Learning from Earthquakes

The Izmit (Kocaeli), Turkey Earthquake of August 17, 1999

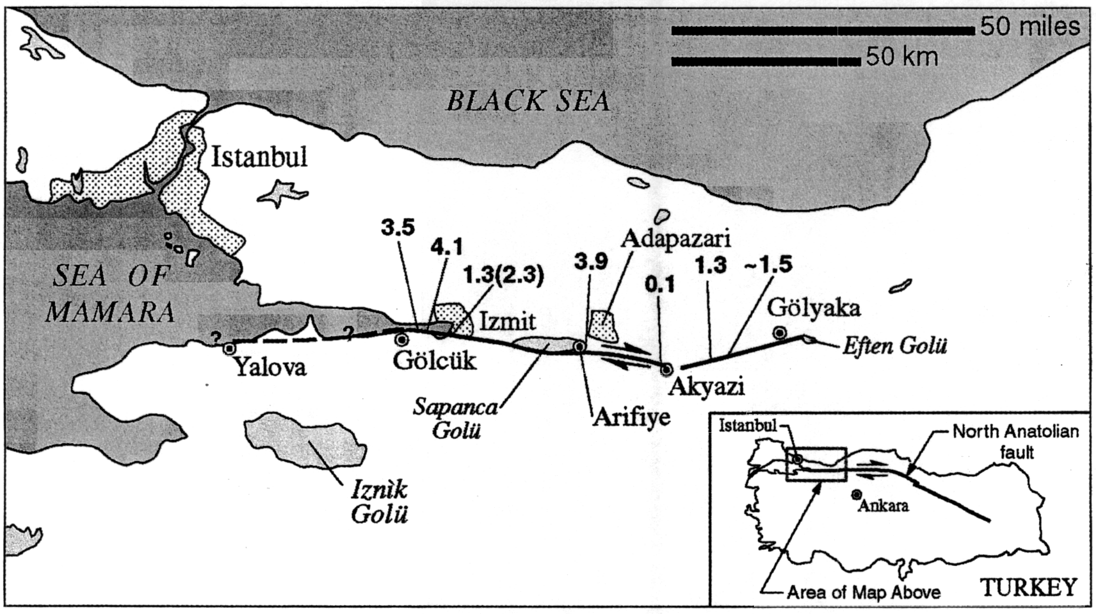

Figure 1 *- Location of the North Anatolian fault (inset) and the fault rupture that generated the August 17, 1999 earthquake. Numbers without parentheses indicate the amount of right-lateral offset in meters; values in parentheses indicate vertical displacement.*

On August 20, 1999 an Earthquake Engineering Research Institute team visited the area affected by the Izmit earthquake. The team was composed of T. Leslie Youd, Team Leader, Brigham Young University, Provo, Utah; Mark Aschheim, University of Illinois, Urbana/Champaign; Nesrin Basoz, K2 Technologies/E.W. Blanch, San Jose, California; Polat Gulkan, Middle East Technical University, Ankara, Turkey; Roy A. Imbsen, Imbsen Associates, Sacramento, California; Gayle S. Johnson, EQE International, Oakland, California; Jay Love, Degenkolb Engineers, San Francisco, California; John B. Mander, State University of New York at Buffalo; William Mitchell, Baylor University, Waco, Texas; Halil Sezen, University of California at Berkeley; Mete Sozen, Purdue University, West Lafayette, Indiana; F.H. Swan, Geomatrix Consultants, Oakland, California; and Peter Yanev, EQE International. Contributors to this report were Aschheim, Basoz, Imbsen, Johnson, Mander, Mitchell, Swan, and Youd.

Introduction

On August 17, 1999 a magnitude M_W 7.4 earthquake struck the province of Kocaeli in western Turkey. The epicenter was southwest of the city of Izmit, in a densely populated area in the industrial heartland of Turkey, and less than 80 km southeast of Istanbul. The earthquake occurred in the middle of the night (3:02 a.m. local time) when most residents were home sleeping. The official data from the U.S. Geological Survey and Kandelli Observatory include: date/time, 1999-08-17 at 00:01:39.80 (UTC); surface wave magnitude, 7.8; body wave magnitude, 6.3; moment magnitude, 7.4; epicenter, 40.702 N, 29.987 E; depth, 17 km.

Faulting

The earthquake was generated by rupture along a branch of the North Anatolian fault (Figure 1). The 1300 km-long North Anatolian fault system is one of the most seismically active right-lateral strike-slip faults in the world. Since 1939, there have been 11 M 6.7-or-larger earthquakes along the fault, nine of which had magnitudes greater than M_S 7.0. These earthquakes followed a systematic pattern that progressed generally from east to west along the fault system. The 1999 rupture was centered on a seismic gap between the 1967 Mudurnu Valley earthquake (M_S 7.1) and the 1963 Yalova earthquake (M_S 6.4). The Izmit segment of the North Anatolian fault was identified prior to the 1999 earthquake as having a high likelihood of producing a damaging earthquake (Toksoz, Shakal and Michael, 1979; Stein, Barka and Dieterich, 1997).

Surface faulting destroyed hundreds of buildings, damaged industrial facilities, port facilities, a military base, pipelines and roads, and was responsible for the collapse of two bridges. Where the fault parallels the coast, large areas subsided and extensive parts of Golcuk and Degirmendere were permanently inundated (see Figure 7). Surface faulting extended 110 km east of Golcuk, and the distribution of aftershocks in the Marmara

