JAPAN SOCIETY OF CIVIL ENGINEERS

SITE INVESTIGATION AND ENGINEERING EVALUATION OF THE VAN EARTHQUAKES OF OCTOBER 23 AND NOVEMBER 9, 2011




Prof. Dr. Ömer AYDAN
Tokai University, Ocean Research Institute, Shizuoka, Japan

Prof. Dr. Reşat ULUSAY
Hacettepe University, Department of Geological Engineering, Ankara, Turkey

Prof. Dr. Halil KUMSAR
Pamukkale University, Department of *Geological Engineering, Denizli, Turkey*

Prof. Dr. Kazuo KONAGAI
University of Tokyo, Institute of Industrial Science, Tokyo, Japan

February 2012

SUMMARY

An earthquake (Van-Erciş earthquake) with a moment magnitude (M_w) of 7.2 and a local magnitude of 6.7 occurred at 13:41 on local time on October 23, 2011 in the Van province located in the eastern Turkey. The major energy release occurred within 20 seconds although the total duration of the rupture was about 50 seconds. According to the official report, the casualties are 604 and the number of injured people is more than 4000, which were caused by collapsed or damaged residential and commercial buildings. A number of buildings collapsed particularly in Erciş town (about 60 buildings) and Van (one building). In this earthquake, liquefaction and associated ground deformations were evident and wide spread sand boils were observed particularly in Erciş Plain and the flood plain of Karasu River at the north of Van city.

17 days after the Van-Erciş earthquake, the region was also hit by another earthquake with a magnitude of 5.6 (M_w) on November 9, 2011 at 19:23 on local time. Because the epicenter of this earthquake is located near Edremit, which is a town on the eastern shore of Van Lake about 16 km to the south of Van city centre, the earthquake is called Van-Edremit earthquake. This earthquake caused the collapse of 25 buildings in Van city centre. Fortunately, 23 of them had been evacuated due to previous damage occurred in October 23, 2011 earthquake. The total dead loss and injured people caused by this earthquake are 40 and 30, respectively. This earthquake also caused additional damage to some buildings and liquefaction.

In this report, site observations carried out throughout the earthquake region and information gathered by the authors are described. This study is an inter-disciplinary work of various disciplines of science and engineering such as geology, seismology, tectonics, and geotechnical and earthquake engineering. This investigation was carried out to cover both engineering and scientific aspects of both earthquakes. In addition to the observations, evaluations and possible causes of the damages, and recommendations for future earthquakes and lessons learned from these earthquakes are presented in the report.

CONTENTS

1. INTRODUCTION

An earthquake with a moment magnitude (M_w) of 7.2 and a local magnitude of 6.7 occurred at 13:41 on local time on October 23, 2011 in the Van province located in the Eastern Turkey, which was subjected to big earthquakes in the past (Figure 1.1). The major energy release occurred within 20 seconds although the total duration of the rupture was about 50 seconds. Boğaziçi University Kandilli Observatory and Earthquake Research Institute (KOERI, 2011) estimated that the earthquake was centered at 38.77578 N, 43.3602 E which places the epicenter about 30 km north of the Van city center at the location of Tabanlı village (Figure 1.2). The earthquake originated at a depth of ranging between 15-19 kilometers according to the different institutes and was resulted from the movement of a 50 km long and 20 km wide thrust fault trending about E-W direction between the Van Lake and Erçek Lake at the north of Van. Although the estimated average relative displacement of the fault is more than 2 m according to the empirical relation proposed by Aydan (2007), there was no clear fault scarp at the ground surface. The rupture mechanism released by USGS (2011) implies that the rupture should cause about 30-60 cm uplift, which may be diluted over soft deposits. Following the main shock on October 23, about 2000 intensive aftershocks have also occurred. One of the aftershocks had a moment magnitude (M_W) of 5.7 and a local magnitude of 5.8, and the other five were greater than 5. The earthquake was felt over a large area in the eastern and southeastern parts of Turkey, including the cities Diyarbakır, Batman, Şırnak, Muş, Erzurum, Bingöl, Bitlis, Ağrı and Iğdır.

According to the Turkish Statistical Institute, the provincial population of Van is 1.035.418 as of 2010 and the population of Van city center is 539.619. The earthquake resulted in heavy damage to buildings and significant casualties in this province, particularly in Erciş town, which is far from the epicenter approximately equal to the distance between Van and the epicenter, Van city center and number of villages in the province. According to the official report released by the Disaster and Emergency Management Presidency (AFAD, 2011), the casualties are 604 and the number of injured people is more than 4000, which were caused by collapsed or damaged residential and commercial buildings. A number of buildings collapsed particularly in Erciş town (about 60 buildings) and Van (one building). Preliminary damaged survey carried out by AFAD as of October 28, 2011 indicates that damaged-uninhabitable buildings and households are 5739 and 8026, and damaged-habitable buildings and households are 4882 and 7660, respectively. The estimated economic loss has not been clarified yet.

Figure 1.1. Location of the Van province (shown by red arrow) in Turkey.

Most of the buildings in Van and partly in Erciş are typically multi-story commercial/residential reinforced concrete structures. A large percentage of the collapsed or severely damaged buildings in these settlements were generally in 5-7 story range. The minarets of many mosques and chimneys of buildings were toppled and adobe buildings commonly built in villages collapsed and/or heavily damaged. There was also some damage to highway bridges. The highway connecting Van to Erciş town and to the city of Ağrı was also slightly deformed at a certain location crossed by the earthquake fault. However, on the contrary to the surface rupture of the 1999 Kocaeli earthquake of Turkey, since the earthquake faulting didn’t result in a continuous and clear rupture on the near surface, except a few concrete canal linings and asphalt pavements at limited locations, no damage to structures due to surface rupture has occurred.

