Available online at www.sciencedirect.com

ScienceDirect

Procedia - Social and Behavioral Sciences 120 (2014) 629 – 636

Procedia
Social and Behavioral Sciences

The 3rd International Geography Symposium - GEOMED2013

Earthquake hazard assessment in Turkey: the Mw = 7.4, Gölcük (August 17, 1999) and the Mw=7.1, Düzce (November 12, 1999) earthquakes

Recep Efe*

Balikesir University, Faculty of Arts and Sciences, Department of Geography, 10145 - Balikesir, Turkey

Abstract

During the 1999, the northwestern part of Turkey experienced two major earthquakes (Gölcük and Düzce) along the North Anatolian Fault Zone. The Gölcük Earthquake occurred on August 17, and caused damage in a zone extending from Duzce to Istanbul. The Düzce Earthquake struck on November 12, 1999 and caused damage in Düzce, Kaynaşlı and Bolu. These two earthquakes caused significant changes in natural environment such as; surface rupture, cracks, landslides, offsets in the riverbeds, discharge of subsurface water from underground, liquefaction and coastal collapse. The surface rupture, which is 168 km long, extending from Kaynaşlı to Gölcük, is the most significant. The changes after the earthquakes were identified from field measurements and assembling the existing maps at 1:25,000 and 1:100,000 scales.

Keywords: Turkey, Golcuk earthquake, Duzce earthquake, geomorphic effect, surface rupture

1. Introduction

Two large earthquakes struck northwestern Turkey in 1999. The Gölcük earthquake occurred on Tuesday, August 17th, 1999 at 03.01.38 local time, and had a moment magnitude of Mw=7.4. The cause of the earthquake was the sudden breakage or rupture of the earth's crust along the western part of the North Anatolian Fault Zone (Fig 4). The Gölcük area is located in the northwestern part of Turkey and on the eastern shore of the Sea of Marmara

* Corresponding author. Recep Efe +90-532-247- 48-07
E-mail address: recepefe@hotmail.com

doi:10.1016/j.sbspro.2014.02.143

(Fig.1). The earthquake lasted for 37 seconds and affected a wide area in northwest Turkey (Istanbul, Izmit, Adapazarı, Düzce, Bolu, Yalova, Bursa, and Zonguldak). This earthquake is known either as the Marmara earthquake or as the Gölcük earthquake.

Following the seismic event, over 17.000 people died and over 24.000 were injured. The earthquake damaged buildings across seven provinces for a distance of 250 km from Istanbul to Bolu.

85 days after the Gölcük earthquake, another powerful earthquake occurred in the Düzce area. The Düzce earthquake occurred at 18.57.21 local time on November 12, 1999, and had a magnitude of Mw=7.1. Düzce is also located in northwestern Turkey. It affected Düzce, Kaynaşlı, Bolu, and Gölyaka and brought severe damage to the area. This earthquake is known as the Düzce earthquake. The Düzce earthquake area is primarily located in the western part of Black Sea Region but it affected the Eastern Marmara region.

Several seismic, geologic, geophysical and tectonic studies were carried out in the area (Sengor, 1979; Sengor et al., 1985; Stein et al., 1997; Taymaz, 2000; USGS, 2000; Witter, 2000; Parke et al., 2000; Atalay, 2000; Efe and Novakowski, 2000). In this study, the Gölcük and Düzce earthquakes of 1999 are investigated both in terms of geologic, morphotectonics and geomorphologic structures, as well as changes in the earth's surface (Efe 2000a).

