

REPORT ON 1999 KOCAELI AND DÜZCE (TURKEY) EARTHQUAKES

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1 Introduction

On August 17, 1999 a magnitude MW 7.4 earthquake struck the Kocaeli and Sakarya provinces in northwestern Turkey, a densely populated region in the industrial heartland of Turkey. The earthquake nucleated at a depth of about 15km at about 10km east of the town of Gölcük. It is associated with a 120km rupture involving four distinct fault segments on the northernmost strand of the western extension of the 1300 km-long North Anatolian fault system. Predominantly right-lateral strike slip offsets were in the range of 3 to 4 m over a significant length of the fault. The earthquake region has been identified as a seismic gap with stress concentrations indicative of a large impending earthquake. The August 17 earthquake is considered to be the largest event to have devastated a modern, industrialized area since the 1923 Tokyo earthquake. Another segment at the eastern end of the fault break has ruptured on November 12 producing the MW=7.2 Duzce earthquake. The region affected by the earthquake is both geographically extensive and economically dynamic. It forms the industrial heartland of Turkey. The four districts most severely affected (Kocaeli, Sakarya, Bolu and Yalova) contribute over 7 per cent of the country's GDP and 14 per cent of industrial value added. Per capita income is almost double the national average. Though containing only 4 per cent of the nation's population, the region contributes over 16 per cent of budget revenues. The immediately surrounding districts (of Bursa, Eskisehir, and Istanbul) have been mainly affected indirectly by their close economic linkages with the former area, e.g., industries and small businesses supplying services or material inputs to each other's production processes. They also are subject to a shared seismic risk and so face magnified uncertainty for the future as a fall-out of the recent events. Taking all seven cities together, the wider earthquake region accounts for 35 per cent of national GDP and almost half of the nation's industrial output. Building losses are reported to amount to about US\$5 billions. Damage to lifelines is estimated to be in the order of US\$1 billion. Industrial facilities and small business losses are respectively about US\$2 and US\$1 billion. If we assume that the indirect socio-economic losses will be about as much as the direct physical losses the total loss figure will be in the vicinity of 16 Billion US\$ (about 7% of GDP of Turkey). Most

of the industrial losses will be covered by the insurance. Most of the residential losses will be borne by the government since under the current disaster law the state serves as the free insurer of households.

2 Seismo-Tectonics

August 17, 1999 (MW 7.4) Kocaeli and November 12, 1999 (MW=7.2) Duzce earthquakes are consequences of the motion a wedge of continental crust, known as the Anatolian Block, being squeezed between the Arabian and the Eurasian plate. This motion is accommodated by two major strike-slip faults: the North and East Anatolian faults (Figure 1). The August 17 Kocaeli and November 12, 1999 Duzce earthquakes were both associated with the North Anatolian fault. This major fault is predominantly a single right-lateral strike-slip fault with a differential slip rate of 10-20 mm/yr. The faulting on this mega tectonic entity has segmental character with a characteristic earthquake in the Mw=7+ range. The last earthquake sequence began with the 1939 Erzincan earthquake, followed by earthquakes in 1942, 1943, 1944, 1951, 1957, 1967, and finally the 1999 earthquakes (Figure 2). The Duzce earthquake is associated with the so-called Duzce fault, which forms a morphological boundary at the south of the Düzce Plain with and extends 70 km between Akyazi and Kaynasli. At Adapazari and Bolu, Düzce Fault joint to the North Anatolian Fault System.



Figure 1. Regional Tectonic Map (<http://www.ipgp.jussieu.fr>)

The historical seismicity of the region during the last two millennia is well studied (Ambraseys and Finkel, 1991, 1995 and Parsons et. al, 2000). In this century, starting with 1939 the North Anatolian Fault Zone had a generally westward migrating sequence of earthquakes, which, for long, has indicated the

potential for the Kocaeli and Duzce earthquakes (Toksoz et al, 1979 and Barka and Kadinsky-Cade, 1998). The recent seismicity of the region is provided in Figure 3.

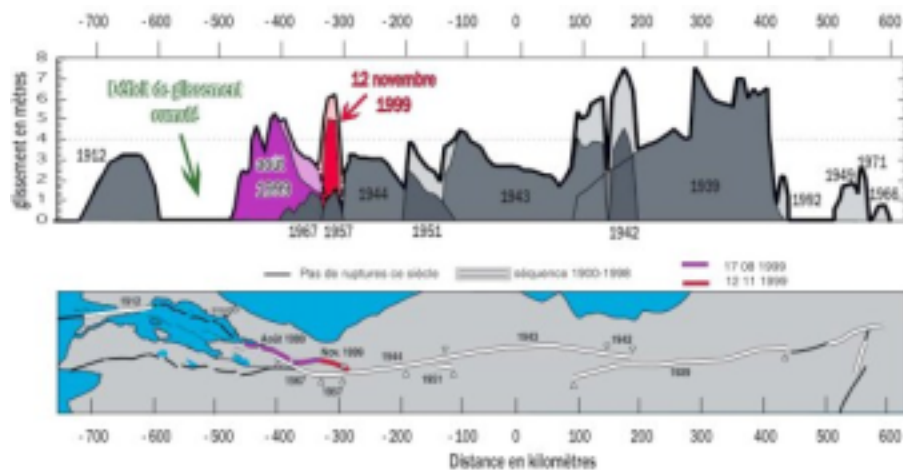


Figure 2. Migration of Earthquakes on the North Anatolian Fault in this century and distribution of fault offsets. The deficit in Marmara Sea is indicated (<http://www.ipgp.jussieu.fr>)

3 Surface Faulting

The August 17, 1999, Kocaeli earthquake produced right-lateral onshore surface slips along an east-west trending zone of right-stepping fault strands over a distance of about 120km. The slip was typically 2.5 to 4.5 m, reaching a maximum of approximately 5 m at a location about 30 km to the east of the epicenter. Followed or formed parallel sets of faults oblique to the trend of faulting. The surface expression of rupture consisted of tension cracks and fissures with limited positive relief along a 10-20m zone.

Düzce Earthquake produced a surface fault rupture of approximately 40 km on the so-called Duzce Fault between the eastern terminus of the Kocaeli Earthquake rupture at Eften Lake and Bolu Tunnels at Elmalik. The maximum right-lateral offsets were measured to be about 4 m. The rupture has also a vertical component ranging between 10 to 150cm.

4 Source Process

USGS Rapid Moment Tensor Solution provides the following parameters for the two events:

17.08.1999 Kocaeli Earthquake: Epicenter: 40.639 29.830, mb=6.3, MS=7.8,
Seismic Moment: $M_0=1.4 \cdot 10^{20}$ Nm, $M_w=7.4$
11.12.1999 Duzce Earthquake: Epicenter: 40.768 31.148, mb=6.5, MS=7.3,
Seismic Moment: $M_0=4.5 \cdot 10^{19}$ Nm, $M_w=7.1$

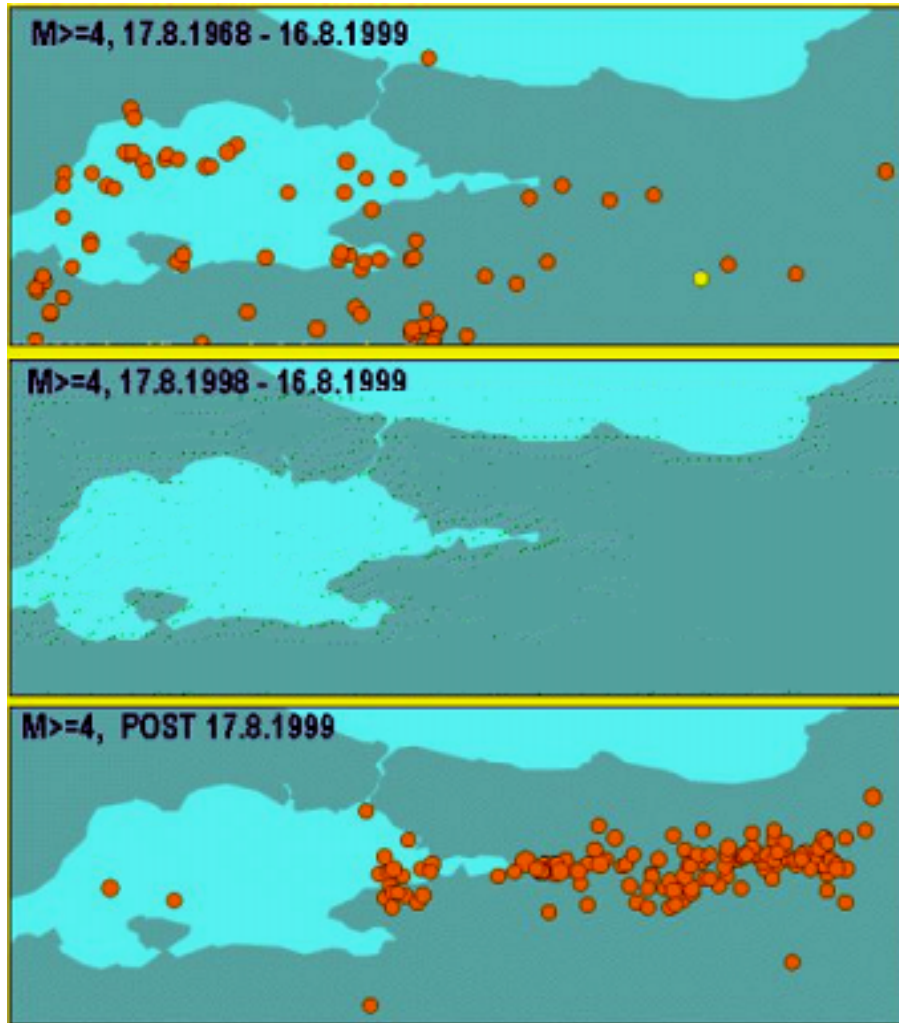


Figure 3. Recent Seismicity of the Region

Source time functions for these earthquakes provided by University of Michigan indicate essentially single triangular slips with maximum moment rates of

