2781	42408	RAW or SLC or PRI
08/26/99	336	2781	22735	RAW or SLC or PRI
09/10/99*	064	2781	42637	RAW or SLC
09/11/99	064	2781	22964	RAW or SLC
09/16/99	157	819-4 nodes	42730	RAW or SLC
09/17/99	157	819-4 nodes	23057	RAW or SLC

Note: RAW refers to unprocessed data; SLC is single look complex; and PRI is precision averaging. Asterisks refer to scenes that were used to create interferograms for this event

Source: ESA

the İzmit Bay region. Visible in this image is the fire that occurred at the Tüpraş Oil Refinery, approximately 70 kilometers southeast of İstanbul.

Aerial Photographs. Some aerial photos were taken of the affected areas; these, however, have yet to be widely distributed. One photo was published in a local İstanbul newspaper. The photo was scanned by one of our collaborators in Turkey (IMAGINS) and was used during our field survey of the Avcılar area. This is discussed further in the next section.

Global Positioning Systems. Two separate GPS systems were used in the field during this investigation. The first was a high-precision single-frequency 12-channel NovAtel GPS receiver. This system was generally used while driving through the different study areas, see Figure 10-5. A second system – a handheld Magellan unit – was used when field studies were conducted on foot.

Real-time GPS-GIS Interface. One of the major improvements in documenting the effects of this earthquake was the use of a real-time GPS-GIS system. Using the GPS systems mentioned above, the MCEER/EDM team was able to associate damage information,

Photograph by R. Eguchi

Figure 10-5 Vehicle used to collect damage/GPS data in Avcılar and Adapazarı. Note the antennae being held by front passenger.

including photographs, with accurate geographical coordinates. Where there was real-time Differential GPS broadcast over FM-RDS, which was the case in Avcılar, the positional accuracy was one meter or less. When using the handheld Magellan unit, the accuracy level dropped to plus or minus 30 meters. Figure 10-6 shows the equipment setup for this GPS-GIS interface. One of the advantages to using this system was that the investigation team was able to create reasonably accurate road maps when none were available. These maps were created by plotting GPS coordinates (while in transit) directly

Photograph by M. Matsuoka

Figure 10-6 Real-time GPS-GIS setup for in-field data collection and processing

Source: IMAGINS

Figure 10-7 Aerial photograph of the city of Avcılar. Shown on this figure are sites (identified by small circles) visited by the MCEER/EDM team in September 1999.

onto Landsat 5 imagery. The interface between the NovAtel GPS receiver and the MapInfo GIS software was provided by GeoTracker from Blue Marble Geographics.

10.3.2 Avcılar

Avcılar is located in the southwestern part of İstanbul bordering the Marmara Sea. Although located roughly 80 kilometers from the epicenter of the August 17, 1999 earthquake, there was substantial – but isolated – damage to multi-story residential buildings. At the time of our visit, most of the severely damaged structures had already been demolished. Since there was very little to record, other than the location of these demolished buildings, the team opted to use this time as an opportunity to refine and calibrate our GPS-GIS data collection system.

Figure 10-7 shows an aerial photo of the part of Avcılar that we focused on. Visible on this photograph – scanned from a newspaper article – is the shoreline facing the Marmara Sea, at the bottom of the figure.

In this part of Avcılar, there were about a dozen buildings that experienced significant damage, resulting in complete collapse of the structure, or substantial damage requiring demolition of the building. While traveling to each of these sites, the investigation team utilized the real-time Differential GPS-GIS system. With accuracy levels within one meter, we were able to record the precise location of each of the demolished buildings. This information will be used to assess whether these particular sites can be recognized from either satellite imagery or aerial photos. Most other structures in this area experienced little, if any damage.