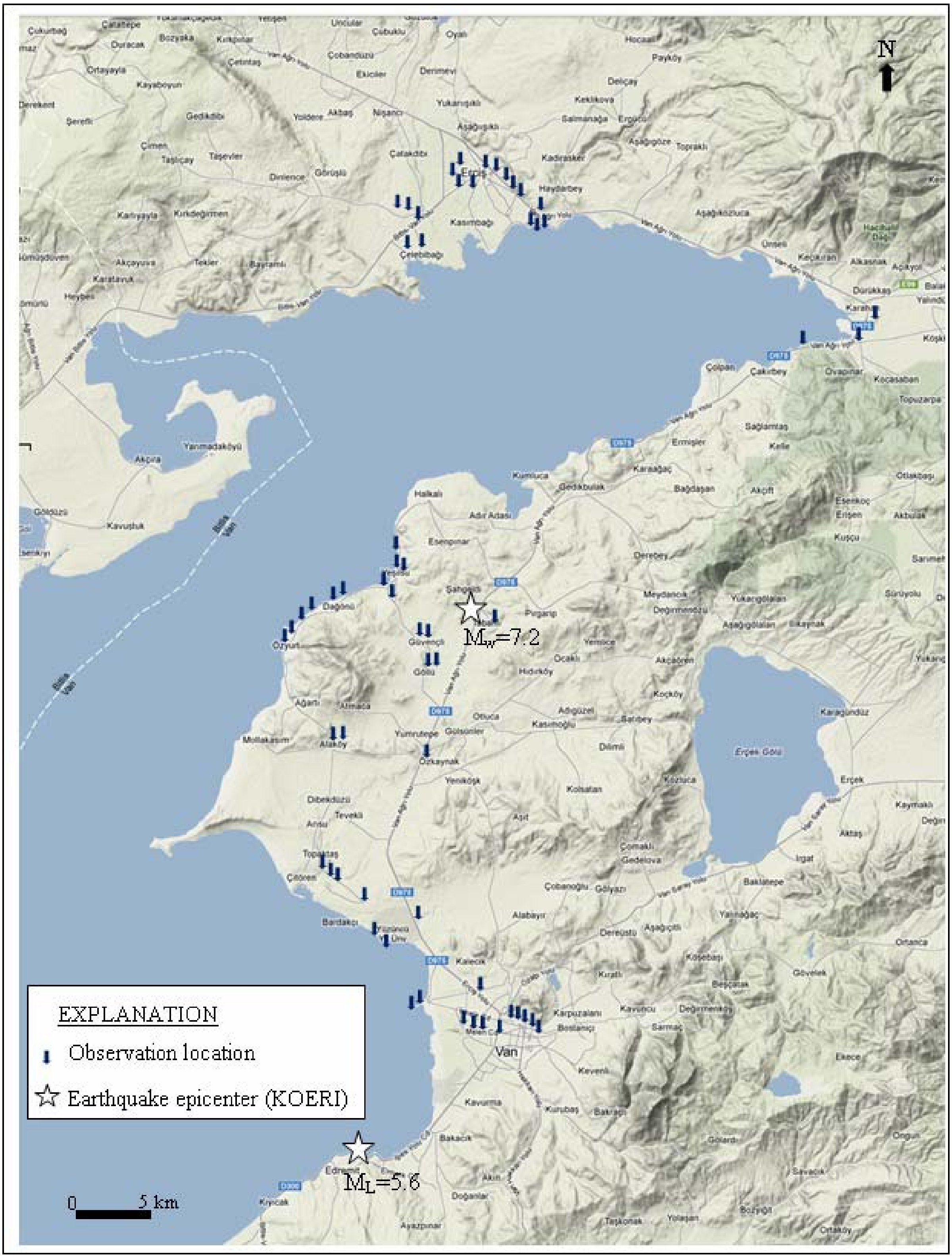


Figure 1.2. Map showing the sites visited during the reconnaissance study by the authors after the Van-Erciş earthquake, and the epicenters of the October 23, 2011 (M_w=7.2) and November 9, 2011 (M_L=5.6) earthquakes.

In this earthquake, liquefaction and associated ground deformations were evident and widespread sand boils were observed particularly in Erciş Plain and the flood plain of Karasu River at the north of Van city. In addition to poor quality construction and inappropriate construction materials, the damage was caused partly by the permanent displacement of ground by the liquefaction and liquefaction-induced lateral spread of the ground, at the northern part of the earthquake-affected region, in the vicinity of Erciş town.

One of the typical effects of this earthquake is a change in the shoreline of Van Lake. The measurements at certain locations on the lake shore at the northern and eastern parts of the earthquake region indicated that uplift of the recent shoreline ranging between 15 and 35 cm has occurred. This is due to the movement of the hanging-wall of the thrust fault causing the earthquake. The distances from the earthquake epicenter to Van and Erciş were approximately same. However, the damage was quite heavy in Erciş as it was on the hanging-wall side of the causative fault while the damage in Van city was relatively less as it was on the footwall side of the causative fault. Therefore, in this report, this earthquake is called "Van-Erciş Earthquake of October 23, 2011".

17 days after the Van-Erciş earthquake, the region was also hit by another earthquake with a magnitude of 5.6 (M_w) on November 9, 2011 at 19:23 on local time. The epicenter of this earthquake is located near Edremit which is a town on the eastern shore of Lake Van about 16 km to the south of Van city center (Figure 1.2) and the earthquake is called Van-Edremit earthquake of November 9, 2011. The moment tensor solutions of USGS (2011) and GFZ (2011) indicated that the causative fault of this earthquake was a strike-slip fault. The focal depth of the earthquake estimated by KOERI (2011), EMSC (2011) and USGS (2011) is between 5 and 6 km. However, it is 21.5 and 23 km according to the Earthquake Department of AFAD (ERD; 2011) and GFZ (2011), respectively. This earthquake caused the collapse of 25 buildings in Van city center. Fortunately, 23 of the collapsed buildings had been evacuated due to previous damage occurred in October 23, 2011 earthquake. However, two hotel buildings were open during this second earthquake and some of the people staying there

lost their lives. The total dead loss and injured people caused by this earthquake are 40 and 30, respectively. This earthquake also caused additional damage to some buildings.

This report outlines the investigation undertaken between November 3 and 5, 2011 by a reconnaissance team consisting of four investigators, who are the members of Japanese Society of Civil Engineers (JSCE), on various aspects of the Van-Erciş earthquake of October 23, 2011 occurred in the Van province. In the first half of the report, geology, hydrogeology, tectonics and seismo-tectonics of the Van province are outlined from a general point of view. The second half involves seismic characteristics of the earthquake and faulting, assessments of strong ground motion characteristics, local site conditions and damage to various types of structures, transportation and industrial facilities and lifelines, and geotechnical damages in conjunction with site observations, measurements and computations performed by the authors and evaluation of soil characteristics obtained from various sources. Finally evaluation of the findings from these investigations and lessons learned from this earthquake are concluded. In addition, based on the information gathered from different sources and the tests carried out some liquefied soils, the general characteristics of the November 9, 2011 Van-Edremit earthquake and associated damages are also briefly introduced. The sites visited by the authors during the reconnaissance study are also shown in Figure 1.2.

2. GEOLOGY AND HYDROGEOLOGICAL CHARACTERISTICS OF THE EARTHQUAKE AFFECTED AREA

2.1. Geology

The Van Lake Basin is located at the East Anatolian Plateau which is resulted from the collision between the Eurasian and Arabian Plates in Late Miocene (Şengör and Kidd, 1979; Şengör and Yılmaz, 1981). The basin, formed in Late Pliocene (Şaroğlu and Yılmaz, 1986), is underline by a basement consisting of Bitlis Metamorphics, Upper Cretaceous ophiolites and Tertiary aged marine sediments. In the Van Lake region surrounding Van Lake, different rock units and alluvial deposits formed between Paleozoic and Holocene are observed. As seen from the simplified geological map given in Figure 2.1, the Van Lake region includes metamorphic rocks belonging to the Bitlis Massif at the south, volcanic and volcano-clastic rocks at the west and north originated from the old volcanoes called Nemrut Süphan and Tendürek, volcanic and ophiolitic rocks of the Yüksekova Complex at the east, and young-recent fluviatil and lacustrine deposits.

Based on the generalized stratigraphical column of the region, the oldest units are represented by the Bitlis Massif which mainly consists of rock units of different metamorphic facieses (mainly schist, gneiss, marble and quartzite) and ophiolites belonging to old ocean floor (Yılmaz et al., 1981) (Figures 2.2 and 2.3). The age of these rocks are considered as Pre-Permian. The Upper Cretaceous ophiolitic melange of the Yüksekova Complex (Yılmaz et al., 1993; Parlak et al., 2000) is mainly composed of serpentinite, radiolarite, gabro and limestone blocks. Although it is not shown in Figure 2.2, a flysch facies of Upper Paleocene, which is composed of detritic rocks, is also considered as the latest facies of the Yüksekova Complex (Çiftçi et al., 2008). In some areas, these rock units are overlien by Tertiary formations with an angular unconformity.