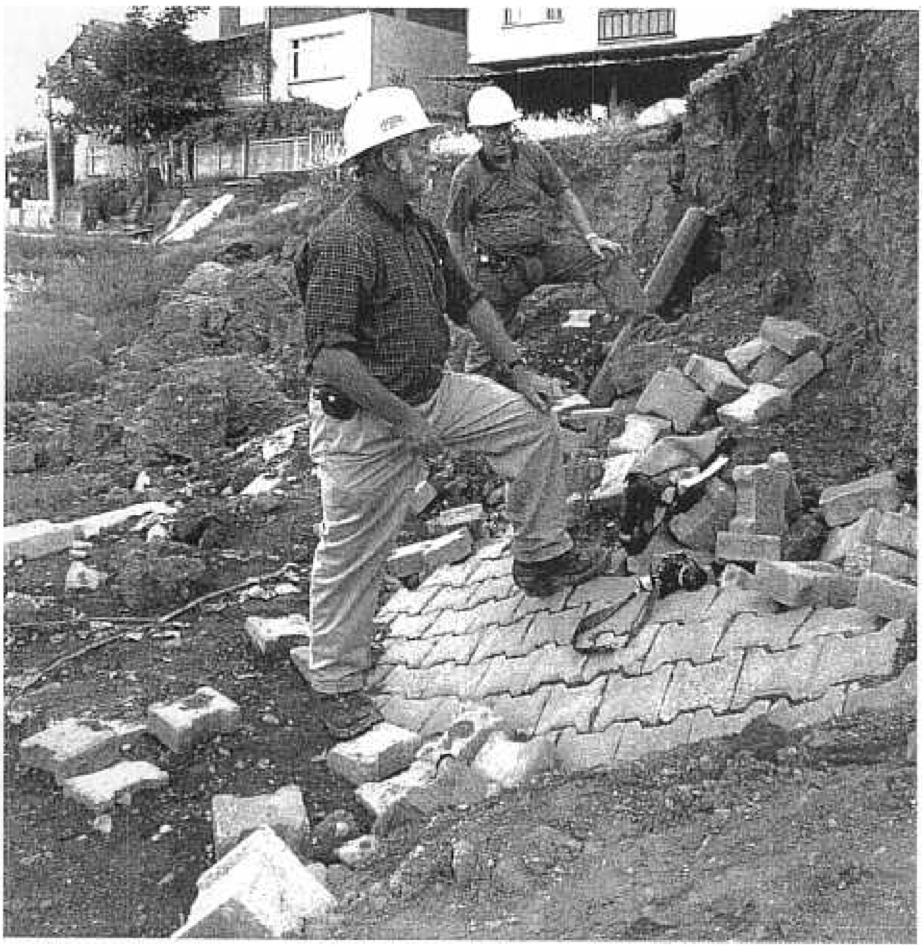

Figure 2 *- Fault scarp east of Golcuk. The vertical displacement is 2.3 m down-to-the north, with 1.3 m of right slip.* *(Photo: Mark Milstein, Atlantic News Service)*

Sea suggests the faulting may have extended another 50 to 60 km to the west of Golcuk. If so, the total length of the rupture may be as long as 160 to 170 km. The fault offset is predominantly right-lateral strike slip. The exception to this is a short section of the fault to the east of Golcuk, where the displacement is predominantly dip slip (Figure 2). Displacements in the range of 3 to 4 m were common over a significant length of the fault. The maximum displacement reported so far is 5.1 m immediately east of Arifiye (USGS and Southern California Earthquake Center). The average slip along the length of the fault is probably in the range of 3 to 3½ m.

Detailed mapping of the surface faulting is being carried out by an international team of Turkish and foreign geologists, including geologists from the U.S. Geological Survey and U.S. universities. Dr. A. A. Barka at the Istanbul Technical University is coordinator.

Geotechnical Effects

This reconnaissance investigation provides useful information on three geotechnical engineering issues: performance of structures astride or adjacent to fault rupture, performance of shallow foundations underlain by liquefied sediment, and performance of mechanically stabilized earth (MSE) walls.

Many structures were located astride or near the surface fault rupture. Several four- to seven-story apartment buildings were torn apart by the fault rupture and collapsed, while similar buildings within a meter or two of the fault were undamaged. One building at the Ford automobile assembly plant, which is nearly complete but not yet occupied, was deformed by about 0.5 m of right-lateral fault displacement distributed over a 100-m-wide zone. Floor slabs in this code-compliant building were fractured and split apart, and columns were tilted as footings moved with the earth. The tops of columns were pinned to the roof and remained in place. The columns cracked and underwent ductile deformation, but retained ample strength to support the roof structure without danger of collapse (Figure 3). Although substantial repairs will be required, the building deformed without threat to the life safety of occupants. In general, for buildings not directly astride the fault, ground shaking had greater influence on performance than did proximity to the fault.

The city of Adapazari was constructed over lake bed sediments containing layers of liquefiable silts and sands. Hundreds of buildings

Figure 3 *- Column pushed through the floor slab and tilted due to 0.5 right-lateral fault displacement. Column underwent ductile deformation without losing significant axial load capacity.* *(Photo: Youd)*

Figure 4 - Building that toppled due to liquefaction-induced loss of bearing strength beneath shallow mat foundation. *(Photo: Youd)*

settled, tipped or toppled as liquefaction weakened soils beneath reinforced mat foundations (Figure 4). More than 60 percent of multistory buildings in the severe liquefaction areas suffered partial or total collapse due to structural failure. Follow-up investigations are in progress to determine layer thicknesses, soil properties, and foundation loads. These investigations, which were initiated in response to the EERI investigation, should add a considerable body of case history data to better define loading and soil conditions associated with liquefaction-induced foundation failures.

A pair of MSE walls retaining a bridge approach fill were severely tested by the earthquake (Figure 5). The primary fault rupture was only a few meters from the walls and passed beneath the bridge structure, which collapsed. Differential settlement also occurred beneath the walls due to a rigid reinforced concrete box culvert beneath the walls. Shear deformations from the differential settlement propagated upward through the paneled faces, with some panels separating as much as 75 mm, allowing a small amount of fill material to seep through the face. However, damage to the wall was relatively minor: no straps broke, no facing panels fractured, and there was no immediate threat of wall collapse.

Isolated areas with relatively high rates of structural damage indicate that local site conditions may have influenced ground response and damage distribution. For example, several buildings collapsed in Avicilar west of Istanbul, where instrumental records indicate higher peak accelerations than in surrounding areas with little damage. Detailed site studies and analyses will be required to determine the causes of the local concentrations of damage.

Effects on Buildings

The earthquake damaged buildings across seven provinces for a distance of 250 km from Istanbul to Bolu. As many as 70% of the buildings in portions of the cities of Adapazari, Golcuk, Izmit, Topcular, and Kular were severely damaged or collapsed (Coburn, Halling and Sezen, 1999). Nearly all the fatalities and injuries can be attributed to building collapse. As of September 6, 1999, the Government Crisis Center reported 20,957 buildings were heavily damaged or collapsed. Other reports suggest that up to 115,000 buildings were damaged beyond repair. Building losses are reported to amount to about US$5 billion.