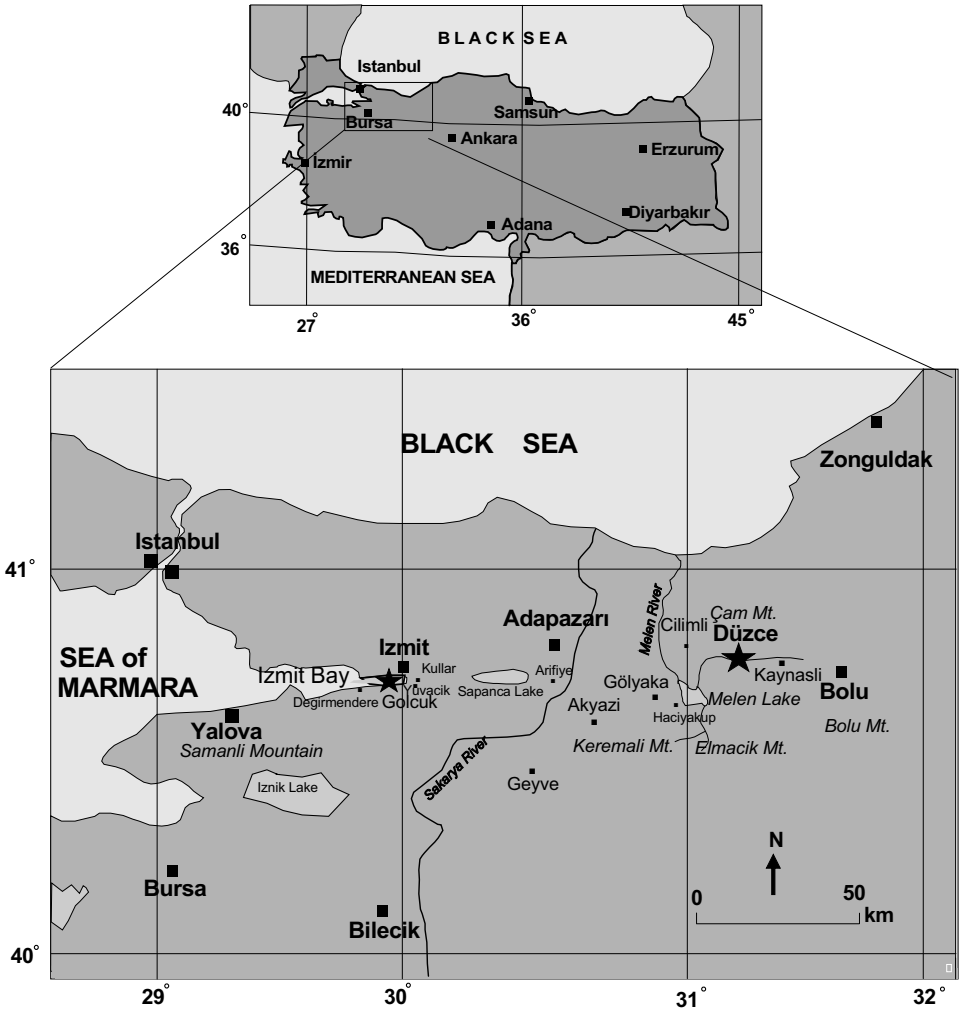

Fig. 1. Study area

2. Material and Method

The study area is located in the northwestern part of Turkey and encompasses the area between Bolu and Istanbul (Fig. 1). The study area is between 28º 30’ and 31º 75’ east longitude and 40º 30’ and 41º 30’ north latitude. Study was conducted depending on field observations. 1/25000 scale topographical maps were used to determine the direction of surface ruptures.

3. Findings and Discussion

3.1. Geologic and geomorphologic features

The distribution of earthquake intensity was strictly affected by the physical properties of the area. These physical properties primarily include tectonic structures, but also involve geology, geomorphology. In this respect, physical characteristics can be employed to explain earthquake intensity and the distribution of damage.

3.1.1. Geology

The geological structure of the eastern Marmara was mostly formed during the Eosen-Oligocene period by the closing of the intra-pontid which is the part of Tethys Ocean. There are different geological formations (e.g., from Paleozoic to Quaternary era) found in the study area (Brinkmann, 1971).

The oldest formations of the study area consist of Precambrian and Paleozoic metamorphic rocks containing serpentine, schist, gneiss and granites. Paleozoic formations are outcropped in the Elmacık and Samanlı mountains on the southern part of earthquake area. Silurian, Devonian upper Carboniferous recrystallized and dolomitic limestones occur on the north of Adapazari.

Geological formations belonging to the Cretaceous period are widespread in the northeastern area of Sapanca Lake, Izmit and to the north and northwest as well as the northwestern side of Geyve and its northeastern part. Metamorphic rocks that belong to the Triassic era begin south of Sapanca Lake toward Iznik Lake. Triassic and Jurassic limestones occur in the this part of the zone.