The Van formation, cropping out at the south of Van, and west of Erciş and Adilcevaz towns at the north, mainly consists of alternations of sandstone, mudstone and turbitides including pebble layers (Figures 2.1 and 2.2). This formation has thinly-to-moderately spaced beddings and its age is Late Oligocene-Early Miocene (Sağlam, 2003). During the deposition of the Van formation at the east, thickly bedded and fosillifereous limestones have also deposited near to Adilcevaz and Erciş at the northern part of the region (Sağlam, 2003). However, these limestones, called Adilcevaz limestone, are not separately shown on the map given in Figure 2.1.

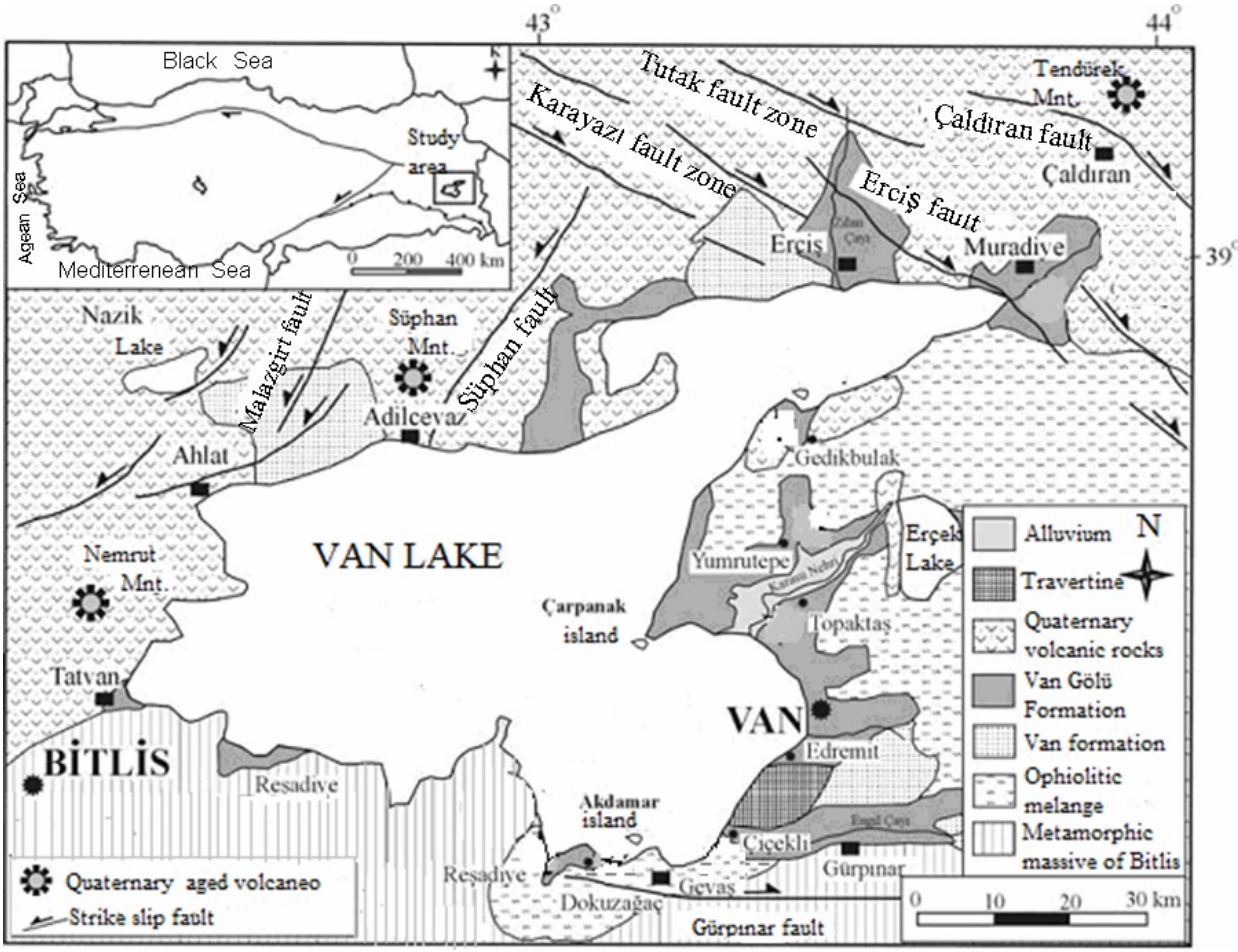


Figure 2.1. Simplified geological map of the close vicinity of Van Lake (modified and from Üner et al., 2010)

The Van Gölü formation, observed at the eastern and northern parts of the region (Figures 2.1 and 2.2), is mainly represented by fluvial deposits consisting of loosely packaged conglomerates and sandstones, and marl-sandstone-claystone alternations deposited in lacustrine environment. The majority of these deposits have formed depending on the variations in the water level of Van Lake occurred after the latest ice period (Late

Pleistocene) (Degens et al., 1978) and they unconformably overlie the old units (Özkaymak, 2003).

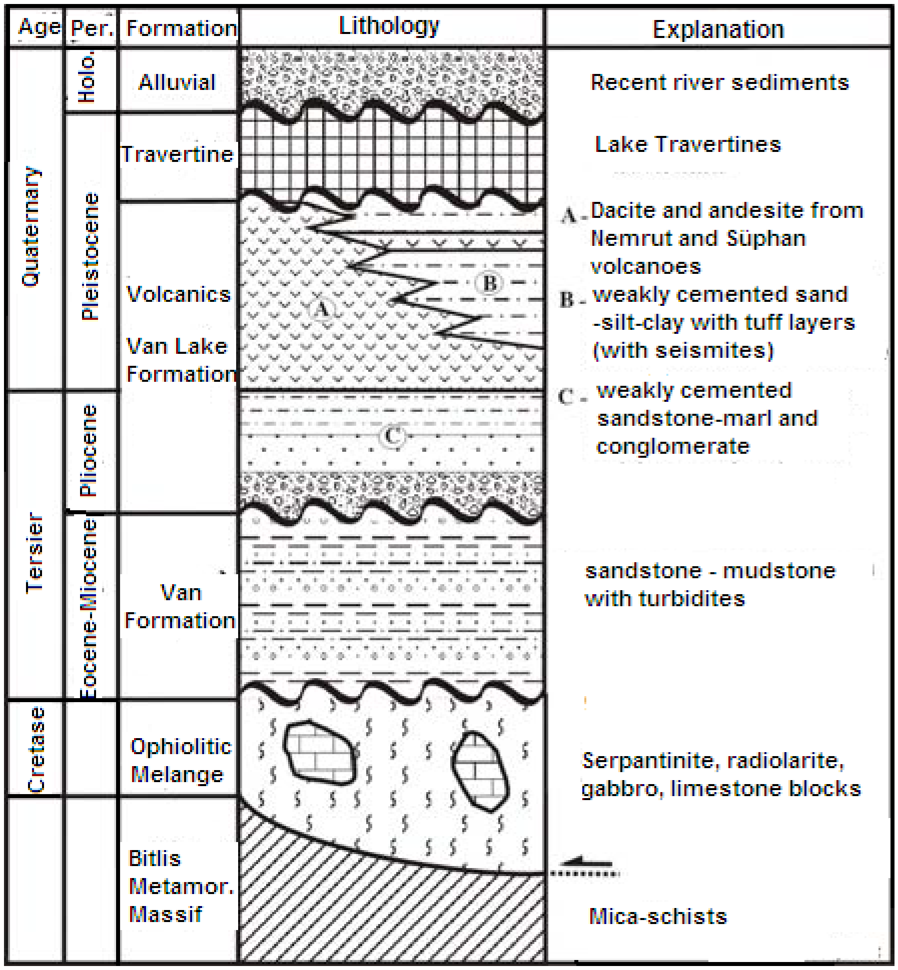


Figure 2.2. Generalized and simplified columnar section of the region shown in Figure 2.1. (after Aksoy, 1988 and Acarlar et al., 1991)

A volcanic activity started in Late Miocene and continued to the recent is a result of compressional tectonic regime affecting the region (i.e. Yılmaz, 1990; Aydar et al., 2003; Keskin, 2005). In this period, the materials ejected from Nemrut, Süphan and Tendürek volcanoes, became the sources of the volcanic and volcano-clastic rock units covering the northern part of the Van Lake region (Figures 2.2 and 2.3). The volcanic units in the vicinity of Nemrut Mountain are in basaltic and rhyolitic character, while the volcanics of the Süphan Mountain are represented by rhyolites and andesites. In addition, these volcanics include andesites and tuffites. Typical outcrops of the basalts in the earthquake-affected region are observed at the near east of Erciş town.