Sources of damage were manifold. Buildings experienced fault rupture

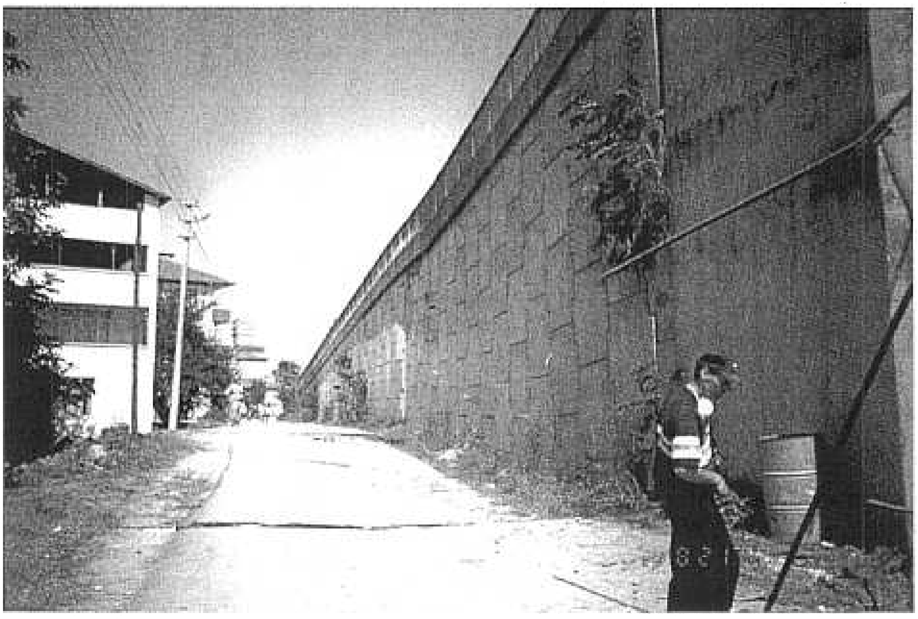

Figure 5 *- Mechanically stabilized earth wall within a few meters of the primary fault rupture. Although subjected to differential settlement, it suffered only minor damage.* *(Photo: Youd)*

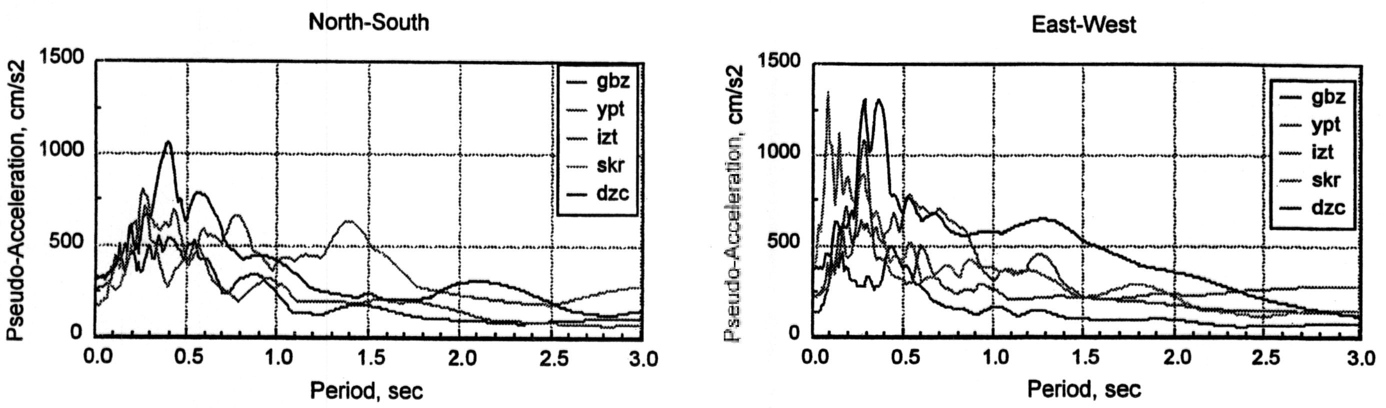

Figure 6 *- Response spectra (5% damped): a) north-south components, and b) east-west components. The north-south component in Sakarya was not available.* *(Records provided courtesy of the Earthquake Research Department of the General Directorate of Disaster Affairs and Bogazici University.)*

and ground shaking, and in some regions were subjected to ground settlement, liquefaction, or subsidence and sea water inundation (Figure 7). Numerous buildings were located on top of the fault trace, where there were lateral offsets of up to 4 m or vertical offsets of up to 2 m. Some buildings reportedly were "washed" into the Marmara Sea by waves resulting from ground subsidence.

Response spectra are computed for the north-south and east-west components of ground motion for five stations located approximately along the fault: Gebze (GBZ), Yarimca Petrochemical (YPT), Izmit (IZT), Sakarya (SKR) and Duzce (DZC) (Figure 6). Of these, the largest peak ground acceleration was about 0.4g at Sakarya.

Reinforced Concrete Frames with Hollow Clay Tile Infill: Almost all urban residential buildings were reinforced concrete frames with hollow clay tile infill walls, typically three to seven stories in height. As in the 1992 Erzincan earthquake, frames having four or more stories were much more likely to be damaged or to collapse. Even so, there was great

Figure 7 *- Inundated buildings in Golcuk. Tectonic displacement along the fault and liquefaction-induced subsidence resulted in extensive areas of flooding along the south shore of Izmit Bay. Note also out-of-plane roof infill, and collapsed building in foreground.* *(Photo: Aschheim)*

Figure 8 *- Typical weak-axis column hinging.* *(Photo: Aschheim)*

variation among neighboring buildings that resembled one another, with some collapsing and others having moderate or little apparent damage.

Column cross sections typically have large aspect ratios (e.g., 25 by 60 cm), with hollow clay tile infill placed directly against the narrow sides of the column. This allows the columns to be located within the partition wall, and results in columns with irregular locations and orientations since they are positioned within the partition walls. Smooth bars are typically used for longitudinal and transverse reinforcing. Transverse hoops having short 90-degree hooks are typically spaced at 20 to 25 cm along the clear height of the column; cross ties were not evident. Column splices usually are located just above the floors, consisting of a straight extension from below, with a hooked bar from above terminating at the floor slab.