The Izmit Bay is located along the North Anatolian fault zone. In its eastern parts, there are vast alluvial plains between Sapanca Lake and Izmit Bay. The ground of these plains generally consists of very thick, moderately clay or silty sand strata. Sedimentary deposits with rounded pebble, gravel and sand are common in the plains.

Areas adjacent to the fault line are not suitable for development by virtue of these ground features. The percentage risk of liquefaction is high in the lowest plains of the area. Particularly in Adapazari, Gölcük and Yalova, serious damage occurred because of ground features.

Fig.2. Inundation by seawater due to coastal subsidence near Gölcük

Fig.3. Mole track along the ground rupture near Akyazı .

3.1.2. Geomorphology

The study area includes the Kocaeli plateau to the north, and the Samanlı, Elmacık-Keremali mountains to the south. The depression is bordered by an escarpment that extends to the coast of the Black Sea and is known as the Lower Sakarya plateau. The Sakarya River passes through the escarpment area and discharges into the Black Sea. The Çam mountain is in the northeastern area of the Adapazari valley and the Keremali mountains in the south of the valley. All depressions in this area have been influenced by tectonics. Overall, the existing topography was formed by the Sakarya and Melen rivers and their tributaries and neotectonic movements.

3.2. Morphotectonics

North Anatolian Fault Zone (NAF): This is a dextral intracontinental strike-slip fault more than 1350 km in length which has apparently propagated from Eastern Turkey (Karlıova) to the Gulf of Corinth in the Aegean Sea Fig. 4). Basically, the NAF constitutes a boundary between the Eurasian and Anatolian plates. As a result, Anatolia is extruded westward between the NAF and the conjugate East Anatolian Fault, pushed by the collision between Eurasia and Arabian plates. The slip-rates estimates on the NAF vary between 20 mm/yr (from seismological considerations) to 5 mm/yr—from geological evidence (Barka, 1996; Hubert et al.,1997; Oral, 1994). There are smaller faults which make up the western branches of North Anatolian Fault in the study area (Efe, 2000a; Efe, 2000b; Parke et al.,2000).

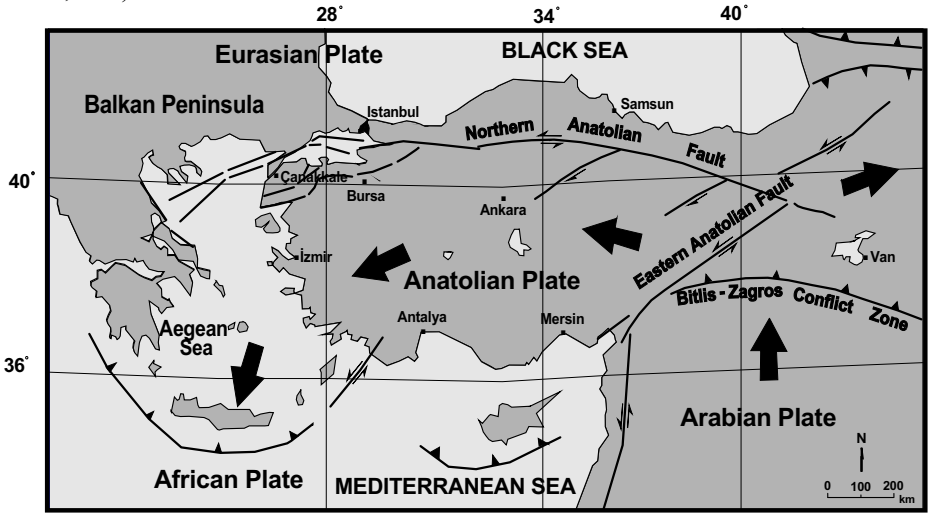

Fig.4. Plate tectonics model explaining recent and actual tectonic activity in Turkey (Sengor et al, 1985). The major tectonic plates are the African, Arabian, Eurasian and Anatolian plates.

Düzce-Kaynaşlı Fault: The fault, which borders the Düzce basin, is located between Golyaka and Kaynasli. The total length of the fault is 43 km and it branches into two to the east of Kaynaşlı.