10.3.3 Seymen

Seymen is located on the southern side of İzmit Bay, just east of Gölcük (40^{o} 42′ N latitude and 29^{o} 54′ E longitude). This particular area was of interest to the MCEER/EDM team because 1) damage to buildings (the area is composed of entirely residential apartment buildings) varied widely ranging from slight to complete collapse; 2) the area was unoccupied at the time of our visits, and 3) the buildings were situated in large, open areas. From the standpoint of detecting damage from space-borne systems, this area would be ideal. Figures 10-8 through 10-10 show some of the buildings where detailed data were collected by the investigation team.

As part of an ongoing research project, researchers at the University of Southern California (Mansouri and Shinozuka) are exploring ways in which SAR data can be used to characterize earthquake damage to buildings. Simulation algorithms are being developed that will model such failures as tilting, first floor collapse and complete building failure (i.e., massive pancaking). During this reconnaissance trip, Mansouri collected detailed measurements on several of the buildings that had collapsed during the earthquake. All of the buildings were constructed of reinforced concrete with rectangular footprints and had tiled roofs. Because of the orientation of these buildings (two rows of six buildings

Photograph by R. Eguchi

Figure 10-8 Isolated building in Seymen. This building experienced first floor collapse and well as damage to the top floor. This building should be visible from aerial photos; it may be detectable using radar pre- and post-event images.

Photograph by R. Eguchi

Figure 10-9 Near complete collapse of a five-story concrete structure. Should be visible from both aerial photos and SAR imagery.

each) and because of the large spaces between buildings, this site was considered an ideal one from the standpoint of testing or validating their analytical models.

As indicated earlier, SAR images of this area – both before and after the earthquake – have been obtained from ESA and RADARSAT. Pre- and post-event SAR data is preferred for detecting damage after catastrophic events. Using SAR data, it is possible to create images at night or through cloud cover. Also, because of its ability to facilitate change detection analysis, SAR technology is considered the most effective technology in attempting to "quantify" the effects of large disasters.

Photograph by R. Eguchi

Figure 10-10 Severe damage to multi-story apartment buildings. Lower floors have "pancaked" and building is not tilted. May be visible from aerial photos; collapse of lower floors may be detectable from radar imagery.

Over the next year, Mansouri and Shinozuka will be calibrating their simulation algorithms by testing them against the Seymen data. Some of the questions that they will attempt to answer are: (1) what damage conditions or failure modes are detectable using coarse resolution SAR data, (2) can damage be accurately simulated using these new simulation algorithms, and (3) how can these findings be extended to assess damage to larger areas.

10.3.4 Adapazarı

The town of Adapazarı is located about 125 kilometers east of İstanbul. The town sits on a recent lakebed, and suffered extensive liquefaction during this earthquake. This was one of the most heavily damaged areas in this event; damage to multi-story apartment buildings was severe, many commercial structures were also seriously damaged.