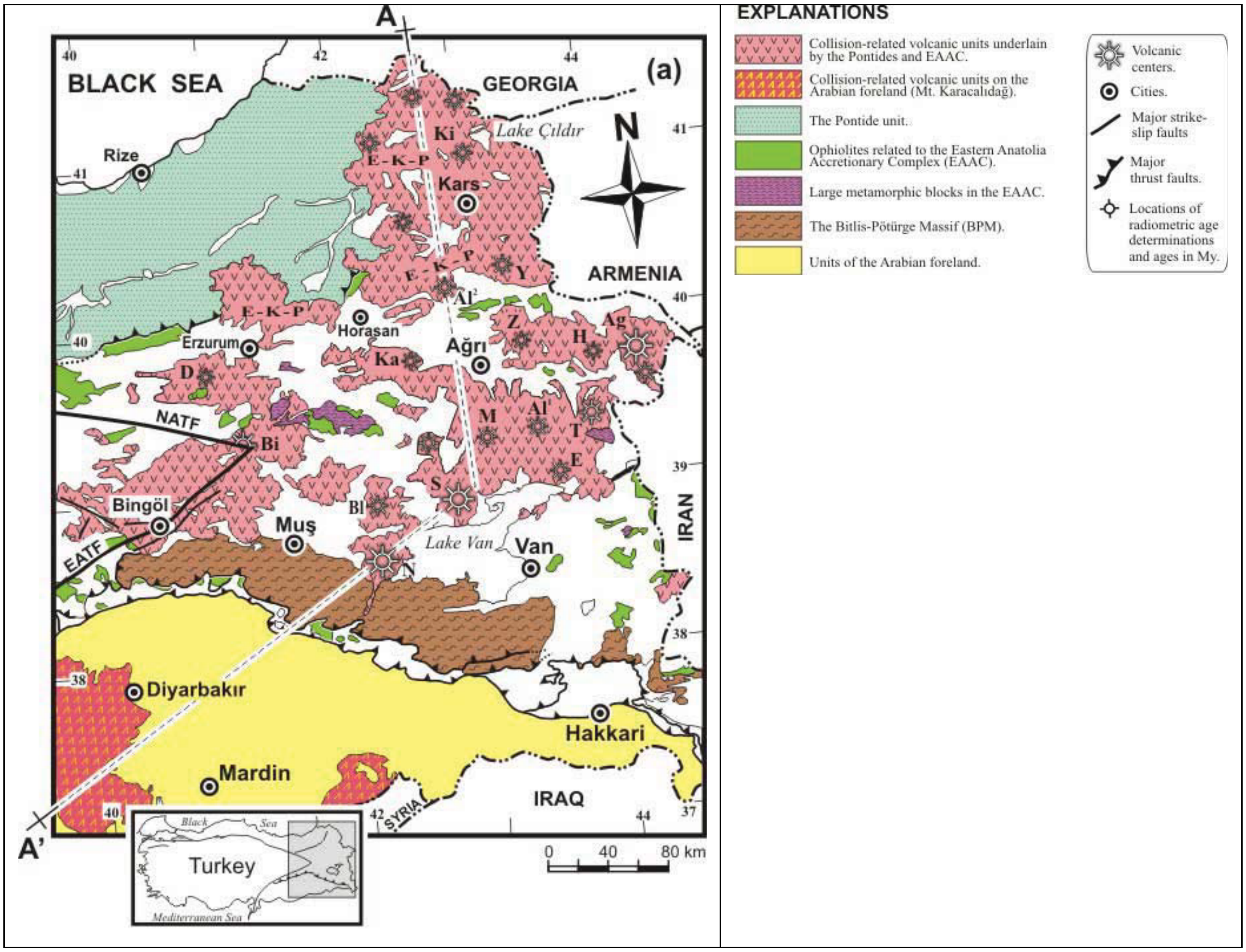


Figure 2.3. Simplified geological map of the Eastern Anatolia region showing tectonic units, collision related volcanic products and volcanic centers (E-K-P: the Erzurum-Kars Plateau; NATF and EATF: North and East Anatolian Transform Faults. Volcanic centers: Ag: Mt. Ağrı (Ararat), Al1: Mt. Aladağ (SE of Ağrı), Al2: Mt. Aladağ (NW of Horasan), Bi: Mt. Bingöl, Bl: Mt. Bilicandağı, D: Mt. Dumanlıdağ, E: Mt. Etrusk, H: Mt. Hamadag, K: Mt. Karatepe, Ki: Mt. Kısırdağ, M: Mt. Meydandağ, N: Mt. Nemrut, S: Mt. Süphan, T: Mt. Tendürek, Y: Mt. Yağlıcadağ, Z: Mt. Ziyaretdağ) (Keskin, 2005).

Quaternary aged travertines are observed in Edremit town at the south of Van (Figure 2.1). These yellowish-brown travertines, called Edremit travertine (MTA, 2002), are massive and their bedding planes are not clearly developed, and although their thickness is not uniform, it ranges between 50 and 80 m (Kıraner, 1959). It is considered that Edremit travertines have formed from the waters rich in dissolved carbonates which were associated with the Pleistocene volcanism (Degens et al., 1978).

The Holocene deposits in the region are mainly consist of alluvial fan deposits, lacustrine and fluviatile deposits and debris material including loosely-to-moderately cemented gravel, sand, silt and unconsolidated clay horizons. Selçuk and Çiftçi (2007) interpreted these sediments as representing four phases of deposition, such as lacustrine deposits, lacustrine-fluviatile deposits, shore sand deposits and recent fluviatile deposits (Figure 2.4). Sudden changes in their lithologies and thicknesses were also reported by the same investigators.