respectively 0.18×10^{20} Nm/s and 0.08×10^{20} Nm/s for the Kocaeli and Duzce events. The associated durations are reported to be 14s and 10.5s.

The seismic moment of the Kocaeli earthquake can be easily verified by the field data. Using the observed fault length of 120km, width of 15km, average displacement of 2.5m, and a shear modulus of 32GPa we can obtain a static moment of 1.4×10^{20} Nm. Taking an average fault rupture area of 120 km x 15 km, the average stress drop can be found to be about average stress drop = $2.5 \times M_0 / S \times 1.5 = 6$ Mpa.

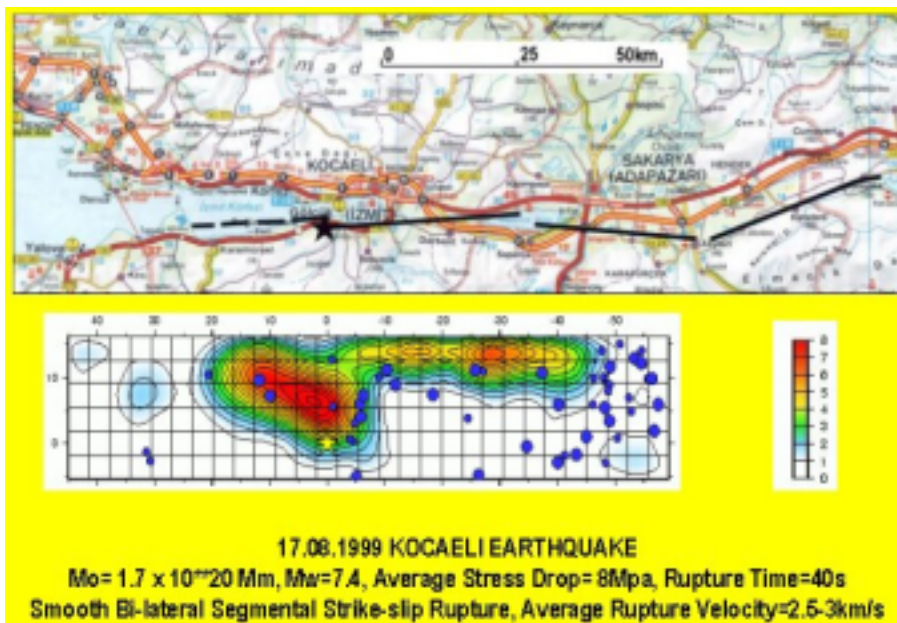


Figure 4. Epicenter, fault rupture and fault slip distribution associated with the Kocaeli Earthquake (Slip distribution from Yagi and Kikuchi, : <http://www.eic.eri.u-tokyo.ac.jp/yuji/trk2>)

Seismic imaging of the Kocaeli earthquake rupture done by Bouchon et al. (2000) indicates almost pure lateral strike-slip rupture that runs west at a velocity of about 3km/s and towards east at a very high velocity of 4.7km/s for a distance of about 40km before dropping to about 3.1km/s at the easternmost segment. The largest slip 7m occurs between 25 to 45km east of the epicenter. West of the epicenter the slip is large between distances of 10 to 30km. The rise time is generally between 2 to 4s. According to Delouis et. al (2000), the pure strike-slip rupture in Kocaeli earthquake is dominated by the bilateral braking of a central asperity located between Karamursel (29.7E) and Arifiye (30.3E). Slip lasts 45 to 50 s but most of the energy is released in 15s. Rupture velocity to the west is 3km/s.

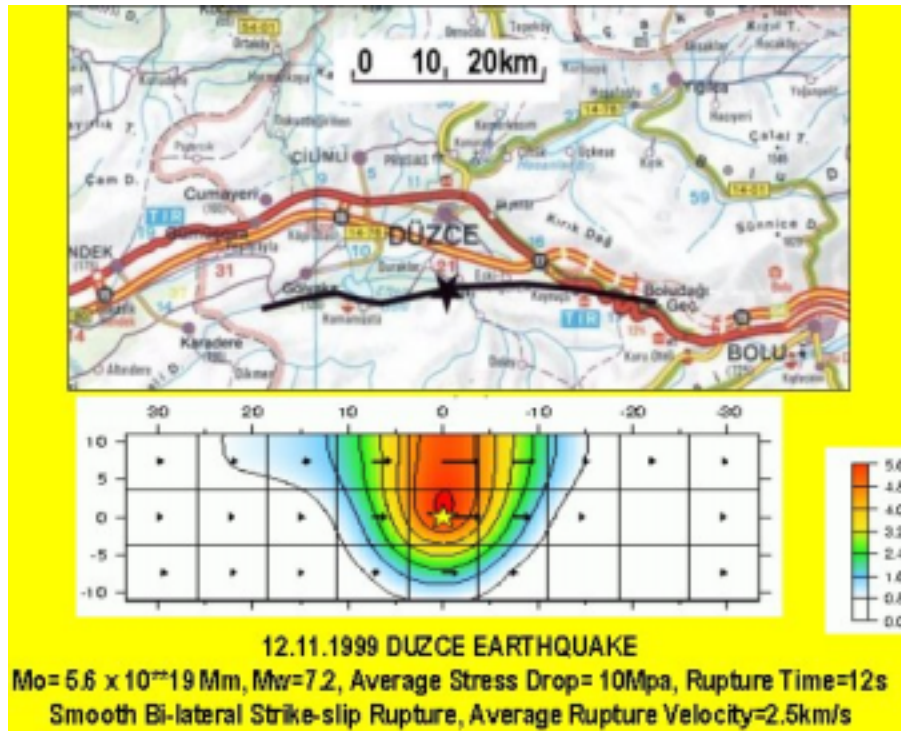


Figure 5. Epicenter, fault rupture and fault slip distribution associated with the Duzce Earthquake (Slip distribution from Yagi and Kikuchi, : <http://www.eic.eri.u-tokyo.ac.jp/yuji/trk2>)

Rupture velocity to the east is faster but there is no evidence for or against supershear rupture. Yagi and Kikuchi (1999) characterize the rupture process in Kocaeli earthquake by an asymmetric bilateral rupture propagation and smooth slip (Figure 4). It consists of two major fault segments, a rupture propagating to the west and a second rupture propagating to the east. The maximum dislocation and the maximum dislocation velocity are 6.3 m and 2.7 m/s, respectively, both found at the former segment. The total source duration is 20 s. The average dislocation is about 4 m. The extent of the coseismic rupture suggests that a considerable part of the anticipated seismic gap remains unruptured. It is inferred that the rupture first propagated along the western fault segment, and then it triggered another rupture on the eastern fault segment. The maximum ground accelerations measured in this earthquake are rather small, only half of the value observed in various large earthquakes, while the maximum ground velocities are comparable to those observed in large earthquakes. The smoothness of rupture propagation is responsible for the comparable ground velocity but small acceleration in this earthquake.

Yagi, Y. and M. Kikuchi (1999) have found out that in the Duzce earthquake, the rupture propagated 10 km to the East and 20 km to the West (Figure 5). Average dislocation over the ruptured segment is about 2.7 m. The source duration is 12 s. Using the observed fault length of 30km, width of 15km, average displacement of 2.7m and shear modulus of 32GPa we obtain a static moment of 3.9×10^{19} Nm. Taking an average fault rupture area of 30 km x 15 km, the average stress drop associated with the Duzce event can be found to be about $2.5 \times M_0 / S^* \times 1.5 = 12$ Mpa.