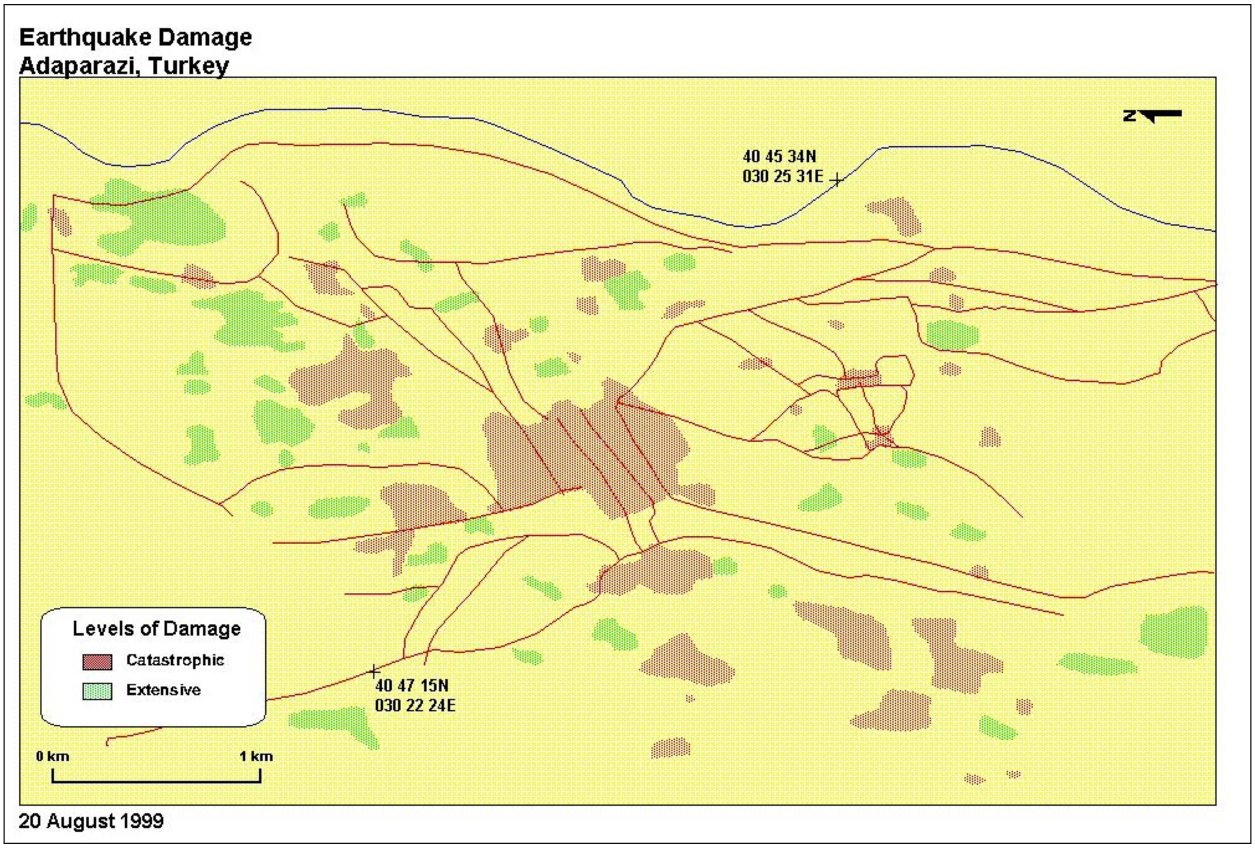
The MCEER/EDM team spent an entire day in Adapazarı attempting to collect damage information from local authorities. Despite the fact that the requests were made almost two months after the earthquake, there was still very little data available on number of damaged buildings, whether structures were safe or unsafe, and how many people had perished in this earthquake. Because of this, the investigation team decided to conduct its own survey of Adapazarı.

One of the primary objectives of this trip was to collect enough information to validate a series of earthquake damage maps that were produced by the U.S. State Department shortly after the earthquake. These maps appeared on the Internet on the Kandilli Observatory website. In total, the U.S. State Department produced five maps: Yalova, Seymen, Derence, Adapazarı and West Gölcük.

One example of the type of map distributed by the State Department is seen in Figure 10-11 for the Adapazarı area. The map identifies areas of catastrophic and extensive damage. This map was put on the Internet on August 20, 1999, three days after the earthquake. According to officials at the State Department, high-resolution satellite images were used to classify the town into these two damage categories. Our purpose in validating these maps was to create a "ground truth" database that could eventually be used to calibrate a series of interferograms developed from this earthquake.

Unfortunately, the scale and projection of these maps was a little misleading. When compared directly with Landsat images – which were in a valid geographical projection – many of the obvious features (roads, rivers, and city boundaries) – did not match. The State Department maps appeared to present a distorted image of the affected areas.

Since returning from Turkey, EQE spent considerable time trying to "warp" the images so that the State Department maps actually coincided with the major land features and roadways of the region. As it turns out, it is possible to approximately fit these maps to the correct projections by overlaying the maps onto available Landsat images and "warping" the map to match obvious landmarks (e.g., roads, rivers, major intersections, etc.) The next section discusses how the MCEER/EDM team attempted to validate the damage maps.