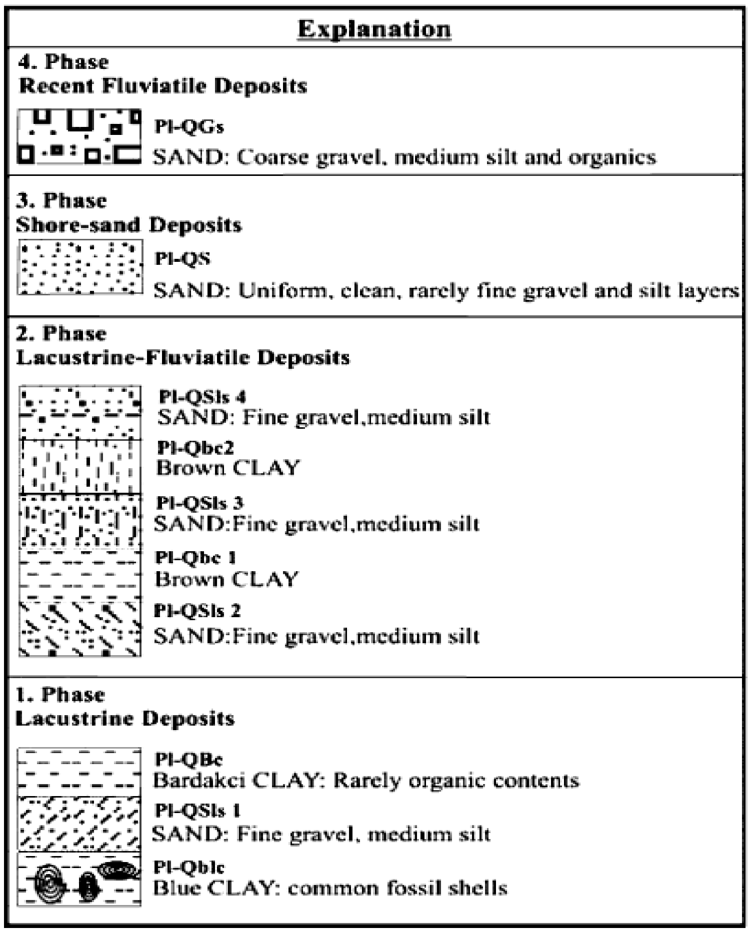


Figure 2.4. Four phases of deposition for the Holocene deposits in the vicinity of Van interpreted by Selçuk and Çiftçi (2007).

2.2. General Hydrogeological Characteristics of the Earthquake Region

The earthquake region is under the influence of continental climate marked by long and snowy winters, and dry and hot summers. Although flooding is not common, heavy rainfalls or a rapid increase in temperature leading to snow melt may cause flooding at the beginning of spring.

Van Lake is situated at 1,648 m asl (above sea level) in the eastern Taurus mountains and the largest fourth largest terminal lake in the World (a body of water with streams flowing into it but no streams flowing out). Its surface area is about 3,600 km^2 and mean depth is between 200 and 300 m and maximum water depth of the lake was measured as 451 m near Adilcevaz at north (Selçuk and Çiftçi, 2007; Özler, 2008). Van Lake was formed about 100,000 years ago when the volcano-clastic products of Mt. Nemrut damaged the Murat River valley around Tatvan (Degens and Kurtman, 1978). The lake water level varies between 1648 and 1650 m since 1969 and an increase of 2 m in water level was observed between 1987 and 1997, and then a drop in water level occurred until 2001 (Özler, 2008). Van Lake has a large drainage area (12,500 km^2) and 101 rivers and streams in different sizes flow to the lake (Özler, 2008). In this area, there are ten big rivers flowing to the lake following different routes as seen in Figure 2.5. Among them Karasu River, flowing in NE-SW direction, is the longest river in the earthquake affected area and formed a large plain at the north of Van. Similarly, another plain at the northern part of Van Lake has been created by Zilan Stream in the vicinity of Erciş.

The region affected by the Van-Erciş earthquake of October 23, 2011 covers a very large area between Van and Erciş settlements. The groundwater table is generally close to the ground surface in the cities and towns situated on low lands where damage was quite heavy. In the following paragraphs, the groundwater conditions in and close vicinities of Van city and Erciş town were briefly evaluated based on the data obtained from previous studies performed in the region.

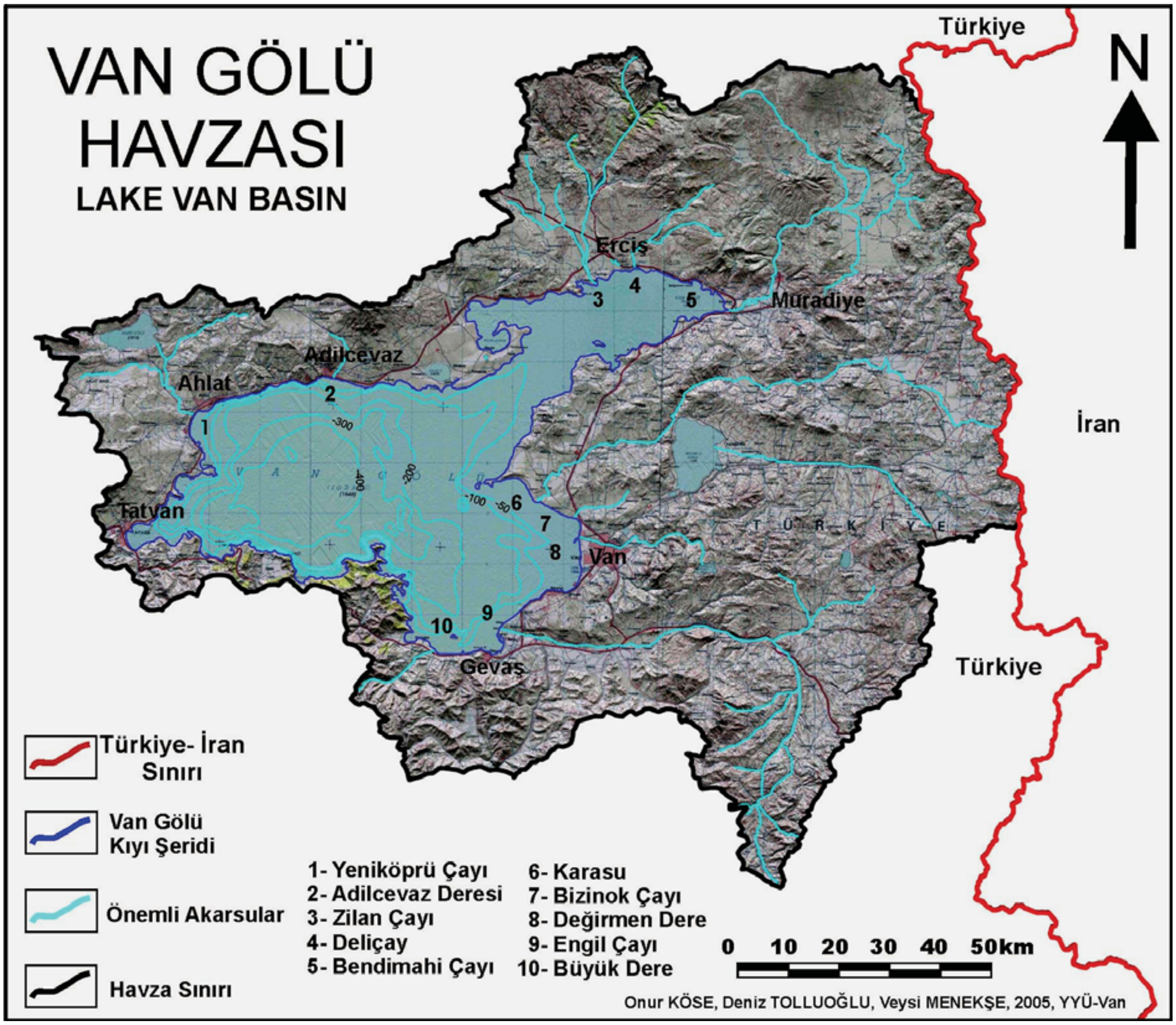


Figure 2.5. Boundaries of the Van Lake Basin and main rivers (arranged by Çiftçi et al., 2008 from Köse et al., 2005).