Flexural hinging at the ends of the columns often led to buckling of longitudinal reinforcement, sometimes resulting in shear failures at the hinges under weak axis bending (Figure 8). Strong-axis demands typically caused flexural hinging at the ends of the columns and buckling of longitudinal reinforcement, or they caused shear failures at the mid-heights of the columns (Figure 9). Columns usually showed indications of large demands in only one principal direction. Soft (or weak) story mechanisms were common. In some cases, column axial forces resulting from overturning moments appeared to contribute to column failures. Loss of joint integrity was infrequent but appeared to contribute significantly to collapse in at least several cases. The presence of infill sometimes had the effect of limiting the effective height of the column, leading to flexural hinging or shear failures.

Other Types of Construction: Other building types were affected, but their relative paucity results in anecdotes rather than generalizations. Some damage to reinforced concrete shear walls in high-rise apartment buildings was reported. Shear failures were observed in reinforced concrete columns at the Petkim and Ford plants. A precast concrete warehouse under construction collapsed, presumably because the roof diaphragm had not been installed, leaving the framing without lateral restraint. A flexible roof diaphragm in another precast building led to excessive roof deflections and out-of-plane failure of the infill.

Buckled steel braces were observed in other buildings, including those at the PacMaya plant. Bolts at the connections between steel columns and roof trusses sheared at a recently designed automobile manufacturing plant. Older construction, typically one or two stories in height and con-

Figure 9 *- Typical strong-axis column shear failure.* *(Photo: Aschheim)*

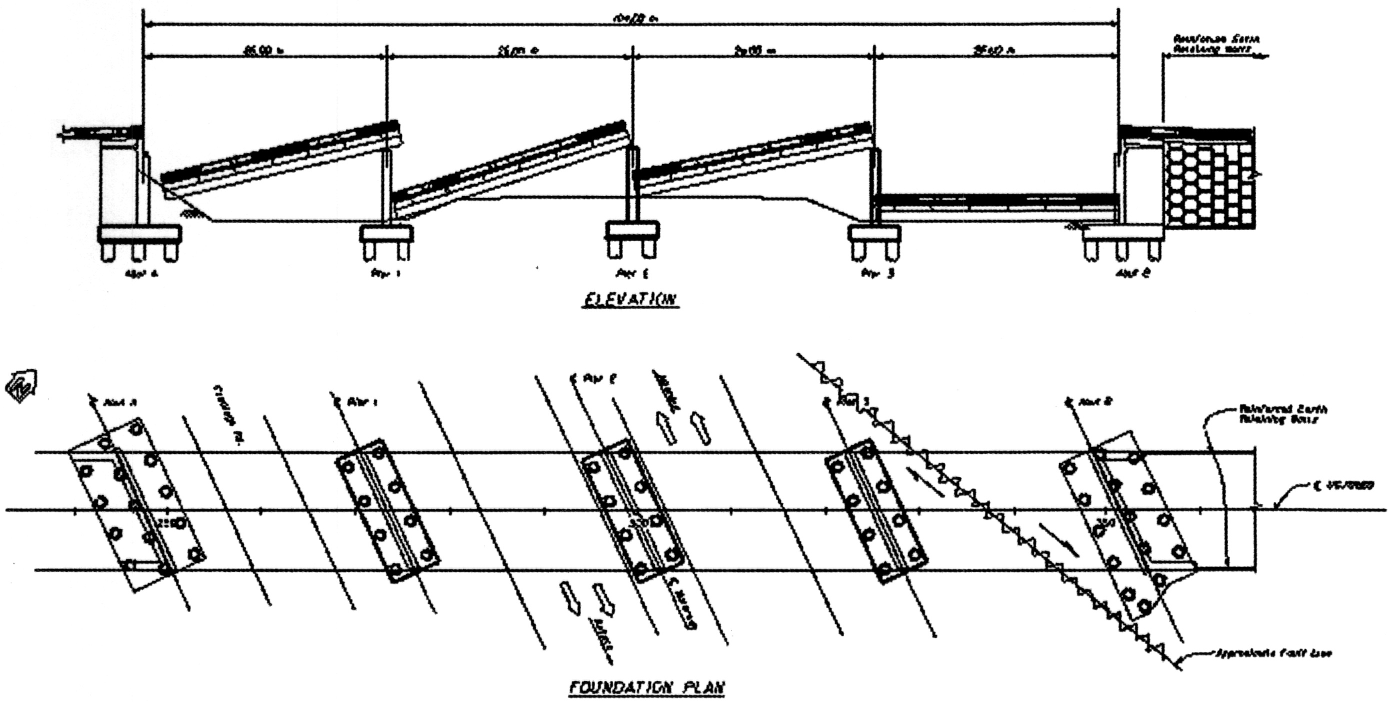

Figure 10 - *Plan and elevation of collapsed overpass*

sisting of adobe or clay brick masonry bearing wall construction, usually performed well, though severe damage was observed on occasion.

Building Codes and Practices: The Great Erzincan Earthquake of 1939 led to the development of the first seismic codes in Turkey, beginning with temporary regulations in 1940 and the first code in 1942. Numerous revisions have been made, with the most recent codes issued in 1975 and 1997. The 1975 code is modern and includes ductile detailing requirements of that era, such as 135-degree hooks in column hoops and cross ties, denser transverse reinforcing in the vicinity of beam- column joints (and within the joints), and strong-column-weak-beam design concepts (Architectural Institute of Japan, 1993). Most of the damaged region lies in the highest seismic zone in Turkey. However, codification of earthquake-resistive details and design philosophies apparently had little influence on construction practices, since ductile details were rarely observed.

Damage to Highways

The engineered structures on the highway system fared well considering the magnitude of the fault rupture movements and the significant—in terms of accelerations and velocities—ground shaking. Damage was restricted to an area south-southeast of Sakarya (Adapazari). In this locale, two main highways run west-east, parallel to the Anatolian Fault. This segment of E80, also known as the TEM (Trans European Motorway), goes south to Ankara, beyond the affected area. It is a four-lane divided toll road. The E100 (the old main highway) is a two-lane road, which continues in the easterly direction. Several overpasses crossing the E80 sustained minor damage in the form of pier tilting (arising from ground movement), cover concrete spalling of the decks at movement joints, and approach fill settlement. Such damage did not substantially impair the use of the main highways or the roads traversing these highways.