Hendek Fault: The Hendek fault is in the western part of the Düzce Basin and it extends between Sapanca Lake and Cumayeri in a NE-SW direction. It is a strike-slip fault with a right–lateral movement and its length is 50 km.

Çilimli Fault: The Çilimli fault lies on the north of Düzce basin and its length is approximately 19 km. This fault forms a morphological discordance between the base of the Düzce basin and the Çam mountains in the north. The Çilimli fault is active and is a strike-slip fault with a right lateral movement.

3.3. Geomorphic effects of the earthquake

The Gölcük and Düzce earthquakes caused both micro-and macro-level changes to the natural environment. These changes vary in magnitude and are readily observable in the field. Alterations to the natural environment

related to the Gölcük and Düzce events include the following: Surface ruptures, tension cracks and splits, collapses and landslides, surface offsets in the riverbeds, liquefaction, and coastal collapse.

Surface Ruptures: The Gölcük earthquake caused a surface rupture that is 125 km long (Fig. 3). The surface rupture is observable in many locations between Gölcük and Gölyaka. However, another rupture, which is 43 km long, occurred as a result of the Düzce earthquake to the east of the Gölcük fault. The total length of the two ruptures is approximately 168 km. The maximum right-lateral slips were observed at Gölcük (4 m) and Arifiye (4.5 m).

Fig. 5. Adapazari (upper left), Gölcük (upper right), Gölyaka-Düzce (lower left and right).

3.3.1. Surface Rupture of Gölcük Earthquake

The Gölcük earthquake caused a surface rupture 125 km in length. The fracture extends from Karamursel to Gölyaka. Along the rupture zone, right-lateral dislocations of up to 4.5 m occurred. The direction of this surface fracture is 80N-85E-EW. Deformation occurred on the coastal side of the Degirmendere and Golcuk along the fault lines. Seawater inundated areas about 100 meters inland.

The fault line intersects the Sea of Marmara on the southern side of the Izmit bay. To the east of the Izmit bay, in Yuvacik, the surface fracture divided into two parallel segments approximately 60 m apart of each other. This area collapsed about 1 meter. The amount of right-lateral off-set is 2.40 m in and around Kullar village (Fig. 4). The analogous observation is much higher in value on the east of Sapanca Lake. The amount of the dislocation is 4.4 m to the east of Arifiye and 4.75 m southeast of Arifiye.

3.3.2. Surface Rupture of Düzce Earthquake

Düzce earthquake occurred along the Düzce fault on November 12th, 2009. In this earthquake, the Akyazı, Karadere, Aksu, Gölyaka and Düzce-Kaynaşlı faults moved and ultimately consisted of an approximately 73 km rupture on the surface. The fault line, which formed during the Düzce earthquake, commences at Hacıyakup village, which is located to the east of Gölyaka. The fault line passes from the southern side of Melen Lake and extends towards Kaynaşlı. The surface rupture extends E-W direction, but it varies between N75W-N75E. The lateral offsets in the west near Efteni lake 3.5 meters, but it reaches to 4.8 meters around Güven village. The average offset is nearly 3 meters. Maximum displacement is found out in the middle part of the rupture. Strike slip displacement decreases at the both end of the surface rupture (Lettis et al., 2000). The offsets can be observed on roads, stream channels and fences. The surface rupture cuts the road and cause deformation on the legs of viaduct near Bolu Tunnel.

3.4. Tension Cracks and Splits

The surface rupture that resulted because of the Gölcük and Düzce earthquakes is not represented by a single line. The zone is 100 m in length and contains tension cracks and splits. Cracks and splits lie parallel to the main rupture in many places, but those cracks developed in different destinations in some places.

3.5. Collapses and Landslides

Collapses and landslides in different scales were observed in a variety of locations, including the following localities:

1. South of Izmit Bay: Degirmendere Gölcük and surrounding areas in the south of Izmit Bay: Residential areas along a 100 m wide strip of the Degirmendere coast were completely destroyed by the earthquake. In Kavakli and Gölcük, landslides occurred on the flat areas between the shore and the road, mostly on filled-in areas (Fig. 2).
2. The shoreline of Sapanca Lake: Several collapses and landslides were observed on the north and southern coast of Sapanca Lake.
3. The western parts of Gölyaka and especially on the southern slopes of Keremali mountains.
4. Haciyakup and the surrounding areas around Efteni Lake (Fig. 5).
5. The slopes of the mountains near Kaynaşlı, the tunnel of Bolu Mountain and surrounding areas, plus the Bolu Mountain portion of the Istanbul-Ankara highway.