Based on long-period measurements in 33 borings drilled in the Van Plain, the groundwater table in Van and its close vicinity has an inclination from east to west and SW depending on topography, and the depth of static water level in these boreholes ranges between 1 and 29 m (Figure 2.6) (Özler, 2008). Özvan et al. (2005) also indicate that groundwater table is very close to the ground surface next to Van Lake (1646 m) and at a depth of 12 m in the city center. In addition, a study for the microzonation of Plio-Quaternary soils at the Yüzüncü Yıl University (YYU) campus area, which is located on the shore of Van Lake at the NW of Van city center (Figure 2.6), was carried out (Selçuk and Çiftçi, 2007). This study based on the data from 31 boreholes suggested that the depth of the groundwater level in YYU campus area was between 1.5 to 10 m with flows to S and SW indicating the presence of a shallow-seated groundwater table (Figure 2.7).

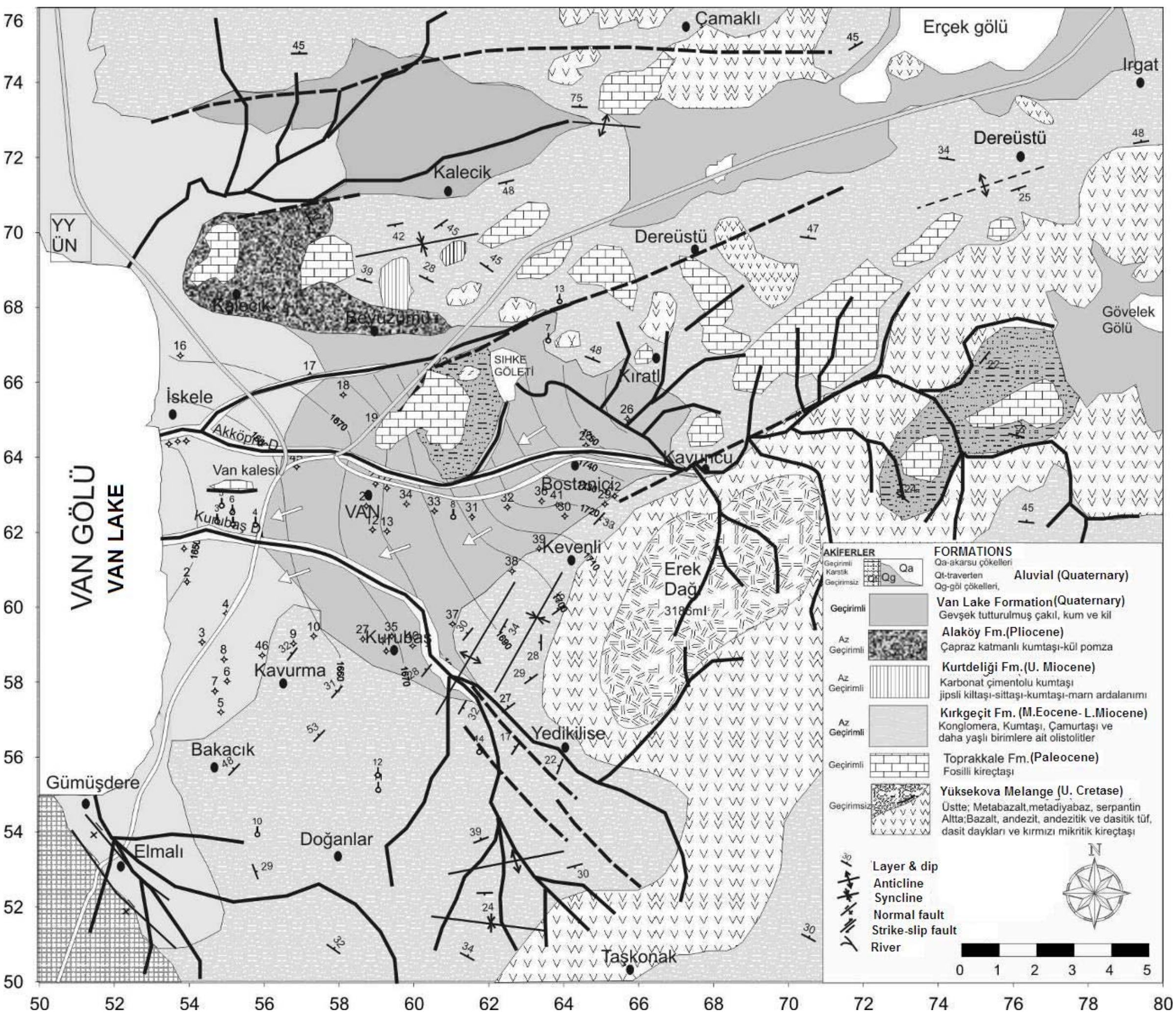


Figure 2.6. Hydrogeological map of Van and its vicinity (Özler, 2008)

The Van aquifer is an 11 km wide and 14 km long aquifer with an area of 90 km^2. Özler (2008) mentioned that the Van Gölü formation forms this aquifer in the vicinity of Van and has shore plain aquifer characteristics. Inclination of the layers in this formation, which is mainly composed of sands and gravels with clay interlayers, is between 15 and 30^0 towards Van Lake. This aquifer was separated two sub-aquifers by Özler (2008): (i) upper non-pressurized aquifer with a total thickness of approximately 150 m at the east, and (ii) towards Van Lake it transforms to a pressurized aquifer due to an increase in the thickness of the upper clay layer (Figure 2.8). This investigator also reported an artesian (+2 m) in the boreholes drilled at the vicinity of port of Van. From Figure 2.8, it is clear that particularly at south, a sandy-gravelly layer with a thickness of 5-10 m is observed at the surface. This layer shows a pressurized character due to the presence of a clay layer of 2-8 m thick overlaying it. This clay layer is overlain by the main aquifer composed of sandy-gravelly layers of 5-50 m thick. This aquifer becomes thicker at northern part when compared to that in the southern part. In this aquifer, the variation of the depth of groundwater table with time (between 2001 and 2002) shown in Figure 2.9 suggests that the groundwater table reaches up to its maximum level in March and April, and to the lowest level in July and August, and the groundwater table does not fall at an elevation below the water level in Lake Van (Özler, 2008).