U.S. State Department

Figure 10-11 Earthquake damage map produced by the U.S. State Department for the Adapazarı region (August 20, 1999) - uncorrected

Figure 10-12 shows a Landsat 5 image of the Adapazarı area. Shown on this same figure is the route taken by the investigation team on October 2nd. It is interesting to note that at the time of our visit, there appeared to be no publicly available maps of the city.[2] Therefore, our only means of tracking our route was to plot the latitude/longitude of the van – as determined from the portable GPS system – directly onto a Landsat image of Adapazarı. Although it took some time to set up, this system was invaluable in assigning geographical coordinates to specific damage sites.

The route, shown in Figure 10-12 as a black line, began near the Mosque (center of the figure) and proceeded in a counterclockwise direction. Also noted on Figure 10-12 are color-coded circles that represent various levels of site damage (on a city block level), ranging from none or slight to catastrophic damage. Unlike the Avcılar survey, we did not have access to Differential GPS. Therefore, some wavering of the route trace is noted. In theory, the coordinates that are registered are within a block of the actual location.

[2] As it turns out, one of the guides that we used during this half-day trek had a tourist map of the city, which she kindly turned over to us as we departed.

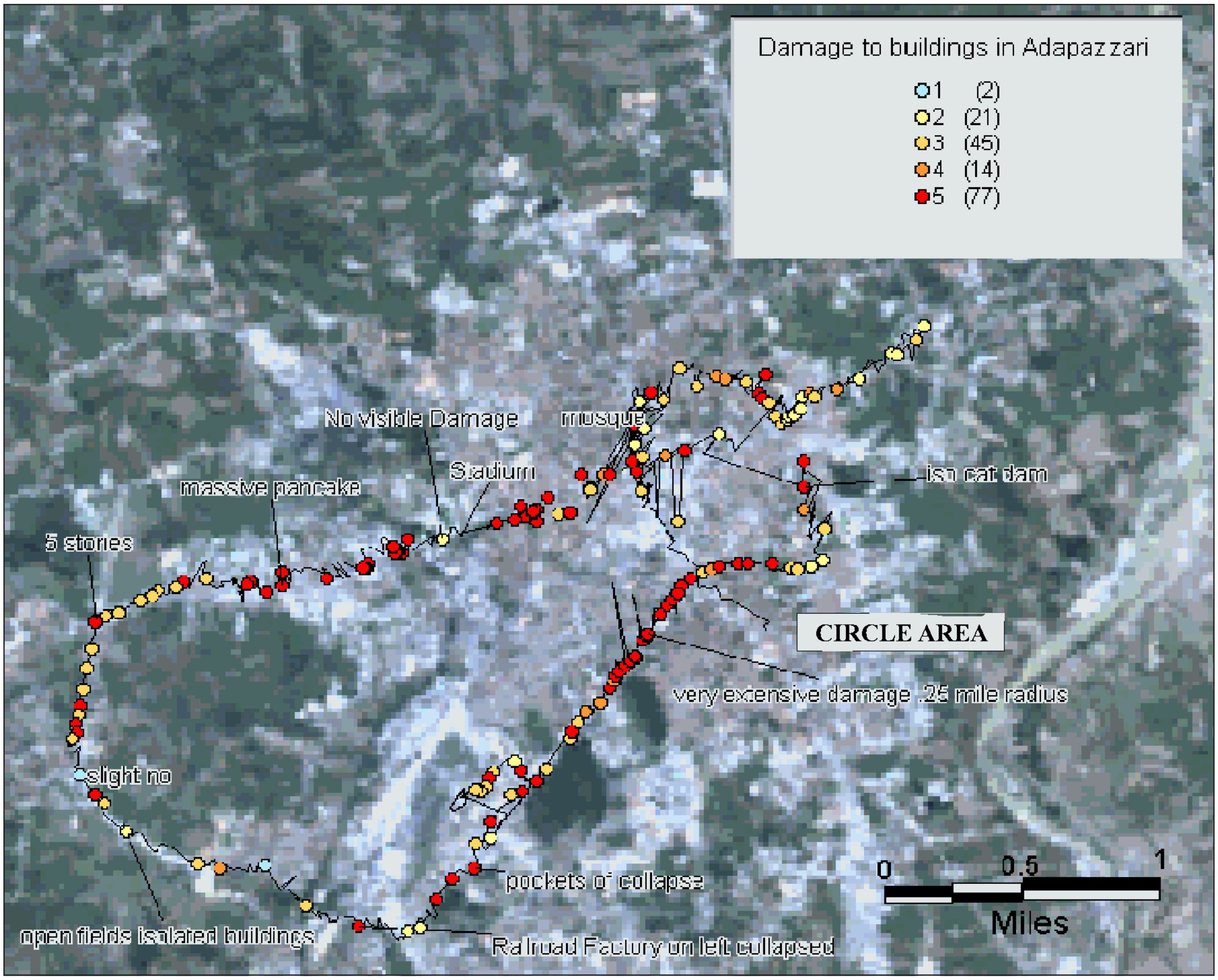


Figure 10-12 Landsat 5 image showing Adapazarı (light area in center of figure) and the route taken by the MCEER/EDM team on October 2, 1999 (route shown as a continuous black line). Also seen are individual damage assignments that were made along the route. Note: A damage index of 1 is associated with an observation of slight to no damage; an index of 5 reflects catastrophic damage.

To help select the best route to take, we enlisted the services of a government worker who was familiar with many of the city's reconstruction projects. With her help, we were able to map out a route that took us through the most heavily damaged areas, as well as other areas (generally outside of town) which did not suffer much damage. Most importantly, this route took us in and out of those areas that were classified as catastrophic and extensive damage by the U.S. State Department.

In addition to assigning damage levels to each block, we attempted to record this information via (1) digital still cameras, and (2) digital video camera.[3] Also recorded via laptop computer were written comments regarding our damage observations at specific sites. Some of these comments appear on Figure 10-12. Note on the figure, the area designated as "Circle Area." This was one of the most devastated areas in the city.

[3] A digital video camera was used on a second trip to Adapazarı on November 20, 1999.

Figure 10-13 shows two ERS radar images of the Adapazarı area, taken before and after the earthquake. As in Figure 10-12, the team's route is seen in these figures as a string of small circles. Unlike the previous image, which was optical, the images in Figure 10-13 were derived from processed SAR data and show up as pixels of varying intensity. Each pixel in the raw data set represents a rectangular area of approximately 4 meters by 21 meters, depending on the terrain. Since each of these images was taken from the same satellite track, the view or position of the image is similar.