5 Distribution Of Intensities and Sea Wave

The maximum MSK intensity of the Kocaeli earthquake was X, essentially assigned on the basis of fault rupture and excessive ground deformations. Figure 6 provides an isoseismal map of the earthquake prepared by Earthquake Research Division of General Directorate of Disaster Affairs.

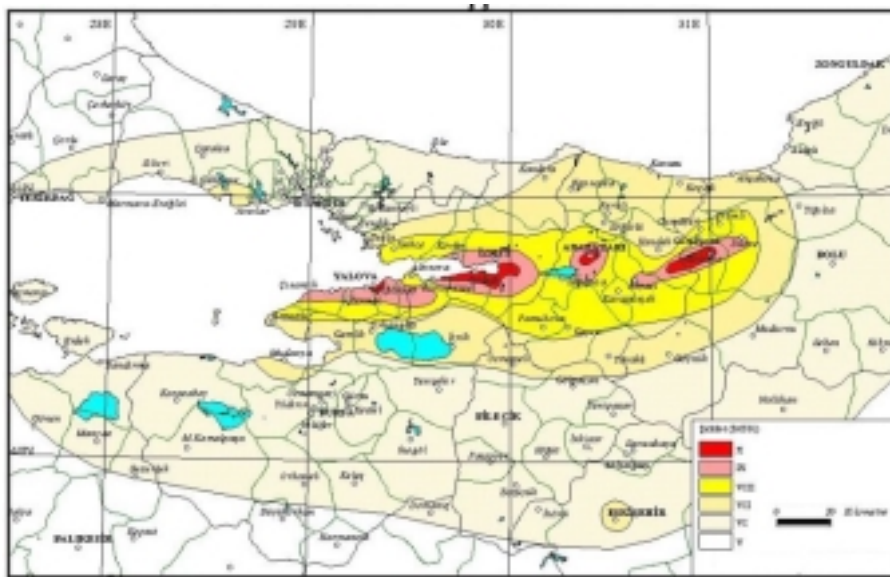


Figure 6. Isoseismal Map of Kocaeli Earthquake (<http://www.depem.gov.tr/>)

In Kocaeli earthquake large sea waves were reported in Izmit Bay. Run-up heights ranged up to 2.5m along the shores of the middle basin of the Gulf of Izmit between Hereke and Degirmendere after a general depression. The cause of this phenomenon is argued to be near shore tectonic subsidence and submarine sediment slumping. Figure 7 pictures a ferryboat carried onshore by a strong seismic wave.



Figure 7. Ferry Boat in Izmit Gulf thrown to shore due to strong wave action

6 Strong Ground Motion

The strong motion stations operated by the General Directorate of Disaster Affairs, the Kandilli Observatory and Earthquake Research Institute of Bogazici University and Istanbul Technical University have produced at least 27 strong motion records for the Kocaeli earthquake within 200 km of the fault.

Kocaeli earthquake has generated six motions within 20 km of the fault (Sakarya, Yarimca, Izmit, Duzce, Arcelik, and Gebze), adding significantly to the near-field database of ground motions for $M_w \geq 7.0$ strike-slip earthquakes. The strong motion data pertaining to Kocaeli and Duzce earthquakes can be downloaded from Earthquake Research Division of General Directorate of Disaster Affairs (<http://www.deprem.gov.tr/>) and the Department of Earthquake Engineering of Bogazici University (<http://www.koeri.boun.edu.tr/earthqk/earthqk.html>). The peak ground accelerations recorded at the near fault stations in both earthquakes are provided in Figures 8 and 9. The two stations closest to the fault rupture are Sakarya (3.3 km) and Yarimca (4.4 km). Sakarya is founded on stiff soil, while Yarimca is founded on soft soil. Of these, the largest peak ground acceleration was about 0.4g at Sakarya. All of the attenuation relationships over predict peak accelerations observed in Kocaeli earthquake at distances less than about 20 km. However the peak velocities is in the order of what has been observed in previous earthquakes of similar nature. It should be noted that the attenuation relationships rely heavily on extrapolation from larger distances and smaller magnitude earthquakes to define ground motion predictions in the distance and magnitude range and may not yield

correct values in the near field for large magnitude events. Other reasons for low accelerations may be the smoothness of rupture and the relatively low stress drop in the Kocaeli earthquake. At distances greater than 20 km, the acceleration data from the Kocaeli earthquake are generally bound by the plus and minus two standard deviation predictions. As it has been observed in almost all past earthquakes, the ground motion amplitudes are larger for the soil sites (Yarimca, Düzce) than for the rock sites (Gebze, Izmit, Sakarya)



Figure 8. Peak horizontal ground accelerations recorded in the Kocaeli earthquake



Figure 9. Peak horizontal ground accelerations recorded in the Duzce earthquake

The Duzce (DZC) record is the only record closer than 20 km that falls above the median prediction. This record was affected by rupture directivity. The Ambarli (ATS) site recorded unusually large accelerations (above the plus two standard deviation prediction for each attenuation relationship), possibly due to strong focusing and site effects.

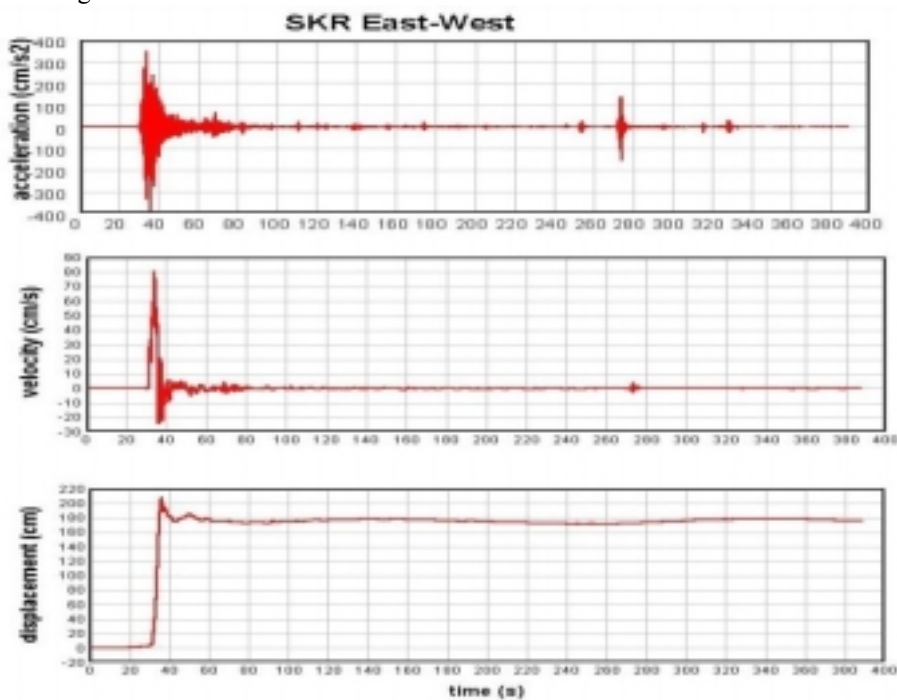


Figure 10. Acceleration, velocity and displacement traces associated with the Sakarya E-W record obtained during Kocaeli Earthquake.

In Kocaeli earthquake the fault ruptured from Golcuk first to the west approximately 40 km then rupturing approximately 80 km to the east. Forward directivity may be observed both to the east and west of the fault. The western segment of the August 17 fault ruptured from east to west in the Izmit Bay for an unknown distance. As indicated in the source rupture models developed for the earthquake, the directivity effects may have contributed to damage in Yalova. And Cinarcik. Forward directivity can be observed both to the east and west of the fault. Sakarya and Yarimca records display strong velocity pulses and a static displacement of 2.0 m and 1.5 m, respectively, in the E-W component (Figure 10). The N-S component of the Yarimca (YPT) record also displays a significant static offset (1.2 m), indicating some movement to the north. Yarimca record is rather

complex compared to others and clearly indicates an early aftershock with high frequency vibrations originating very close to the main shock epicenter. The complexity of the waveform at YPT may also indicate the influence of the local geology at the site. At Arcelik (ARC) the waveform is simple. The largest motion is in fault normal direction with the peak amplitude directed towards south. At Sakarya record (SKR) the time difference between the s- and p-wave arrivals is only 1.8s. This may be taken as an indication that the rupture might have propagated at a supershear velocity of 4.7km/s between the source and the SKR station. Figure 11 provides a comparison of response spectra of several records with the code-based spectrum.