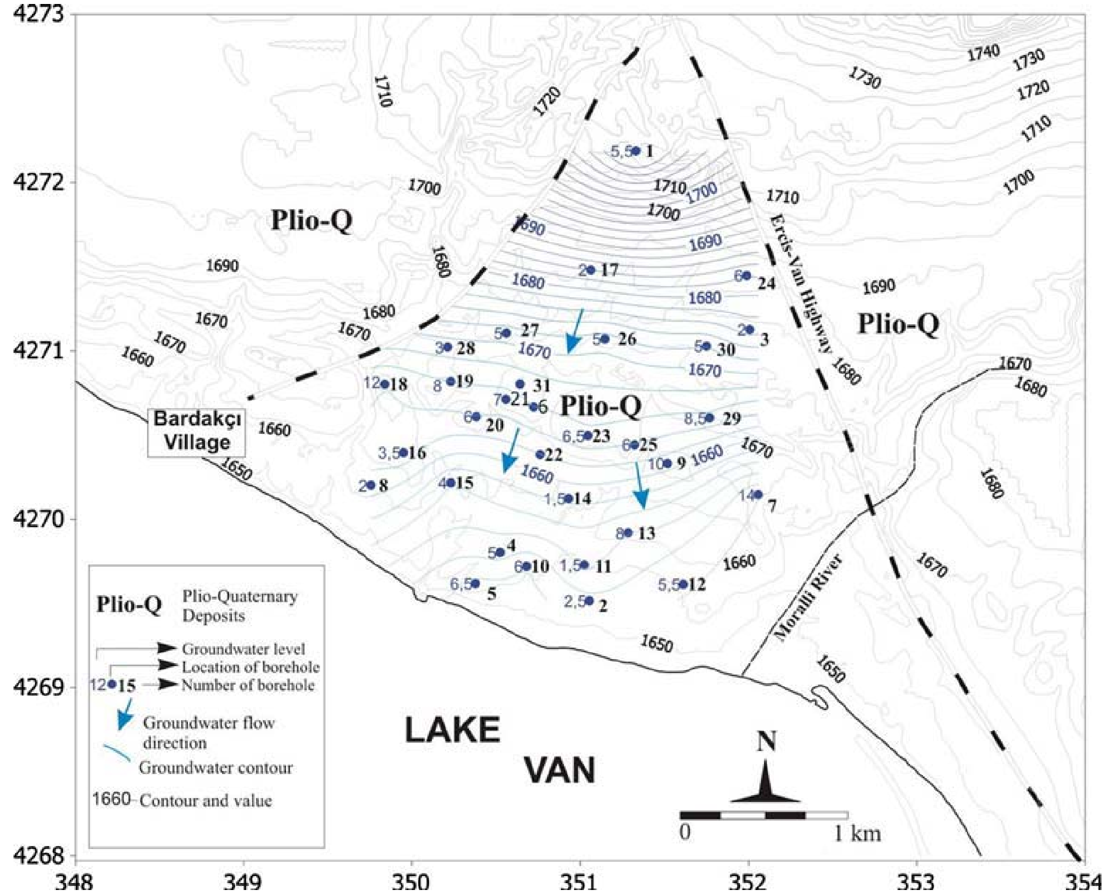


Figure 2.7. Hydrogeological map of the Yüzüncü Yıl University campus area (Selçuk and çiftçi, 2007)

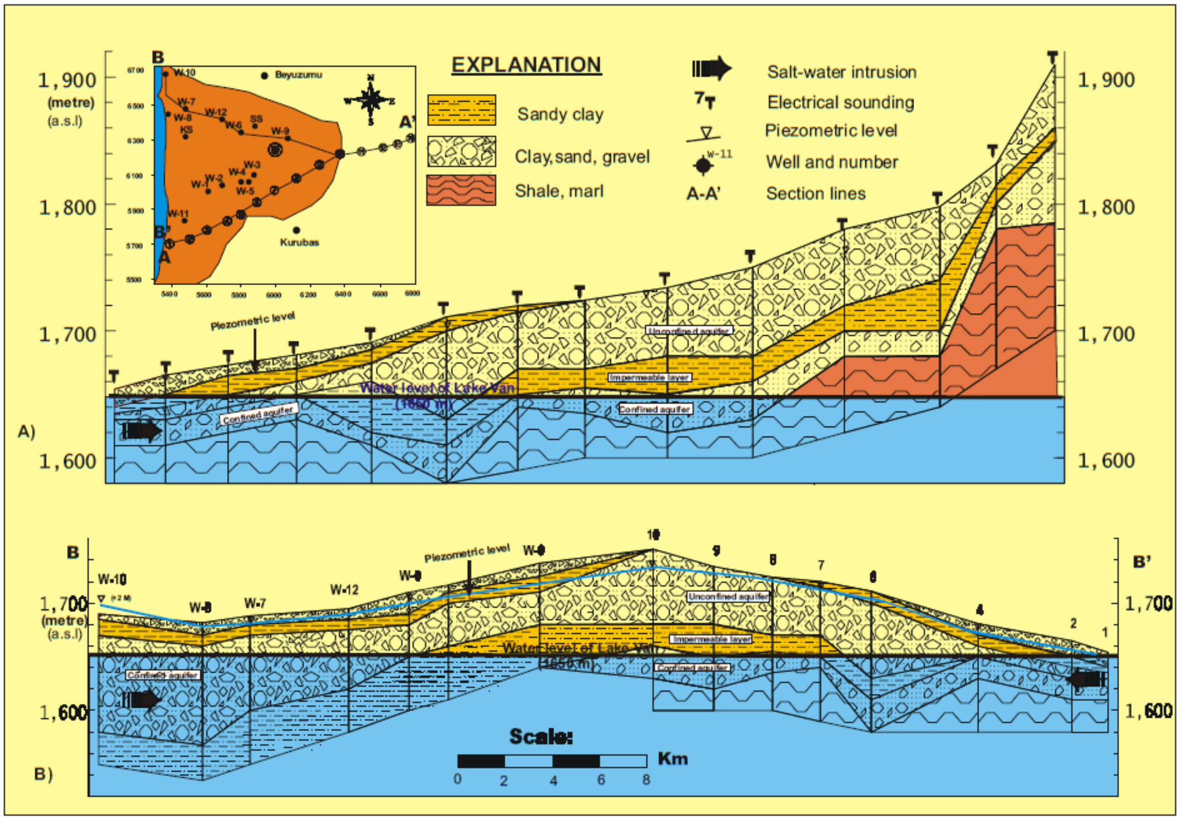


Figure 2.8. Hydrogeological cross-sections of the Van aquifer based on the data from boreholes and geophysical investigations (Özler, 2008)

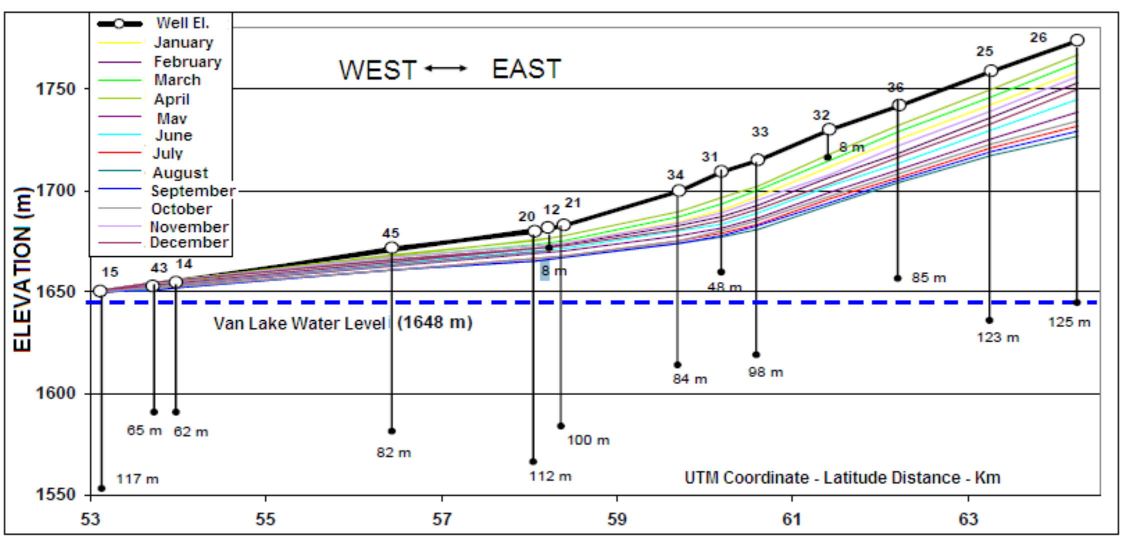


Figure 2.9. Variations in monthly piezometric level of the groundwater in Van aquifer (Özler, 2008)

The most damaged settlement in the earthquake-affected region is Erciş town located at the northern side of Van Lake. The main drainage system of the Erciş Plain was formed by Zilan and İrşat streams (Figures 2.5 and 2.10). Discharges of the Zilan and İrşat streams measured at the locations, where they reach to Van Lake, were 4622 lt/s and 918 lt/s, respectively (DSİ, 1977). The aquifer in this area, similar to that in the Van Plain, is represented by Plio-Quaternary deposits with a thickness reaching up to 188 m (DSİ, 1977). The measurements from 11 water wells in Erciş by Köy Hizmetleri Bölge Müdürlüğü indicated that depth of the static water level was between 0 and 12 m, and in some boreholes artesian pressures were also noted (Figure 2.10) (Özvan et al., 2008). At the outside of the Erciş Plain, the depth of groundwater table increases and may reach up to 74 m deep. 18 boreholes drilled by Özvan et al. (2008) in Erciş town for a geotechnical investigation indicated shallow-seated groundwater table ranging between 1 and 8 m which confirm the previous information obtained from water wells in the close vicinity of the town by DSİ (1977). In addition, the groundwater table map of Erciş Plain, which covers a larger area than the map given in Figure 10 and prepared by DSİ (1977), is also shown in Figure 2.11. This map clearly indicates that direction of groundwater flow is towards SE and SW and the depth of groundwater table becomes considerably shallower near to the lake.