In general, right stepping (right lateral) and slope stepping (south block) displacement occurred at Kaynaşlı and its surrounding areas. The earthquakes caused landslides on the steeper slopes. Some mountain ridges occurred because of the compressing seen locally on the fault zone.

3.6. Offsets in River Channels

The earthquake also affected some of the rivers flowing from the Samanli and Elmacik Mountains in the south lowland between Izmit Bay and Kaynaşlı. The fault zone running parallel to the rivers coming from the north caused some horizontal and vertical dislocations. These displacements reached three meters in the rivers that flow through the Düzce depression between Gölyaka and Gölormanı. The creeks near Hacıyakup village and the Ilizar and Degirmendere river beds that connect to Melen Lake also experienced displacement (Fig. 5). The surface rupture can be traced from the changing geomorphology of the region. Offsets of some streams are more than the displacement that occurred in this earthquake, which seems to have been affected by the previous earthquakes.

3.7. Liquefaction

Liquefaction and the emergence of sandy surface were observed on many occasions following the Gölcük and Düzce earthquakes. The liquefaction arose through the lateral dislocations of the thick alluvial lands that include sand layers. Fieldwork undertaken in the study area demonstrates that there is always a possibility of liquefaction during any earthquake that occurs in the Izmit, Gölcük and Adapazari areas. Liquefaction common on the

unconsolidated ground undergoes compression, squeezing out water from between soil particles. Increasing the available water volume in the ground decreases frictional resistance and load bearing capacity, consequently decreasing the resistance of the ground. The landslides that were seen in Kavakli and Degirmendere occurred because of liquefaction processes.

3.8. Coastal Collapse

Collapsing events and landslides that have occurred between the shorelines and the road in the Kavakli and Gölcük region were seen mostly in filled-in areas (Fig. 2). The deformations involved collapses, sliding and warping, and lead to important geomorphologic changes in the coastal zone. However, some damage is specifically related to strong ground shaking such as the collapse in the central coastal zone of Gölcük and Sapanca Lake.

4. Conclusions

The August 17th, 1999 Gölcük earthquake had a magnitude of 7.4 and the November 12th, 1999 Düzce earthquake had a magnitude of Mw=7.1. After the earthquake occurred, a surface fault between Gölcük-Gölyaka with a length of 125 km emerged. Also, the Düzce earthquake had a surface fault (73 km) between Arifiye and Kaynaşlı towns. The Arifiye-Kaynaşlı fault moved 30 km during the Gölcük earthquake. The total surface rupture is 168 km. Ground features, tectonic structure and geomorphologic features affect an earthquake's intensity and related damage. In addition, housing construction design and materials also contributed to catastrophic outcomes. A variety of factors ranging from poor construction practices to inadequate site planning were involved. Many physical features (hydrology, geomorphology) have been altered due to the earthquakes. This area of Turkey will continue to be active in a seismic sense, and appropriate steps need to be taken now to minimize the effects and fatalities of the next earthquake.

References

Akyuz, H.S.; Barka, A.; Altunel, E.; Hartleb, R.; Sunal, G. (2000). Field observations and slip distribution of the November 12, 1999 Duzce earthquake (M=7.1) Bolu-Turkey. The 1999 Izmit and Duzce Earthquake: preliminary results. (Ed. Barka, A., Kocacı, O., Akyuz H.S.).

Ambrasseys, N.N. and Finkel, C.F. (1995). The seismicity of Turkey and adjacent areas, A historical review, 1500-1800. Istanbul, Publ. Muhittin Salih Eren, 240 pp.

Ambrasseys, N.N. and Finkel, C.F.(1992). Longterm Seismicity of Istanbul and the Marmara Sea Region, Terra Nova 3: 527-539.