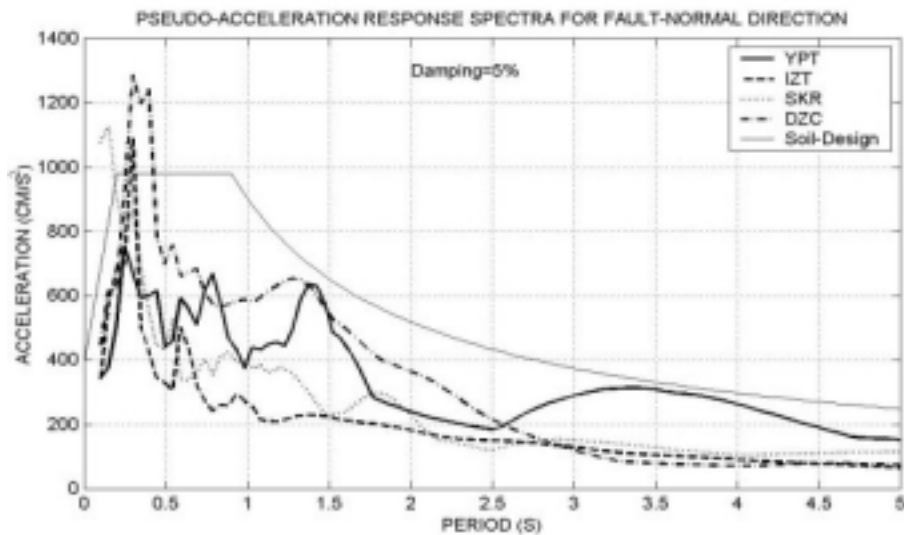


Figure 11. 5% damped linear response spectra for fault normal components of YPT, IZT, SKR and DZC records obtained during Kocaeli Earthquake and comparison with the code-based spectrum.

During the Kocaeli earthquake the Düzce (DZC) station was in the forward directivity direction of the eastern segment of the fault and as expected, the fault normal motion is dominant. The acceleration response spectra for the DZC motion exceed of the UBC design spectrum at periods less than 0.5 s and greater than 3.0 s. At longer periods the fault normal component is above the fault parallel component, as expected for forward directivity situations. Düzce earthquake generated two strong motion records in the near field from the stations operated by the General Directorate of Disaster Affairs. A mobile array installed in the Golyaka region (western terminus of the rupture) installed by Lamont-Doherty Observatory and French research team also recorded several accelerograms. The peak acceleration levels on these accelerograms are in the vicinity of 0.8g (Figure 9). The peak accelerations recorded in Duzce earthquake are more in line with the available attenuation relationships. The stress drop associated with this event is also at least

twice higher than that of the Kocaeli earthquake. In the November 12 Duzce earthquake Bolu was in the forward directivity of the ruptured segment of the fault. This is evidenced by the short duration of the strong motion at Bolu compared to Düzce. Düzce station recorded two near field strong motions during these two earthquakes. A comparison of their acceleration spectra indicates similarity for frequencies higher than 2Hz. In mid frequency ranges, the November 12 record has larger spectral accelerations. This may be a manifestation of different source characteristics. It should be noted that these results do not provide very strong evidence for the directivity phenomena as described in Somerville et al (1997), This may be due to very sparse sampling of the ground motion and the rather unfavorable location of the stations for observation of directivity effects.

During the Duzce earthquake the closest strong motion stations to the fault rupture were Düzce, Adapazari, Bolu and Mudurnu. These stations were operated by General Directorate of Disaster Affairs. The peak ground accelerations were 0.51g at Düzce, 0.81g at Bolu, 0.02g at Adapazari and 0.12g at Mudurnu. The high intensity ground motion obtained in Bolu can be a manifestation of forward directivity, sudden stopping phase of rupture and/or site response. The long duration and the long period energy content seen in Düzce record may be indicative of basin response and softening of soil media.

7 Geotechnical Effects And Site Response

Along the southwestern shore of the Gulf of Izmit large scale ground subsidence has occurred due to combination of vertical tectonic motion associated with pull-apart structures and land sliding. Many buildings located near the surface fault were torn apart by the fault rupture and collapsed, although there were similar buildings near the fault with no apparent damage.

In Adapazari, located over young riverbed sediments with soft and liquefiable silts and sands, hundreds of buildings sank, as much as 1.5m, or tilted due to shear failure of the foundation media and liquefaction (Figure 12). Surface manifestations of liquefaction in Adapazari and Sapanca included sand boils and lateral spreading. Buildings punched down into the soil softened by the shaking and high numbers of oscillation cycles, which lifted up the sidewalks due to the injection of soil material (Figure 13). However the softened and/or liquefied soil media also acted as an isolator dissipating the energy at the foundation level and avoiding shaking damage to the buildings.

In Duzce earthquake no surface indication of liquefaction was reported in Düzce nor Kaynasli However, several building settlements observed in Duzce, similar to those in Adapazari in Kocaeli Earthquake, indicates that some total or partial liquefaction might have taken place below the thick silty-clayey layer (Aydin, 2000).



Figure 12. Overtumed buiding in Adapazari due to weakened/liquefied foundation



Figure 13. Building in Adapazari that sank into the ground and the displaced soil heaved

Only limited slope failure, mostly in the form of road embankment failures was observed in both events. The only major landslide took place on west bound lane of E-5 highway at Bakacak in Duzce earthquake which disrupted the traffic for several days until a bypass road was constructed (Figure 14). The landslide occurred on the natural slope and in the highly weathered parts of the rock.



Figure 14. Landslide on E5 Highway in Duzce Earthquake

In the eastern part of Gölcük, a broad regional subsidence occurred affecting the Ford Factory under construction and several urban settlements (Figure 15). The subsidence is believed to be the result of a graben-like action associated with a local pull-apart tectonic structure. The subsidence caused a 4-km-long section of the coast near Gölcük to submerge about 3 m.

Avcilar, to the west of Istanbul, exhibited relatively high rates of building damage indicating the influence particular geological conditions, also evidenced by strong motion records with higher peak accelerations than in surrounding areas. Site effects at Avcilar were estimated using S waves from both type of records (Ozel et.al, 2000). The results show that the amplifying frequency band is, in general, lower than 4 Hz and the geology of the area is capable of amplifying the motions by a factor of 5-10. In this frequency band, there is a good agreement between the spectral ratios from the two main shocks and their aftershocks. Kudo et. al (2000) has shown that the large and long duration of strong motion records at Ambarli (ATS) are closely related to the low velocity ($V_s \sim 200\text{m/s}$) of surface layers. The S-

wave velocity structure at Avcilar is similar to the lowland Ambarli (ATS) and the strong ground motion at Avcilar during the mainshock is estimated to be similar to that at ATS.



Figure 15. Subsidence at Golcuk along the southern shore of the Izmit Bay

Site effects in Adapazari and Golcuk areas were studied by Kudo et al. (2000) on the basis of array observations of microtremors and aftershocks. Results indicate that ground motions in downtown Adapazari (extensively damaged area) were significantly different from those of SKR. SKR is located on very hard soil. Similarly, aftershock records also indicate a large difference of strong motions between a hillside and Izmit Bay area in and around Golcuk.

8 Building Damage And Casualties

The two earthquakes caused considerable damage to residential and commercial buildings, public facilities and infrastructures with substantial casualties in an area of 20km by 200km (Figure 16 and 17). In Kocaeli earthquake the majority of the building collapses occurred in towns located on the southern shorelines of the Sea



Figure 16. A general view of building damage in Golcuk



Figure 17. A general view of building damage in Duzce

of Marmara and in Adapazari. A western suburb of Istanbul, Avcilar, also suffered significant building damage despite its distance of about 100km from source zone. Damage is concentrated in Duzce and Kaynasli in the Duzce earthquake. The Duzce earthquake epicenter was located about 6km south of Düzce, where most of the buildings, already moderately and lightly damaged by Kocaeli earthquake, Have collapsed. The damaged buildings in Duzce also included several post-Kocaeli earthquake strengthened buildings.



Figure 18. A “pancake” type collapse in Kocaeli Earthquake

The number of condemned buildings after the earthquakes amounted 23,400. About 16,400 of these were heavily damaged and collapsed buildings during the earthquakes, which encompasses around 93,000 housing units and 15,000 small business units. Another 220 000 housing units and 21,000 small business units have experienced lesser degrees of damage. As much as 120,000 families were left in need of homes after the earthquake. The number totally collapsed buildings (pancake collapse) is estimated to be in the range of 3,000-3,500 (Figure 18). The pervasive building collapses in the two earthquakes caused substantial number of casualties. There were 18,373 accounted deaths and 48,901 hospitalized injuries, of which about 40% will be left permanently disabled. Altogether up to 600 000 people were left in need of homes after the earthquake. About 95% of these losses were associated with the Kocaeli earthquake. In past urban earthquakes in Turkey almost 50% of all medium-rise R/C frame buildings were damaged beyond repair in

Intensity IX+ regions. This ratio is at least 4 times higher than what was observed in 1995 Kobe and 12 times higher than 1994 Northridge earthquakes. The general vulnerability relationship for mid-rise R/C frame buildings in Turkey is provided in Figure 19, where damages grades are indicated from D1 (slight) to D5 (collapse) following the EMS (European Macroseismic Scale) terminology.