The fact that one overpass crossing the E80 at Artifye did collapse was not surprising, as the fault rupture passed directly beneath the bridge (see Figure 10). The fault movement exceeded the available seat width, causing the span to collapse. In so doing, it dragged the remaining three spans off their seats. One of the spans crushed a passing bus, killing ten people.

Damage to the E80 was caused by surface rupturing, settlement of engineered roadway fills, and the settlement of bridge and culvert approaches. The extent of damage to the engineered fills on the E80 motorway extended some 10 km to the west and east of the Sakarya area. Settlements ranging from 100 mm to 500 mm were observed. This damage initially hampered the movement of emergency services equipment and supplies.

Repair of the damage was accomplished quickly in two stages. The first stage consisted of removing damaged portions of the pavement, grading and asphalt patching, and was completed within the first few days after the earthquake. A 50-km/hr speed restriction was imposed. The second stage included resurfacing a 50-km section of the motorway, and was completed 18 days following the earthquake. The traffic is operating normally, at a speed of 120 km/hr.

Problems were also encountered with four highway bridges crossing the Sakarya River (Figure 11). Most notable was the bridge carrying the westbound lanes of the E80 motorway. It consists of ten 40-m simply-supported prestressed-concrete trough-shaped girders seated on laminated elastomeric bearing pads. Shear keys are provided at the end of each box to inhibit transverse and longitudinal seismic movements; the elastomeric bearings accommodate thermal movements. The apparent large impulsive fault-normal ground shaking, coupled with vertical accelerations, caused the shear keys to fail in several spans and unseat their bearings. This damage is consistent with what has been observed in previous earthquakes. The westbound bridge had to be closed for repairs. The eastbound sister bridge sustained less damage to the shear keys and only partial walk-out of the bearing pads; in the absence of complete unseating, the bridge has remained fully operational.

Two long viaducts near Köreez and Düzce were undamaged. The undamaged viaduct near Düzce had been originally outfitted with energy dissipation devices, and initial inspections indicate that seismic movements were arrested by the devices.

Lifeline Systems

Water and Waste Water Systems: Potable water for the region is supplied by three sources: 1) the Gökçe Reservoir near Yalova (serves about 750,000 people in 13 cities from Yalova to Gölcük); 2) Kullar Reservoir in the Izmit Water Project (serves about 1.2 million people in 19 cities from Gölcük to Gebze); and 3) Sapanca Lake (serves about 500,000 people in the Adapazari area).

No significant damage was reported to dams or reservoirs, but pumping stations at both Sapanca Lake and Gökçe Reservoir were out of service for two days due to power outage. Major welded pipes that service the whole region were damaged, especially at fault crossings (Figure 12). Water treatment plants (WTP) sustained minor damage but were operational. Storage tanks were not damaged, but tanks in the Maltepe WTP lost a total capacity of 20,000 m^3 in less than half an hour, due to breaks and leakage in the distribution system. Similar losses took place with a well in Yalova. The distribution sys-