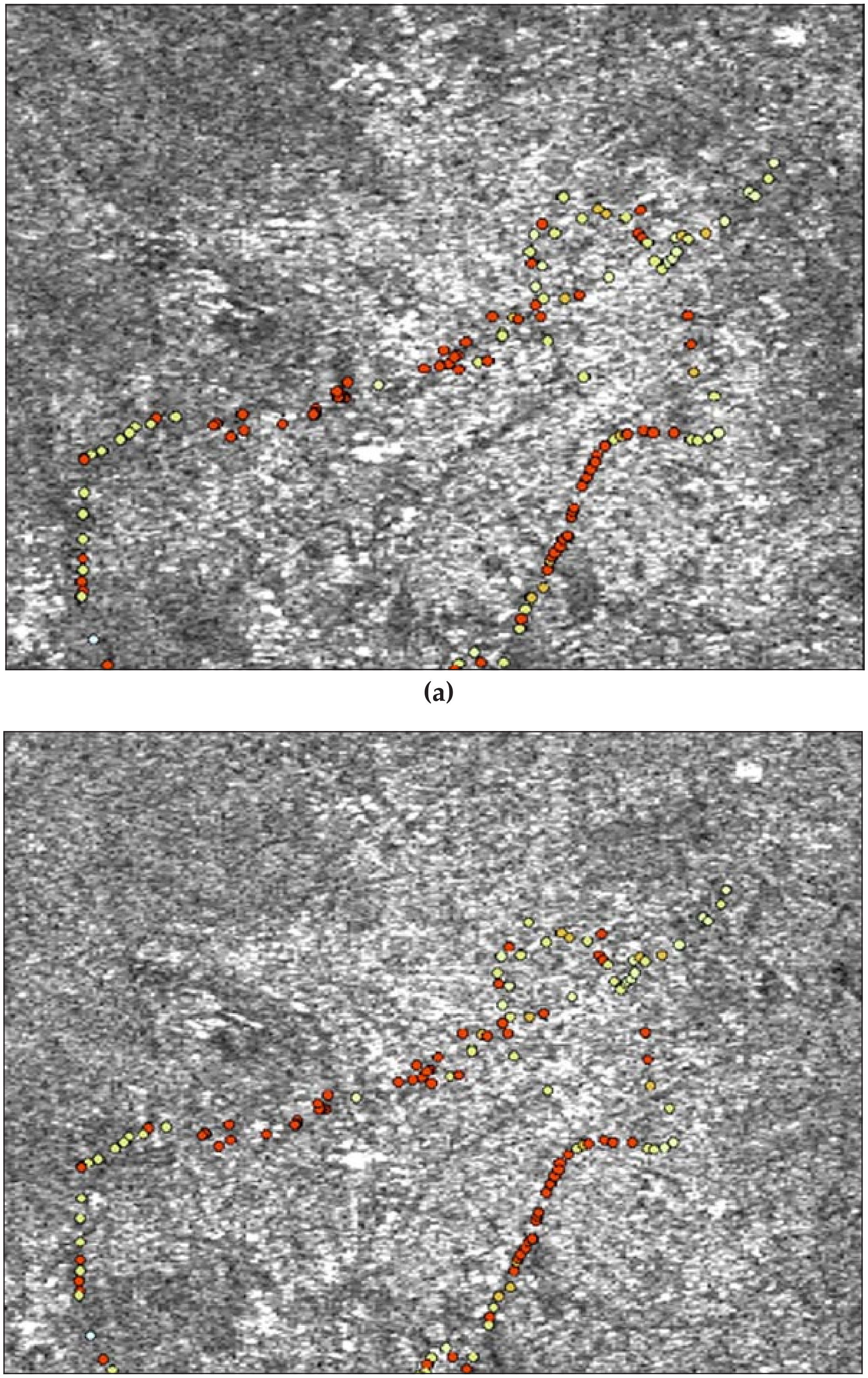
To process these data, EQE imported the single-look complex images into the ENVI (the Environment for Visualizing Images) software, a special imaging processing program designed specifically for remotely sensed data. The single-look complex images provide the highest resolution possible using a SAR imaging system. The resolution or pixel size is dependent on a number of factors including radar hardware parameters. For our data set, the pixel size is about 4 meters in the azimuthal direction (i.e., the direction of the radar platform) and 21 meters in the cross direction. In order to reduce the inherent noise in the radar image (e.g., speckle noise), we applied an averaging filter in the azimuthal direction. This process is normally referred to as multi-look averaging. This reduction in noise, however, comes at the expense of reduced spatial resolution. The end product, after this processing, is a 21 meter by 21 meter pixel.

We anticipate that with this resolution, it will be difficult to recognize from these images physical structures having dimensions of less that 20 meters. Therefore, unless a structure takes up several pixels, it may be difficult to assess any change between before- and after-earthquake images. We are also investigating a "correlation" approach to detect pixel level changes; however, these analyses are not complete at this time.