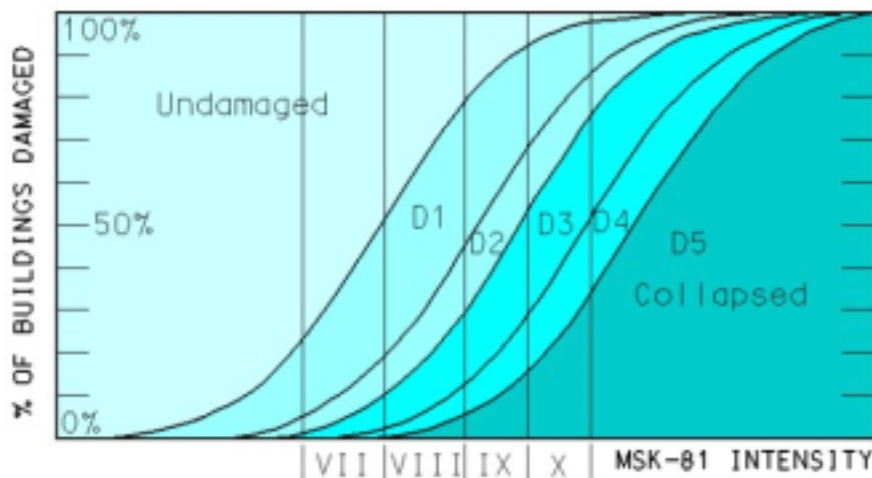


Figure 19. Earthquake vulnerability relationship for general mid-rise R/C buildings in Turkey

Post earthquake fire was limited to a number of ignitions in collapsed buildings. However, these were confined to the source and mostly affected the building contents, due to the non-flammable nature of the commonly used building materials. However, a serious fire occurred at the Tupras refinery.

In contradiction to other earthquakes in developing countries, most of the people affected in these earthquakes were the upper middle class living in multi-story residential apartment blocks that compromise on the quality of construction. The building development system in Turkey was conducive to poor construction. The chronic high rate of inflation associated with high real interest rates was the main impediment to the development of the mortgage (hence insurance) market, large-scale housing development schemes and to the industrialization of housing construction. The high rate of industrialization and urbanization created the ever-present need for inexpensive housing. The sheer number of housing units being built was beyond the capability of municipalities to regulate and supervise. The amount of bureaucratic red tape and the limited accountability of municipal officers created disincentives for proper control. Finally, the government's legal obligation to replace or repair damaged housing after an earthquake provided discouragement for insurance and implicit encouragement and rewards for inexpensive housing with poor earthquake performance. The Marmara Region has been exemplary in very

rapid growth in the last twenty years, due to rapid industrialization. This industrialization and the attendant jobs have attracted migrant population, leading to excessive demand for housing. Much of demand has been met by construction of five to six story reinforced concrete buildings by local builders with inadequate engineering, faulty construction practices and often without inspection by local municipalities. Stemming from the poor earthquake performance of the buildings in Turkey, the death rate in earthquakes has been at least an order of magnitude higher than those of Japan and California. In the past urban earthquakes the number of buildings damaged beyond repair were approximately equal to the number of deaths. In Golcuk, a small town near the epicenter, about 7% of the population lost their lives

The predominant structural system used for buildings in Turkey consists of reinforced concrete frames with a symmetric floor plan and with unreinforced masonry infill walls. Typically hollow clay tiles are used with inadequate mortar at the joints. Although not intended, these walls form the first line of resistance against the earthquake forces and, in many cases, control the lateral drift. Once the infill walls fail, the lateral resistance is to be provided by the reinforced concrete frames alone, with usually have low concrete quality, inadequate reinforcement and poor detailing. Extensive inelastic action at the critical regions has caused varying degrees of building damage that, in extreme cases, lead to formation of hinge mechanisms and pancake-type collapses.

It should be of interest to analyze the recorded ground motion to assess whether the design basis ground motion levels foreseen in the earthquake resistant design codes has been exceeded. It is believed that almost 90% of the mid-rise buildings in the earthquake-affected area were built during the last 30 years. Thus their design were supposed to follow partly the 1961 and mostly the 1975 issue of the Turkish Earthquake Code. According to the 1961 issue of the code the lateral force coefficient applicable to the region was 0.10 for reinforced concrete framed structures up to 40 m high. This coefficient was 0.15 at maximum in the 1975 issue. Elastoplastic nonlinear response spectra of the near-fault ground motions recorded in the Kocaeli and Duzce earthquakes indicate that the spectral accelerations were in the range of 0.25-0.35g for ductility ratios between 3 and 5 and for periods that encompasses the fundamental vibration periods of mid-rise buildings (Figure 20). Since would be difficult, even for those buildings that are in conformity with the 1975 code, to supply adequate capacity for this demand, the main reason behind the good earthquake performance of some structures can be the over-strength supplied by the infill walls. It should be noted that these are very general statements since it is known that the ground motion has very high spatial variability in these period ranges and the difference of damage in seemingly identical might, at least partially, be a reflection of this variability. The answer to question should wait for the installation of dense strong motion networks in urban areas.

Leaving the foundation problems and failure due to being located on the fault rupture aside, poor earthquake performance of most buildings is essentially due to

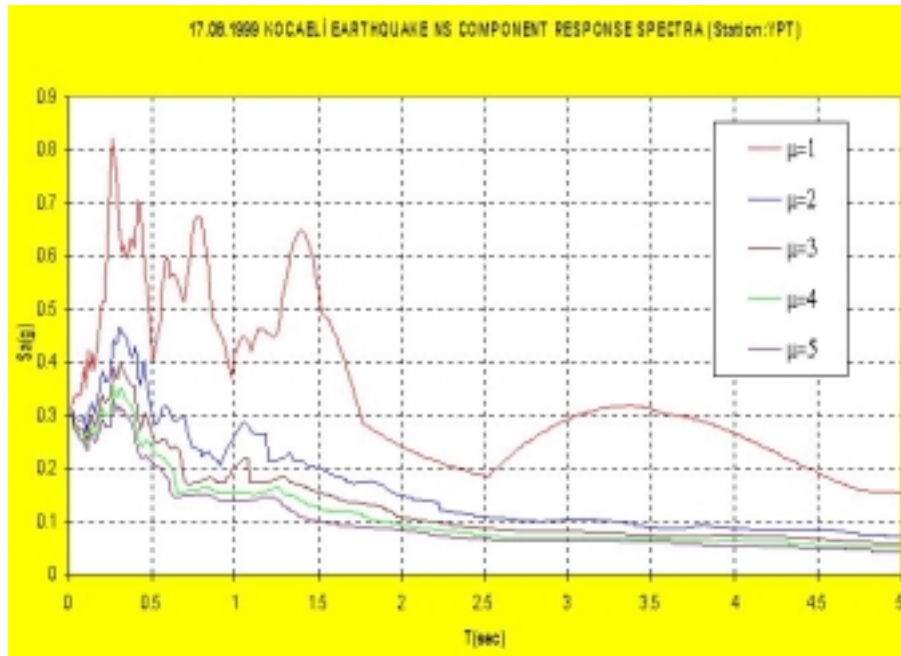


Figure 20. Elasto-plastic response spectra of YPT NS component for different ductilities (after Prof. N.Aydinoglu)



Figure 21. Damage at TUVESAS rail car factory (steel building) in Adapazari

the noncompliance with the earthquake resistant design codes. The contrasting performance between similar buildings that survived and those that failed provides evidence that conformity with the design code and good construction practices can limit damages during strong earthquakes. The damage to reinforced concrete buildings can be attributed to one or more of the following reasons:

- Poor building material quality: The strength of the concrete was in general well below the values specified in the building codes. The use of smooth reinforcing bars (as opposed to the deformed bars) was also common.
- Soft stories: Soft stories increased deformation demands, P-Delta effects and forced the first-story columns to dissipate the all the energy. This effect has caused a large portion of the building collapses. Although, there were many cases where the first story collapsed while the upper stories remained relatively undamaged.
- Strong beams and weak columns: Deep beams used with flexible columns have contributed to the early failure of columns.
- Poor detailing: Insufficient anchorage, splice lengths and confinement have severely limited the ductile response of the reinforced concrete frames.
- Short Columns: In many cases improperly designed infill walls limited the height of the columns, leading to shear failures.

Although relative few in the region, steel buildings fared much better than the non-ductile RC frames. Steel buildings in a large industrial automotive plant under construction (Ford Otosan), was undamaged except due to strains caused by ground settlement and a fault trace intersection. A poorly designed and relatively old steel structure (Railcar Factory) has received heavy damage and partial collapse (Figure 21). Typical causes for failures in steel structures were: inadequacy of anchor bolts at column bases and failure of brace connections. Although most of the better-built pre-fabricated buildings of the industrial facilities survived the earthquakes intact, there were many collapses of pre-cast reinforced concrete buildings due to failure of beam to column connections. A portion of these collapses was observed in incomplete structures that lack the exterior walls.