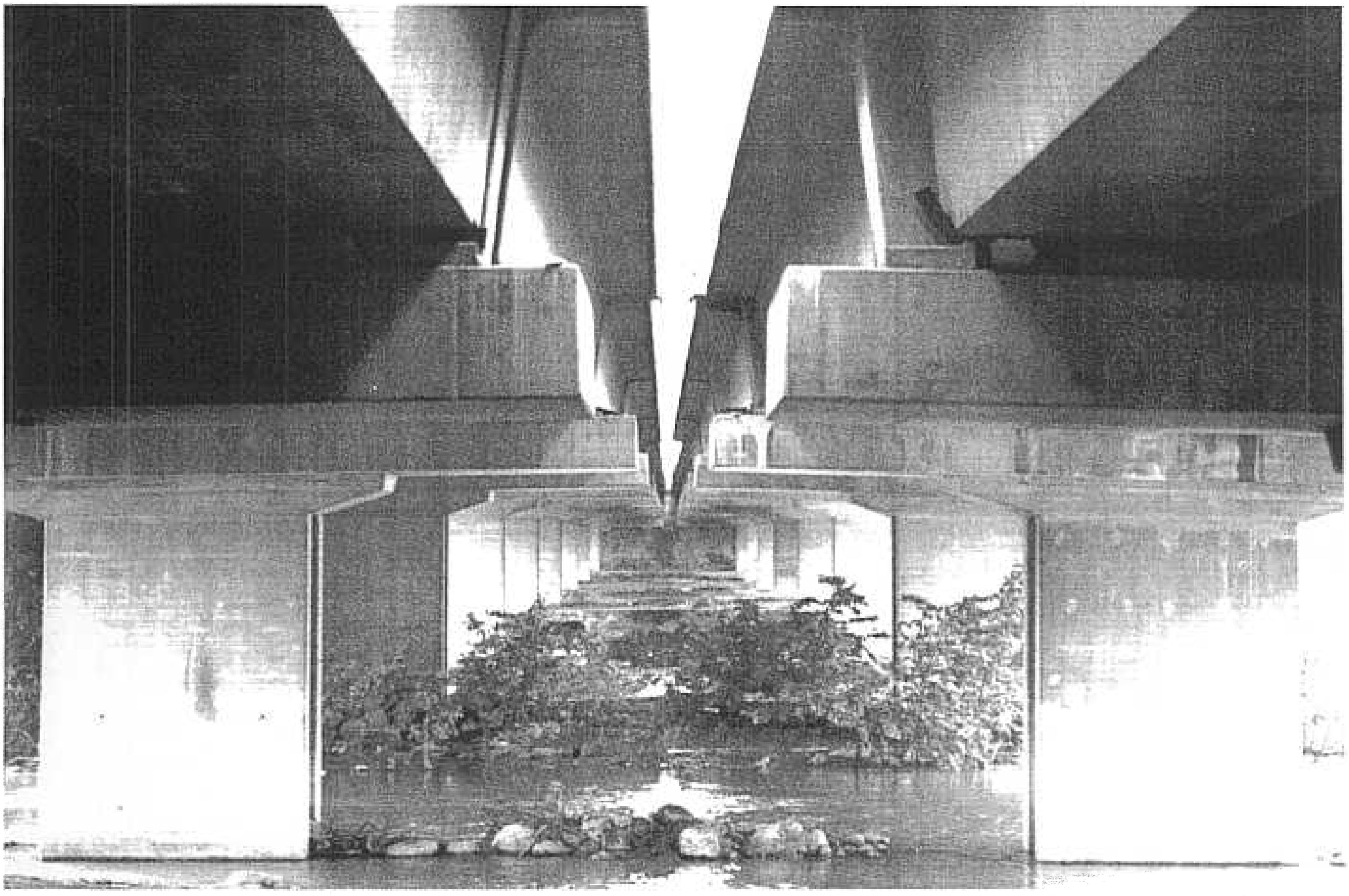

Figure 11 *- The east (left) and westbound bridges over the Sakarya River. Note shifting of the spans and the unseating of the bearings in the westbound bridge. The bearings on the eastbound bridge have partially "walked out," but not unseated.* *(Photo: Mander)*

Figure 12 *- Buckled steel pipe at crossing near Arifiye.* *(Photo: Basoz)*

tem, consisting mostly of asbestos concrete pipes, suffered significant damage throughout the region.

The water system was functional in two to six days, except in the heavily damaged areas. The serviceability level 20 days after the earthquake ranged from 20 to 70 percent. Restoration efforts were hampered by aftershocks and a shortage of materials. Extra workers were available through mutual aid from Ankara and Istanbul. In several cases, e.g. in the Izmit area, the system was fully functional, but was operating only partially due to low demand. Potable, highly chlorinated water was distributed by trucks and water tanks and as bottled water provided by private companies.

Ground failure caused damage to wastewater pipelines in all regions; in Izmit at least 10 km of RC pipes had breaks. Mechanical equipment in the wastewater treatment plant in the Izmit area was damaged, but the two pumping stations were functioning.

Electric Power System: The main power substation in Adapazari sustained damage to its six 380kV transformers, causing a blackout as far as Ankara. Typical damage included tilting of transformers due to support failure (Figure 13) and breakage of porcelain. Control systems were anchored and suffered no damage. The distribution system was somewhat disrupted when buildings collapsed over the distribution lines. Several substations were unscathed by the earthquake, including the Ford auto plant substation, which is only approximately 100 m from the fault. Electric power service was partially restored in three days, and full functionality was restored in 12 days with aid from Ankara and Istanbul. In general, there was a

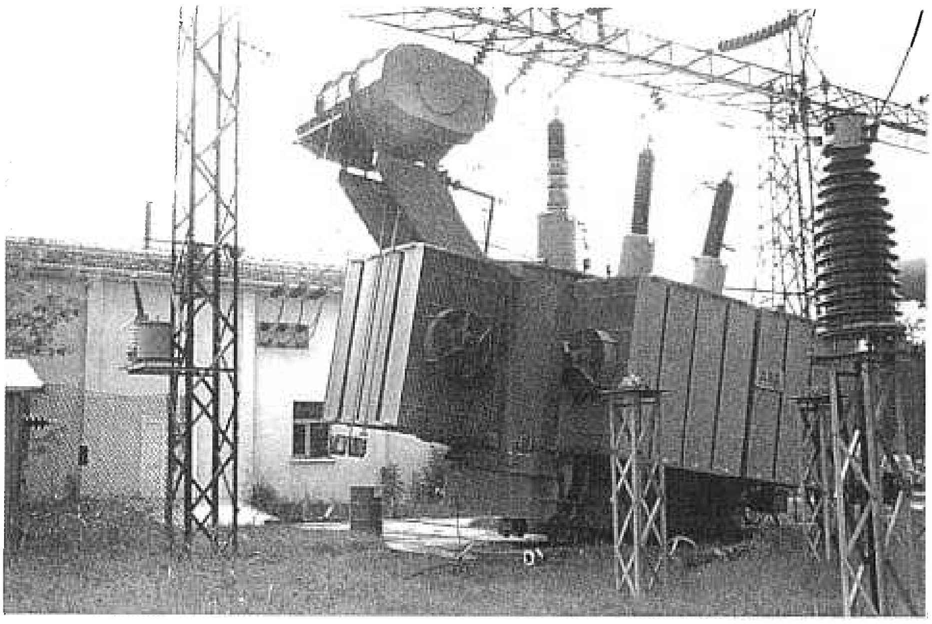

Figure 13*- Damage to transformer in Izmit-2 substation. Tilting due to movement of support.* *(Photo: Basoz)*

sufficient supply of replacement material on-site. Power outage, coupled with lack of emergency generators, impaired the search and rescue efforts.

Telecommunication Systems: Only minor damage was observed at some central offices, causing service disruptions within the first 24 hours. The battery racks in the Yalova central office fell over and the air conditioning sustained some damage. The power outage also disrupted service in the cellular phone system immediately after the earthquake. People who could not reach their family and friends by phone rushed into the damaged areas, causing traffic congestion.

Ports: Most of the ports and jetties of industrial facilities along the northern shores of the Izmit Bay sustained damage ranging from minor to extensive (Figure 14). Extensive damage was observed at fault crossings, for example, at the navy base. It included failure of steel piers and piping systems and the collapse of cranes. At the port of Derince, the largest port facility, two of the three main cranes were nonfunctional due to horizontal and vertical movement of the caisson of up to 40 cm. The port continued its operation using mobile cranes. A few jetties at the industrial facilities were functional by the end of the third week. The total estimated loss for port facilities in the region is on the order of $200 million.

Airports and Railroads: The Istanbul airport was not damaged and served as the major point of access to the region. A military airport near Izmit lost its control tower. Temporary helistops were used for transporting relief groups and supplies. The railroad tracks linking Istanbul to Ankara buckled at a fault crossing near Arifiye. The damaged segments were replaced three days later, delayed by highway damage and power outage.