The two images that are shown in Figure 10-13 were taken almost five months apart. The first image was taken in late spring (4/24/99); the second image was taken less than one month after the August 17th earthquake (9/10/99). Generally, there would be image differences caused by seasonal change. However, for this area, temperature differences within that time span are expected to be mild (55 °F in late spring to 70+ °F in summer); average monthly rainfall between these two periods is also expected to vary only slightly.

In general, pixel intensity will depend upon vegetation level, the density of buildings and their shapes, moisture levels, season, etc. Brighter areas are those that reflect more of the radar energy sent down from the sensor. In Figures 10-13a and 10-13b, the brighter areas are associated with the built-up area of Adapazarı. Both images were exported to MapInfo where they were geo-referenced to the Landsat 5 data. Since the resolution of these images is fairly coarse, we generally see only the major features of the region, e.g., major roadways and streets and some very large buildings. A cursory examination of both images does show some differences between the two figures. In order to view these changes in detail, we must concentrate on smaller portions of these images.

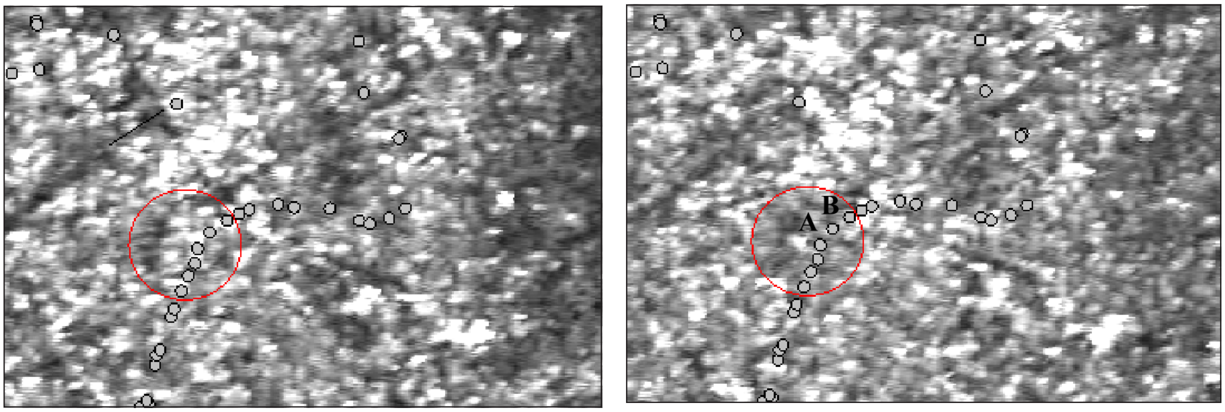
In order to identify any significant changes between the two images, we had to isolate part of the previous figures and concentrate on those areas that the team spent some time investigating while in the field. Once such area is the "Circle Area" which shows up at the tail end of the route (see Figure 10-12 for approximate location). To examine the changes



(a)

(b)

Figure 10-13 Intensity images of Adapazarı based on before and after earthquake SAR data (Data Source: ESA). The light areas correspond to built-up areas, which generally demonstrate a higher degree of reflectance or brightness. A median and Frost filter were applied to reduce white noise and maintain edges.



(a) **(b)**

Figure 10-14 Close-up of "Circle Area" in Adapazarı (see Figure 10-12 for location). Note the designations (a) and (b) in Figure 10-14b which refer to photographs (a) and (b) in Figure 10-15. North is up. Raw data supplied by ESA.

between the two images, we drew a circle of 0.25-mile radius around this area. Comparison of the two images reveals that the after-earthquake image (Figure 10-14b) contains fewer bright spots. As was explained before, many of the buildings in this area had either completely failed (total collapse) or were severely damaged (many tilted buildings). It is expected that this type of damage would result in more scattering and thus, duller images.

Figure 10-15 shows two photographs of damage in the "Circle Area." The first photograph (Figure 10-15a) is taken looking west along the main road. The second photograph is taken from the same location, looking northeast. Note that many of the damaged buildings have been torn down and the debris hauled away (Figure 10-15a). Since the second image was taken about one month after the earthquake, it is possible that the bare ground was being imaged at that time. At any rate, the second image was able to pick up this change.