9 Hospitals And Schools

The performance of public hospital and school buildings has been on the average much better than the general building stock. The main reason behind this is the 50% increase in earthquake design loads for these buildings (i.e. importance factor=1.5) and simple symmetric structural layout with no soft stories. The performance of private hospitals and schools were similar to that of the general building stock.

Out of the 47 public and private hospitals in the affected region, 12 (26%) were damaged beyond repair. 28 health centers were totally destroyed while 20 others were heavily damaged. About 50% of 550 pharmacies in the area have received various levels of damage. In the earthquake affected region 43 schools were destroyed and 381 schools damaged. A total of 22 elementary schools and 21 secondary schools were damaged beyond repair. Another 267 basic education schools and 114 secondary schools have received minor to moderate damage.

10 Lifeline And Infrastructure Damage And Losses

Heavy damage was sustained in the energy, transport, and communications sectors. Oil and gas production facilities suffered extensive damage, highlighted by the fire damage to the Tüpras oil refinery. Modest oil and gas pipeline damage was sustained to municipal distribution systems. Telecommunications damage included ruptured transmission lines, station damages, buildings and network facilities. Office buildings, water pipes and supplies, wastewater treatment, sewerage systems and other structures accounted for additional damage to municipal infrastructure. Damage to the transport infrastructure included 60 km. of the Ankara-Istanbul highway, the railroad and numerous harbors. The public finance need for the repair of infrastructure has been estimated (State Planning Organization) to be about 3 Million USD for the energy transmission, 70 Million USD for the energy distribution, 250 Million USD for the highway system, 40 Million USD for the railway system, 24 Million USD for the ports and 75 Million USD for the telecommunication. A brief treatment of the damage sustained by different sectors is given below.

10.1 Highways

The highway system performed well considering the scale of the fault rupture and the significant near fault ground motion. In Koceli earthquake damage was restricted to isolated bridge collapses at fault crossing locations in the region southeast of Adapazari. The Arifiye overpass totally collapsed due to excessive tectonic displacements. The Duzce earthquake caused damage in Bolu crossing involving an geometric misalignment in an important viaduct and progressive collapse of a tunnel. In Duzce earthquake the E-5 highway was damaged in Kaynasli due to extensional cracking and buckling of road surface in the vicinity of fault crossing. Due to strong shaking a number of trucks were overturned on the E-5 highway near Düzce.

During 17.8.1999 Kocaeli earthquake most of the highway damage was restricted to the section between “Izmit Dogu” and “Akyazi” crossings on the TEM (Trans European Motorway-E80). These crossings are marked “11” and “14” on Figure 22 and the damaged section is highlighted. In this section the road goes



Figure 22. General view of highway and viaduct damages in Kocaeli and Duzce Earthquakes

parallel to the fault rupture at a less than 3km distance. The damage was in the form of surface ruptures (both tension and compression cracking) and settlement of roadway fills. Settlements ranging between 10 to 50cm were observed (Figure 23).



Figure 23. Damage to road surface on TEM Highway in Kocaeli Earthquake

The most common types of damage to bridges and overpasses were displacements of girders at seating, shear key failures, and cover concrete spalling of deck around abutments. Several overpasses and viaducts on TEM sustained damage varying from limited shifting of girders from their seats (Mustafa Inan Viaduct), failure of shear keys and damage of elastomeric bearings (Sakarya River Bridge and D310 Overpass) to total collapse (Arifiye Overpass – D650). Location of these viaducts and bridges are shown in Figure 22. Sakarya River Bridge is located about 2km to the north of the fault. Most girders in the north lane are shifted off their seats as much as 0.5m as a result of the failure of shear keys. Most of the elastomeric bearing pads were dislocated and become dysfunctional. The fault rupture passes under the Arifiye Overpass with a right-lateral offset of 1.5m (Figure 24). The fault rupture passed between the northern abutment and the adjacent pier at

an angle of about 65 degrees with the bridge axis. As a result of this tectonic movement in excess of the seat width the girders were unseated in a consecutive manner and fell from their supports.



Figure 24. Collapse of the Arifiye overpass on TEM Highway in Kocaeli Earthquake.

A section of the Trans-European Motorway (TEM) between Bolu and Düzce is under construction. The motorway follows the northern side of the Düzce basin from Gümüşova to the Asarsuyu portal of the Bolu Tunnels. Bolu Viaducts #1 and #2 (under construction), Bolu Bridge and Bolu Tunnel (under construction), located in the last segment of the TEM to be completed, were strongly affected by the earthquake. Bolu viaducts 1 and 2 carry a 6 km long section of the motorway with a maximum height of 49 m, span of 39m and a width of 17.5m. The piers are supported by 12 1.8m diameter piles. Bolu Viaduct #1, 2.3km long with dual 59 spans, was located directly on the fault rupture. The fault crossed the viaduct at Pier#46 at an angle of 20-30 degrees with the viaduct axis, with a right lateral offset of 2.5m, causing substantial shifts between the superstructure and the piers (Figure 25). Some piers rotated (about the vertical axis) by 13 degrees (Figure 26). Almost all the sliding elements at girder seats and the energy dissipating devices between spans became damaged or useless.

Bolu Tunnels, under construction, consists of two 3.4 km long three-lane tubes with an average diameter of 16m. The tunnel portals are at Elmalik on the Bolu side and Asarsuyu Valley on the Düzce side. The structurally incomplete sections, crossing thick bands of highly plastic clay fault gouge sandwiched between rock units with only temporary shotcrete lining, have collapsed during the earthquake.

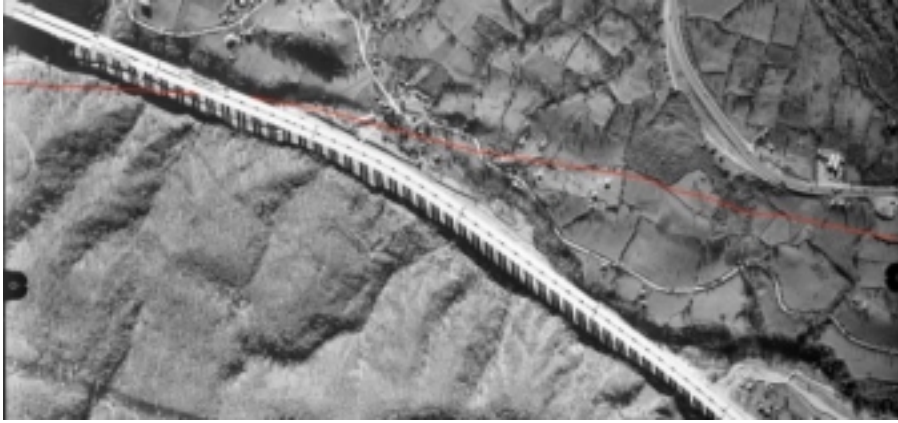


Figure 25. Aerial view of the Bolu 1 Viaduct. The fault rupture is indicated by the red line.



Figure 26. Movement between the piers and the girders of Bolu 1 Viaduct

10.2 Railroads

At the fault crossing near Arifiye, the tracks of the main railroad between Ankara and Istanbul were damaged. The tracks were distorted to an “S” shape by the fault offset at the Tepetarla station damaging about 200m section of the railroad. At

another locations, extensive ground deformations (near Kurtkoy) and tension caused misalignment (Figure 22).



Figure 27. Bucking of the railroad track near Sapance in Kocaeli Earthquake

10.3 Telecommunications

Telephone communication was temporarily lost due to damage to the main fiber optic cable at the fault crossing to the east of Izmit and damage to equipment and batteries in the central telecommunication facilities. The usual telephone congestion occurred due to overloaded lines with extensive private calls. Typical damage to the regional telecommunications systems experienced in previous earthquakes was also experienced in Kocaeli and Duzce earthquakes. Many batteries toppled from racks, broken and need to be replaced. A number of trunk connections, local loops and cross bars were damaged due to ground shaking and/or falling structures.

10.4 Drinking and Waster Water

The earthquake-affected region has a modern water system with steel transmission lines and water treatment plants. Izmit Water Project, the main source of water in the Kocaeli district, received only minor damage. Damage to some water treatment plants were easily repaired with minimum interruption of service. The 80km long water pipeline between Golcuk and Yalova and elevated water tanks were damaged at a number of locations. Water supply within the cities (especially Golcuk,

Adapazari and Sapanca) was cut off for a long period of time due extensive failures in the distribution pipes due to fault rupture and liquefaction.