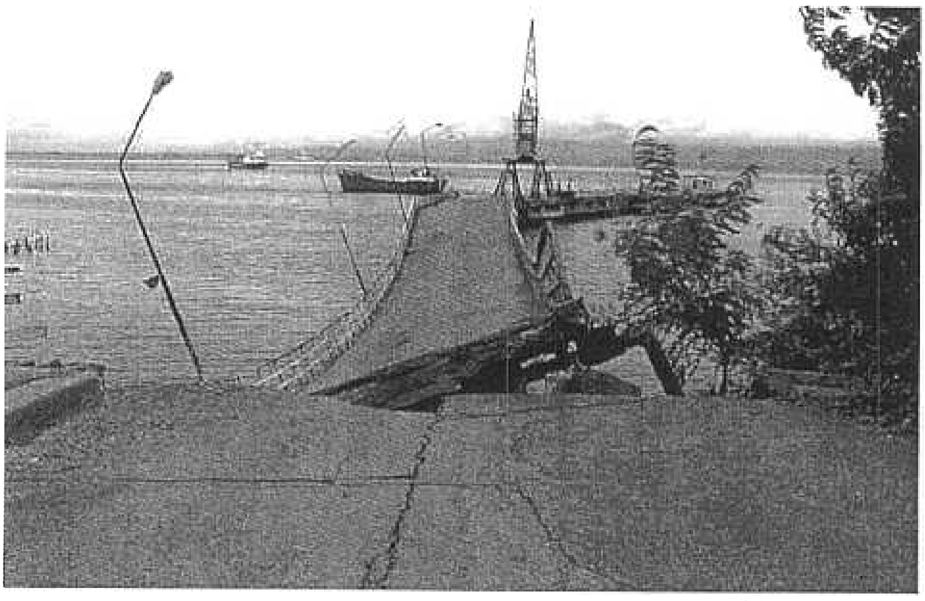

Figure 14 - Private port facility for SEKA paper mill in Izmit. *(Photo: Johnson)*

Observations: The demand on the lifeline systems due to fires following the earthquake was relatively low. Only a few residential fires were reported, which were put out easily. That the prevalent building materials are fire-resistant and that there are no natural gas pipelines in the region reduces the hazard of extensive residential fires. The major fire following the earthquake was at the Tüpras refinery, necessitating evacuations. Loss of electric power, debris on the roads, and lack of water due to pipe breaks hampered the fire-fighting efforts.

Immediate restoration of the "backbone" lifeline systems was successful. Most of the equipment in the electrical, telecommunications and water systems performed well; they were less than five years old and were designed and manufactured according to new earthquake-resistant design specifications. The extensive building

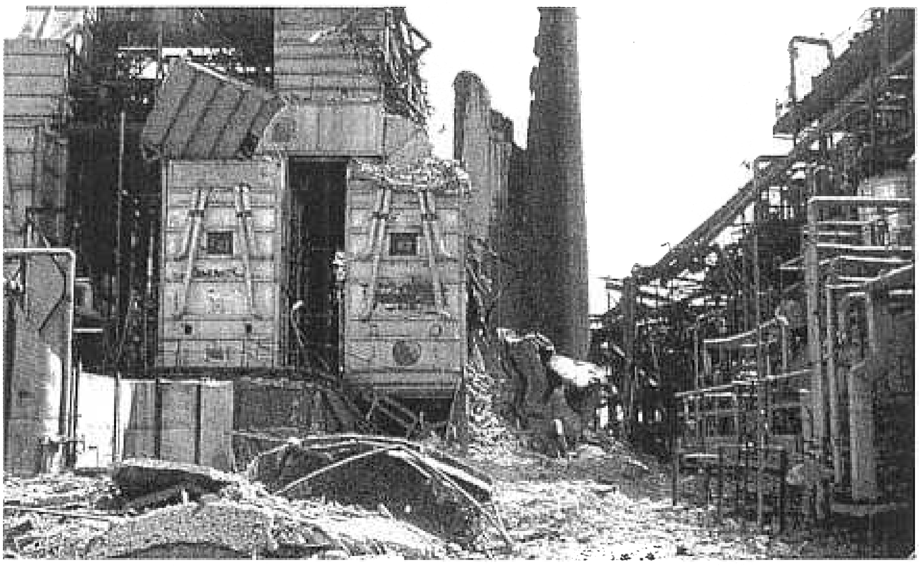

Figure 15 *- Collapsed 90-meter reinforced concrete stack at the Tupras refinery caused extensive damage and fires.* *(Photo: Johnson)*

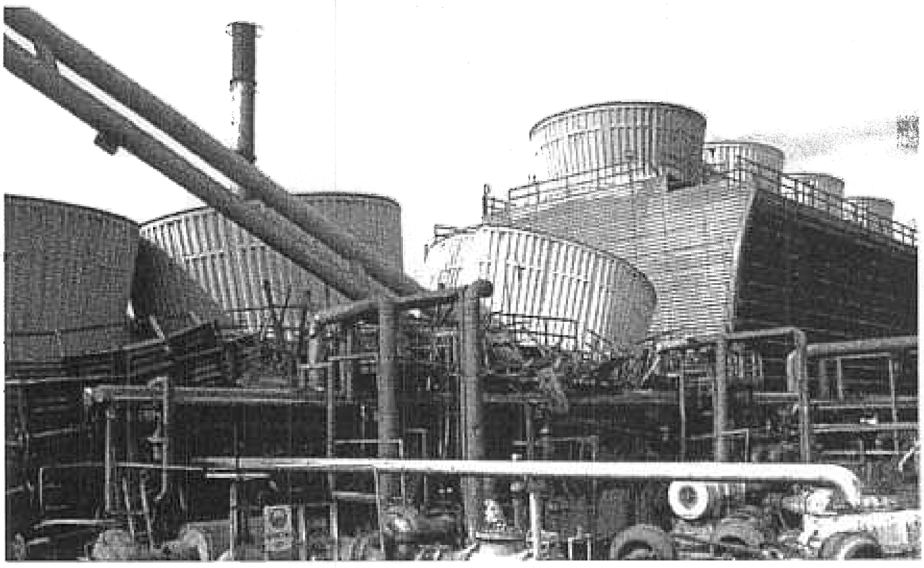

***Figure 16** - Collapsed wooden cooling towers at the Petkim petrochemical plant. Instrument at the site measured peak horizontal acceleration at 0.32g.*
(Photo: Johnson)

damage initially reduced demand for lifeline services; however, with the transition from emergency response to recovery, the demand for infrastructure—especially water and wastewater systems in the tent cities—is increasing.