(a) **(b)**

Photographs by R. Eguchi

Figure 10-15 Damage to apartment buildings in the "Circle Area" of Adapazarı. Left image is view (a) in Figure 10-14b. Right image is view (b) in Figure 10-14b.

In the next several months, we will be examining these data in more detail. In addition to the "Circle Area," we hope to examine other sites where we have collected field data on the earthquake. One useful source is a digital video that was taken on the second trip to Adapazarı in November. By examining these images in more detail, and perhaps, by creating a series of correlation or coherence maps, we can begin to explain the meaning of these image changes. In addition, we hope to return to Turkey to collect other data that may help to quantify the extent of damage to this town.

10.4 Summary

Although largely untested in earthquakes, all of the new technologies employed during our reconnaissance proved to be invaluable in documenting the effects from this earthquake. Listed below are some of the lessons learned while performing this investigation.

1. The Landsat images proved to be invaluable in calibrating on-ground data, such as the locations of major roads, the boundaries of urban regions, and in some cases, the location of large buildings, i.e., buildings with large footprints. Because the resolution was fairly coarse (30 meters), it was difficult to use these data to detect or quantify earthquake damage. These images, however, were easily processed and were available soon after earthquake.
2. The ERS-1 and ERS-2 data proved to be useful once the MCEER/EDM team left the field and returned home. Although these data were available before the trip, it was difficult to process this information because of map registration problems, and because the data contained more than just image data. We are now beginning to work with these data to explore how useful they are in detecting damage through interferometric techniques. We speculate that correlation or coherence maps developed from an analysis of pre- and post-earthquake images will result in the best use of these data and could possibly detect areas where significant damage (e.g., collapsed buildings) has occurred.
3. The use of GPS equipment was essential in documenting the activities of the team. Precise coordinates were established for important damage sites. This information was crucial in relating satellite imagery data to on-ground observations. Also, when connected to the portable laptop computer, many critical analyses were possible in real-time. There was also a significant difference in results when Differential GPS was available. In Avcılar, geographical coordinates were accurate to within one meter. In Adapazarı, where Differential GPS measurements were not possible, coordinates were accurate to within 30 meters. This difference could be critical when attempting to document damage to individual buildings.
4. Having access to in-field GIS software made the documentation process extremely efficient. Many of the records – such as the Adapazarı survey – would not have been possible had it not been for the GPS-GIS setup. The actual survey that was discussed in the previous section took less than 4 hours. If paper maps or other manual methods of documenting damage had been employed, it would have taken at least several days to accomplish what was done in half a day using these new mapping technologies.

5. One important piece of equipment – which was used by investigation team members for the first time – was a digital camera. The advantages to using such a camera is that the images that are taken are immediately viewable, they can be downloaded immediately for transmission to some other site, and when connected to a GPS unit (which was not done on this trip), could produce more reliable documentation of an event.

The MCEER/EDM team would like to acknowledge the Multidisciplinary Center for Earthquake Engineering Research for its generous support of this investigation. In addition, we would like to thank the following individuals and organizations for their help in making this a unique and productive trip. Without this support, many of the activities mentioned above would not have been possible. They are: Dr. Betlem Rosich, ESA/ESRIN; Mr. Serkan Bozkurt, IMAGINS; Mr. Turgay Türker, Türker Engineering; Professor Mustafa Erdik, Kandilli Observatory and Earthquake Research Institute; Dr. M. Namık Yalçın, TÜBİTAK; Dr. Semih Ergintav, TÜBİTAK; Dr. Hülya Yıldırım, TÜBİTAK; Mr. İsmail Barış, Mayor of Gölcük; Mr. Larry Roeder, U.S. State Department; Dr. Charles Scawthorn, EQE; andMs. Hope A. Seligson, EQE.

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