Izmit wastewater treatment plant was closed after the earthquake due to damage to the mechanical equipment. The intercepting sewer pipes between Golcuk were heavily damaged. The salinity of the raw wastewater in the Tuzla Wastewater Treatment Plant increased after the earthquake to the infiltration of seawater to the system through damages in the collector pipes laid below the sea level. In Duzce earthquake the sewage systems in Düzce and Kaynasli were heavily damaged due to ground deformations.

10.5 Dams

State Water Works (DSI) has reported no damage dams and reservoirs. Yuvacik Dam, a 40m high rockfill dam, experienced only very minor settlements although it is located only 4km away from the fault rupture. Gokce Dam (61m high) near Yalova experienced limited longitudinal cracking at the crest. Other dams in the earthquake effected region (Hasanlar near Duzce, Omerli and Darlik near Istanbul, and Kirazdere near Izmit) performed very well with no damage. The nearest dams to the Duzce earthquake epicenter are Hasanlar dam and Gölköy dam. Hasanlar dam, a 72.8m high rockfill dam, is at 12 km from the epicenter while Gölköy dam, a 24.5m high earth-fill dam, is located at about 21km from the epicenter. No damage has been reported for at these dams.

10.6 Electricity

The electricity in Turkey is produced by TEAS (also independent power plants and industrial power plants) and distributed to main transformation stations operated by TEAS. The distribution from these main transformation stations, the electricity is distributed to the cities and industrial facilities by TEDAS. These are state owned companies. Medium voltage (MV) and low voltage (LV) electric power distribution facilities owned by TEDAS and affiliated distribution companies.

No damage was reported in power plants owned by TEAS and other independent and industrial power plants in Kocaeli and Duzce earthquakes. The power transmission facilities affected by the earthquake are located in eight provinces (Sakarya, Kocaeli, Bolu, Yalova, Bursa, Eskisehir, Bilecik and Istanbul).

The damages which occurred in High voltage (HV) transmission substations (Adapazari No.2, Izmit No.1 and Kentsa) include breakage of transformer bushings, breakage of surge arresters, damage of disconnections, movement of transformers and damages to substation buildings. This damage caused power blackout in northwestern Turkey within minutes of the earthquake. The electricity was generally restored to most areas within several days.

On the basis of information provided by TEDAS (Electricity Distribution Authority), about 14 (7% of total inventory) of MV/MV type and 800 (7% of total

inventory) of MV/LV type Distribution Transformers in the affected urban areas have received heavy damage. About 850km (35% of the total) MV type and about 1300km (20% of the total) underground distribution cables in the affected region were damaged. Damage to overhead lines were much less. However, 1050 (7% of the total) MV type towers and 3000 (5% of the total) LV type towers were replaced.

10.7 Ports

Most of the ports and jetties privately operated by industrial facilities in Izmit Bay sustained damage (Figure 28). Extensive damage was observed at Golcuk Navy Base due to fault crossings (Figure 29). Damage included failure of piers, mechanical equipment, piping and the collapse of cranes. The government owned Derince general cargo and grain port, which handles some 2 million tons of cargo annually, suffered heavy damage to docks, cranes and warehouses, including cracks and severe subsidence. Deince Port, which is of the concrete caisson type with shorefront length of about 1.5 km, shifted away from the wharf up to 0.7m horizontally and 1m vertically due to liquefaction-induced deformations, settlements and lateral spreading (Figure 30). Several rail mounted portal cranes and some old steel warehouses were damaged. A substantial number of the jetties at the industrial facilities were also damaged. These include Petkim facilities, Tupras Oil Refinery, Petrol Ofisi, Shell Oil, Trans Turk, Seka Paper Mill and UM Shipyard.



Figure 28. Location of affected ports and jetties in Izmit Gulf in the the Kocaeli Earthquake

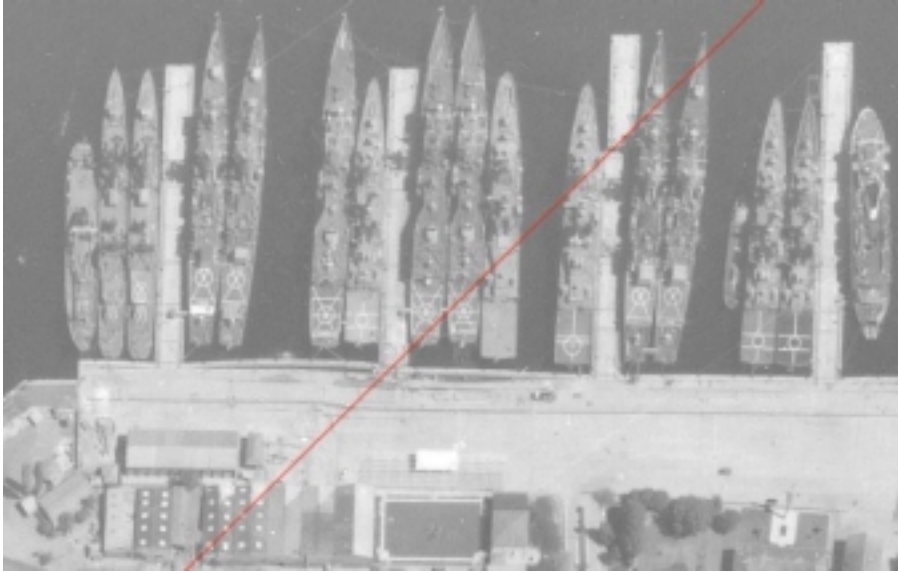


Figure 29. Aerial view of the Navy Base in Golcuk. The fault rupture is indicated by red line.



Figure 30. Damage at Derince Port in Kocaeli Earthquake

10.8 Airports

The new terminal building at Ataturk Airport under construction in Istanbul experienced minor structural problems but the Airport remained fully functional. The control tower of a military airport near Izmit received heavy damage.

10.9 Natural Gas and Oil Pipelines

The government owned Botas (Petroleum Pipeline Corporation) which covers all oil and gas imports and major distribution pipelines, reported no damage on any of their installations. The Russia-Turkey natural gas pipeline in the region crosses the Izmit Bay at about 30 km west of Izmit and the natural gas pipeline connections to industry and power plants in the affected area was operational after the Kocaeli earthquake.

In Izmit (IGSAS) municipal gas distribution system (only urban gas system in the affected area, excepting Istanbul) no damage is reported to the main distribution network. IGSAS reports that about 15% of service boxes (out of a total of 21,000) damaged due to collapsing houses. Some damage to service boxes in Istanbul (especially in Avcilar District) was also reported.

11 Damage To Industry And Losses

The epicentral area can be considered as the home of Turkey's heavy industry, including petrochemical plants and car manufacturers. The major industries are automobile, petrochemicals, manufacturing and repair of motor (and railway) vehicles, basic metals, production and weaving of synthetic fibers and yarns, paint and lacquer production, tire factories, paper mills, steel pipes, pharmaceutical, sugar, cement, power plants and tourism. Many foreign companies have affiliates nearby in the region, including Goodyear, Pirelli, Ford, Honda, Hyundai, Toyota, Isuzu, Renault, FIAT, Ford, Bridgestone, Pepsi Co, Castrol, Dow Chemical, Shell Co., British Petroleum, Mannesmann, Bridgestone, DuPont, Akza Nobel, Phillips, Lafarge and Bayer. Damage to industry was more extensive than those in other earthquakes with similar ground motion levels. The damage encompassed cooling tower collapses, damaged cranes; collapse of steel, reinforced concrete framed and prefabricated structures, damage to jetties, and extensive equipment failures. The extent of damage to industry depended on, distance to fault, site conditions, quality of construction, anchorage conditions of machinery and robustness and redundancy of fire fighting facilities. Losses due to extensive business interruption were substantial as compared to the physical damage. The Kocaeli Earthquake provides a unique opportunity to investigate the performance of industrial facilities subjected to substantial strong ground shaking under near-fault conditions.

11.1 Petrochemical Industry

An extensive concentration of state-owned petrochemical complexes is located within 5km of the fault, including Tupras, Petkim and Igsas. The heaviest damage occurred at the Tupras facility, the largest refinery in the region producing about twelve million tons per year. The refinery was working at about 90 percent of its design capacity and can be considered a modern and efficient plant. The earthquake caused significant structural damages to the refinery itself and associated tank farm with crude oil and product jetties. The consequent fire in the refinery and tank farm caused extensive additional damage (Figure 31). Fire started in one of the Naphtha tanks continued for three days endangering the safety of the whole region. Six tanks of varying sizes in the tank farm of 112 tanks were damaged due to ground shaking and fire (Figure 32). There were damage to cooling towers and the port area. Collapse of a 150m high heater stack on the boiler and crude oil processing unit caused significant damage and started a second fire. The total damage is estimated to be around US\$350 million.



Figure31 A helicopter view of the fire in Tupras petrochemical complex.