Performance of Industrial Facilities

The epicentral area is home to much of Turkey's heavy industry. The typical engineered facilities have more quality control in construction than observed in the residential and commercial structures. However, damage was much more severe and extensive than seen in earthquakes with similar acceleration records, and several major facilities are facing extended business interruption.

Petrochemical Industry: The most widely publicized and spectacular damage occurred at the massive Tupras refinery in Korfez (Figure 17). Several tanks and a cooling tower burned out of control for three days when naptha spilled from a floating roof tank and ignited; all water was lost to the refinery. A second fire started in a crude unit, when a 90-meter high reinforced concrete heater stack catastrophically collapsed, knocking down equipment and pipeways (Figure 15). Tupras also had a wood cooling tower that completely collapsed, and there was an oil spill at the port.

The Petkim petrochemical facility at Korfez is one of the largest state-owned facilities in the country and, like Tupras, is a major supplier to other companies. Petkim had extensive damage to the port, complete collapse of the wood cooling towers (Figure 16), and severe damage to concrete cooling towers. Peak horizontal accelerations of 0.32g were recorded on a soil-founded instrument located at this site.

At least 15 other gas firms are located in the immediate vicinity, with numerous spherical LPG storage tanks surrounding the area. Although no major structural damage was observed at these plants, two truck drivers were killed in a fire ignited by driving through a gas leak from one of the facilities.

Automotive Industry: Car manufacturing and tire industries are abundant in the area. At their main facility in Izmit, Pirelli Tires had extensive damage due to complete structural collapse of one portion, which killed one worker. Pirelli also had difficulties restarting the facility because critical undamaged equipment was in the severely damaged portion of the plant.

The Hyundai car factory across the street from Pirelli clearly experienced strong ground shaking,

***Figure 17**- Tanks destroyed by out-of-control fire in the Tupras refinery tank farm.* *(Photo: G. Johnson)*

as evidenced by nonstructural damage to large air handling systems and cable trays, as well as shearing of bolted connections in the substantial steel-frame structure.

The Toyota factory, located some 40 km to the west in Adapazari, had fault ruptures in its parking lot, about 100 meters from the building. Its buildings are constructed with massive steel frames, with flange thickness of up to five inches. While no structural damage was reported, nonstructural damage included collapsed storage racks, tipped substation transformers, and cars on the line at the time of the earthquake.

Other Heavy Industry: Industrial facilities surveyed included cement plants, steel mills, paper mills, food processing plants, and pharmaceutical factories. Very few of these plants escaped without some significant damage, and nearly all surveyed remained out of operation at least for a week following the earthquake. Port facilities at nearly all of the surveyed facilities near the epicenter were severely damaged.

Examples of specific damage include collapse of two cranes at the Mannesmann Boru pipe factory; roof collapse, transformer damage, and silo collapse at the SEKA paper mill; collapse of a steel frame structure and movement of bioreactor vessels at the Pakmaya food processing plant; storage rack collapse, toxic releases from mixing chemicals, and damaged piping at the Toprak pharmaceutical firm; and collapse of liquid oxygen tank support structures at the Habas medical gas facility.

Summary: As additional information is gathered and studied from these facilities, we expect additional lessons applicable to industrial facilities in other seismic regions of the world, including the United States, on issues such as structural response, nonstructural and equipment performance, and emergency response.

Figure 18 *- Search and rescue continues on Day 8 in Yalova.* *(Photo: W. Mitchell)*

Emergency Response and Societal Impacts

The earthquake was felt in an area of Turkey's industrial heartland of approximately 5000 square miles. The affected population numbered 15 million people. As of September 6, casualties total 15,135 confirmed dead and 23,984 injured, with additional thousands missing and presumed dead. Turkey's National Security Council estimated 200,000 people were made homeless; however, the latest data indicate that 600,000 people are homeless and 200,000 are living on the streets. The prime minister has promised that all victims will have permanent homes by summer 2000. An estimated $10-15 billion dollars are needed for recovery.

This earthquake is significant in a number of important ways; for example, the populace and media have mobilized strong criticism of, and opposition to the government, the housing developers, the contractors, and even the military. The number of deaths and injuries draws special attention to the questionable practices of contractors and building inspectors documented in past Turkish quakes. Against the backdrop of grim news, however, are numerous acts of humanitarian assistance from various countries, including Turkey's longtime adversary, Greece.

Search and Rescue (SAR): Initial search and rescue was strongly criticized as slow and unorganized. This appeared to be the result of loss of communications, lack of command and control, shortage of equipment and materials, and an absence of disaster response training. Much of the initial response was by survivors. International search and rescue teams began arriving within 24 hours, and 65 foreign SAR teams saved 621 lives in intensive efforts that continued for four or five days following the earthquake. Initially there was friction between SAR teams and heavy equipment operators attempting to aid in the search. SAR workers were concerned that additional injuries would be caused by heavy equipment, but later realized the enormity of the task and accepted the method. Not until three days after the event did 50,000 soldiers arrive to assist in SAR and debris clearance.

Emergency Response: Survivors received little government assistance within the first 48 hours, and some got no help for up to four days. Because major hospitals were dam-

Figure 19 *- Red Crescent temporary shelters at Degirmendere.* *(Photo: W. Mitchell)*

aged, field hospitals were established with international assistance.

To quell the populace's fear of subsequent quakes or large aftershocks, Kandilli Observatory, Bogazici University, Istanbul Technical University and others did an excellent job of disseminating technical information. As in most disasters, there was a certain amount of misinterpretation of scientific data, but the scientists did all they could to get the correct information to the public and to emergency responders.

Other Effects: The damaged region represents 10% of the GNP of Turkey. Damage estimates range from $10 billion to $40 billion. An estimated 60,000-115,000 buildings were destroyed or damaged. Of 600 damaged apartments, 550 were built by one developer, who has now fled the country.

This earthquake clearly demonstrated to the nation that improperly constructed buildings kill people, and that accountability matters. Political, social, and economic aftershocks may serve as the catalyst for improving emergency management and reducing damage. Turkey has received a number of lessons several times over in past earthquakes (see the November 1995 and September 1998 *EERI Newsletters*). Now it must start acting on them.

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