Armijo, R.; Meyer, B.; Barka, A.; Chabalier, J.B.; Buhert-Ferrari, A.; Cakir, Z. (2000). The fault breaks of the 1999 earthquakes in Turkey and the tectonic evolution of the Sea of Marmara: a summary. The 1999 İzmit and Duzce Earthquake: preliminary results. (Ed. Barka, A., Kocacı, O., Akyuz, S., Altunel, E.) Istanbul Technical University.

Atalay, I. (2000) Earthquakes of 17 August and 12 November 1999 in Turkey. Abstracts, 29. International Geographical Congress, 14-18 August, 2000, Seoul, Korea.

Barka, A. (1996) Slip distribution along the North Anatolian fault associated with large earthquakes of the period 1939–1967: Seismological Society of America Bulletin, v. 86, p. 1238–1254.

Brinkmann, R. (1971). The geology of western Anatolia: Geology and History of Turkey. Ed. By A.S. Campbell, Tripoli, S. 171-190.

Efe, R. & Sekin, S.(1999). 27.06.1998 Adana-Ceyhan Earthquake. Fatih University Publ. No, 2, Istanbul.

Efe, R. (2000a). Gölcük and Düzce Earthquakes-1999. Cantay Publ.Istanbul.

Efe, R. (2000b). Geomorphotectonics of Northwestern Anatolia. Symposium on Seismicity of Western Anatolia. Proceedings, p. 112-119. ISBN 975-585-148-8. Izmir, Turkey.

Efe, R.; Novakowski, N. (2000). Land Use Planning In Earthquake-Prone Areas. International Symposium on Desertification. Konya, Turkey: June 13-17, 2000.

Lettis, W.; Bachhuber, J.; Barka, A.; Witter, R.; Brankman, C. (2000). Surface Fault Rupture and Segmentation during the Kocaeli Earthquake. The 1999 İzmit and Duzce Earthquake: preliminary results. (Ed. Barka, A., Kocacı, O., Akyuz, S., Altunel, E.) Istanbul Technical University.

Orol, M.B. (1994). Global Positioning System (GPS) Measurements in Turkey (1988-1992): Kinematics of the Africa-Arabia-Eurasia Plate Collision Zone. Ph.D. Thesis. Massachusetts Institute of Technology. Depratment of Earth, atmospheric and Planetary Science. U.S.A.

Parke, J.R.; White, R.S.; McKenzie, D.; Kuscu, I.; Bull, J.M.; Gorur, N.; Sengor, A.M.C. (2000). Active faults in the sea of Marmara, Western Turkey, imaged by seismic reflection profiles. Terra Nova 11 (5), pp 223-227.

Sengor, A.M.C. (1979). The North Anatolian transform fault; its age, offset and tectonic significance. J. Geol. Soc. London, 136, 269-282.

Sengor, A.M.C.; Gorur, N.; Saroglu, F. (1985). Strike-slip faulting and related basin formation in zones of tectonic escape: Turkey as a case study. İn Biddle. K.T. ve Christie-Blick (eds.), Strike-slip Faulting and Basin Formation, Soc. Of Econ-Paleont. Min. Spec. Pub., 37.

Stein, S.R.; Barka, A.; Dieterich, J.H. (1997). Progressive failure on the North Anatolian fault since 1939 by earthquake stress triggering. Geophysical Journal International,1997, Vol 128: 594-604.

Taymaz, T. (2000). Seismotectonis of the Marmara Region: Source Characteristics of 1999 Golcuk-Sapanca-Duzce Earthquakes. The 1999 İzmit and Duzce Earthquake: preliminary results. (Ed. Barka, A., Kocacı, O., Akyuz, S., Altunel, E.) Istanbul Technical University.

USGS, (2000). Implications for Earthquake Risk reduction in the United States from the Kocaeli, Turkey, Earthquake of August 17, 1999. U.S. Geological Survey Circular 1193.

Witter, R.C.; Lettis, R.; Bachhuber, J.; Barka, A.; Evren, E.; Cakir, Z.; Page, W.; Hengesh, J.; Seitz, G. (2000). Paleoseismic tranching study across the Yalova segment of the North Anadolian Fault, Hersek Peninsula, Turkey. The 1999 İzmit and Duzce Earthquake: preliminary results. (Ed. Barka, A., Kocacı, O., Akyuz, S., Altunel, E.) Istanbul Technical University.