The Petkim petrochemical facility had limited damage, which includes settlement at the port and the collapse of a cooling tower. No damage to the equipment in this facility is reported. The fresh water for the Tupras and Petkim complexes, as well as for several other industries in the region (e.g. Seka paper factory), is supplied from Sapance Lake via 30km long pipelines. Fault rapture and soil failure caused extensive damage to pump stations and pipelines at about 20 locations. The failure of the water supply caused problems in controlling the fire at Tupras. Igsas fertilizer plant has experienced extensive damage in the administration building. Ammonia processing and packing units and the port

facilities were partially damaged. At Aksa chemical industries located in Yalova region there was damage in port facilities and storage tanks. All of these facilities also experienced extensive losses business interruption.



Figure 32. Post-earthquake fire damaged tanks in Tupras petrochemical complex

11.2 Automotive Industry

There are numerous car and tire factories in the region. The Hyundai factory experienced significant nonstructural damage. The Toyota car factory had fault ruptures in its parking lot. There was no structural damage to the steel framed building. Nonstructural damage included collapsed storage racks, transformers and cars on the assembly line. Some automatic machinery in the production lines of these factories suffered from alignment problems. Ford Otosan car factory, under construction during the earthquake, has experienced significant terrain subsidence and some structural damage. Pirelli Tires, Brisa Tire and Kordsa tire steel belt and cord company had extensive damage and business interruption.

11.3 Other Industry

Other industrial facilities include cement plants, steel mills, paper mills, and food processing plants, textile and pharmaceutical factories. TUVASAS railway wagon Production Company, Adapazari sugar factory and Asil Celik steel production company has all received extensive structural damage. In TUVASAS a large maintenance building and several small buildings collapsed due to lack of bracing in steel structures. In the sugar factory a stack and an elevator pipe failed and fell into the sugar-processing facility, partly damaging the facility with extensive damage to the equipment inside. Examples of specific damage include collapse of two cranes at the Mannesmann Boru pipe factory; roof collapse, transformer damage, and silo collapses 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. Kudos textile factory in Adapazari, Cak textile factory in Akyazi (Duzce) and Ak-Al textile factory in Yalova had extensive damage due to the collapse of the pre-fabricated reinforced concrete factory buildings. Some tanks in Aksa chemical installation in Yalova experienced damage, which was associated with leakage of chemicals. Food processing plants that have experienced heavy damage include Pepsi Co-Uzay Gida (Izmit) and Merko Gida (Yalova). In Duzce earthquake Süperlit pipe factory, Akisik appliances factory, Sarsilmaz firearm factories in Duzce and Anlas Anadolu tire factory in Kaynasli were heavily damaged. There wren limited damage to the industry in Bolu (Filiz Macaroni Factory and Kelebek Furniture Factory).

Private and public sector estimates of the damage to the industry as a whole range from \$1.1 to \$4.5 billion. The value-added loss in manufacturing is estimated by at \$600 to 700 million. The added value loss stemming from the damage to industry is estimated to be about 700 Million USD (SPO) which may result in a 1.6% decline in the growth of the production sector in Turkey. Other sources put this loss figure as much as into the 2 Billion USD range. For example, according to Kocaeli Chamber of Industry, 214 enterprises (about 19% of all enterprises in the province) reported significant damage amounting to a total of US\$2.5 billion in capital losses. Many major facilities are known to face extensive business interruptions, however the biggest loss will be the loss of qualified manpower. Most of the industrial losses will be covered by the insurance. Payments of claims are estimated to have amounted to about 600-800 million USD. State Planning Organization estimates an \$880 million total loss just for the 19 affected state-owned enterprises in the region. A total of 15 percent capital loss for has been reported for the major state owned enterprise located in the region. (mainly in TÜPRAŞ, TÜVASAŞ, İGSAŞ, PETKİM, SEKA and Asil Çelik). The State planning Organization estimates that the loss of business in these industries may have amounted to 632 Million USD. The tourism industry (based in Yalova) has been virtually destroyed and tourists may not return for many years, so that a fundamental restructuring will be needed.

12 Economic And Business Losses

Estimates of total wealth and income losses range from \$5 to \$14 billion. Estimates for the loss of physical capital accounts range between 4 to 10 Billion USD. Housing sectors accounts for roughly 40%. Average total loss (physical and socio-economic) may be in the range of 16 to 20 Billion USD, about 7-9% of the nation's GDP.

According to World Bank (2000) the damage (wealth loss) significantly exceeds the direct physical damages of the earthquake. The increase arises from the following principal sources: (1) reduced tax revenues from the region due to the

negative output shock, (2) losses from a tax payment deferral announced by the Government, (3) credit subsidies for loan refinancing and new loans to small and medium enterprises which sustained damage in the region, (4) postponed non-tax revenues from public enterprise privatization, and (5) emergency assistance to the population, cost of temporary housing and compensation for loss of life and disability.

State Planning Organization estimates that the earthquake will bring a load of about 6.2 Billion USD on the public finance. About 3.5 Billion USD of this amount will be needed for post-earthquake housing construction. The special earthquake taxes and paid military service scheme introduced by the government have generated about 3 Billion USD in one year after the earthquakes. Foreign finances (World Bank, European Union and others) contributed another 2.5 Billion USD. The decline in GDP during 1999 (-%5) stopped in the first half of 2000 and an increase of (%5) realized on year basis (State Planning Organization, Aug., 2000 report). The improvement in the consolidated budget revenues during the first half of 2000 was significantly assisted by the additional taxes, amounting to 3 Billion USD, due to earthquake disaster.

Damage to large enterprises have been moderate and mostly covered by the insurance (rather reinsurance) sector. However, human capital losses sustained by industry have been more serious, but harder to estimate. Besides temporary disruptions to labor supply due to deaths, injuries, and demotivation, large enterprises in the region are concerned about possible out-migration of qualified employees.

Micro and small enterprises (retail shops, craftsman and artisan workshops, and small service units) were the hardest hit by the earthquake, losing most of their working capital and premises and key family workers. While the total capital stock and value added of the micro and small enterprises might be relatively limited, their large number could bring their total loss to significant levels. World Bank (1999) estimates that about 6,000 small shops (employing less than 5 persons) were severely damaged by the earthquake. The total number of small enterprises (employing 5-10 persons) damaged by the earthquake was estimated to reach 1500. Insurance coverage for small and micro these enterprises are very limited; they are undercapitalized and have limited access to funding. About 20,000 small businesses have terminated their operation leaving behind about 140,000 jobless people. Job losses could be as much as 45% of the pre-earthquake labor force in the earthquake-affected region. Job losses especially for the self-employed may recover in the near future with government credit incentives, debt rescheduling and assistance for rebuilding. Several source have reported small business losses to be in the order of 1 Billion USD. The loss of capacity in small and micro enterprises has additional adverse socio-economic effects due to loss of unemployment, production and economic linkages with larger firms.

13 Earthquake Insurance

It is reported that about 620,000 earthquake policies are in force in Turkey with a total insured sum of about 102 billion USD. The gross retention of Turkish insurance companies is around US\$24 billion. About 5% of these policies were in the earthquake-affected area with more than 7 billion USD portfolio. The total insured losses are reported to be around US\$0.6 billion as reported by Munich-Re. Since the vast majority of this is reinsured internationally, the payment by the domestic insurance companies is around US\$25 million. The information gathered on the differences between the damaged and undamaged structures and the observational vulnerability relationships will help insurers to gain valuable insight on the catastrophe modeling and evaluate portfolios and underwriting financial risk. The insurance premia in the affected region have significantly increased after the earthquake.

Through a World Bank project a national mandatory earthquake insurance plan has been initiated. The main reason behind this scheme is to relieve the government from the burden of replacing earthquake-damaged housing. On December 17, 1999 a government decree to start a national scale mandatory earthquake insurance scheme for housing units along with cancellation of the legal government obligation for the post-earthquake housing was announced. A government-sponsored insurance pool "Turkish Catastrophic Insurance Pool (TCIP)" is now being put in place, which will transfer the national risk into world-wide risk-sharing pools, managed by international reinsurance companies and backed by substantial capital resources. Insurance coverage for each housing unit will have a coverage limit of about US\$30,000 per house. For the additional value usual private insurance coverage will be permitted. Although the new scheme is expected to be operational by 28 September 2000, the mode of operation has yet to be decided. The government hopes that in the future, the TCIP can contribute to the control of construction through differentiation of premia on the basis of earthquake vulnerability. Several opponents to the plan express that it would be impossible to find adequate reinsurance capacity, the TCIP will not be anything different than a property tax and the government would have been much better to insure itself while retaining the existing scheme of post-earthquake housing assistance.

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This paper is mostly based on the online material available in the web page of the Bogazici University - Department of Earthquake Engineering: <http://www.koeri.boun.edu.tr/earthqk/earthqk.html>. The following list of references is provided to provide further information to the reader. Not all entities are referenced in the paper. Some references are Internet – Online web addresses.

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