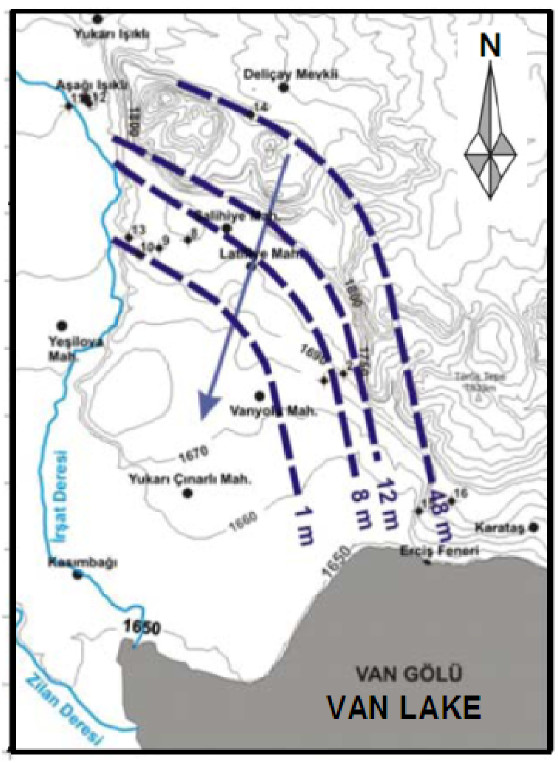


Figure 2.10. Groundwater depth contour map of Erciş town (Özvan et al., 2008)

From the groundwater level measurements taken from a number of boreholes drilled in Van and Erciş plains, it can be concluded that the water table is generally close to the ground surface and depth of the static level from the surface ranges between 1 m and 12 m. But no published and/or reported information on hydrogeological characteristics of the areas particularly those between Van and Erciş (Karasu Plain at the north of Van and west of Erciş) are available. However, wide spread liquefaction occurred during the Van-Erciş earthquake of 2011 and a number of main streams and their sub-branches flowing are the main indicators of the presence of shallow-seated groundwater table in these areas.

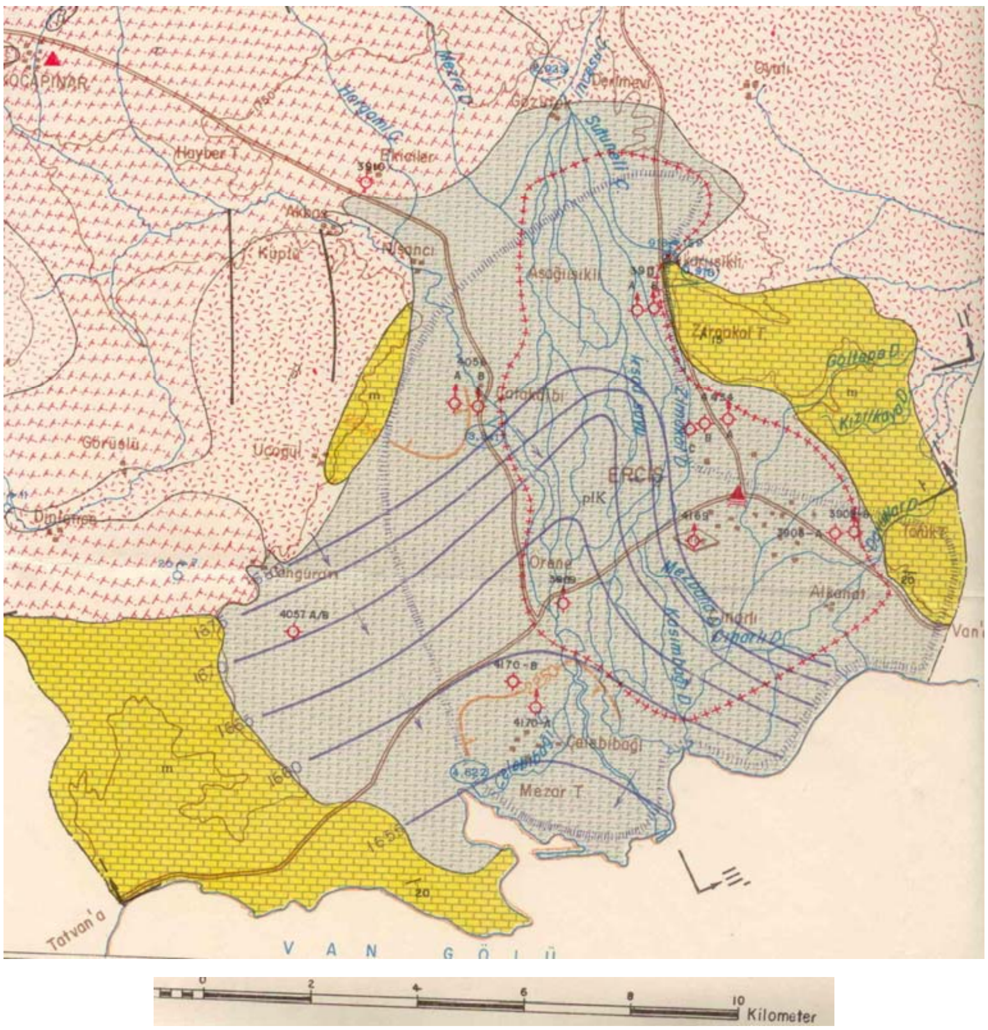


Figure 2.11. Groundwater contour map of the Erciş Plain (after DSİ, 1977)

3. NEOTECTONICS OF THE EAST ANATOLIAN REGION AND MAJOR ACTIVE FAULTS IN THE EARTHQUAKE-AFFECTED AREA

3.1. General Neotectonics of the East Anatolian Region

The Van Lake Basin is located at the northern front of the Bitlis Suture Zone (BSZ) formed predominantly as a result of neotectonic activity. It is bounded by the Kargapazarı junction between the North Anatolian Fault (NAF) and East Anatolian Fault (EAF) to the west and Zagros fault zone to the east (Figure 3.1). The northern branch of Neo-Tethys was closed by final collision and suturing of Eurasia in the north and the Anatolian-Iranian platform in the south (i.e. Adamia et al., 1981; Koçyiğit, 1991). But the Bitlis Ocean, which is the southern branch of Neo-Tethys, persisted by the late Middle Miocene (Serravalian) and then closed entirely by the continent-continent collision of the Arabian and Eurasian plates (Şengör and Yılmaz, 1981; Dewey et al., 1986) (Figure 3.1). Geological studies carried out in the region (i.e. Şengör and Kidd, 1979; Dewey et al., 1986 Şaroğlu and Yılmaz, 1986) suggest that the neotectonic activity in Eastern Anatolia dates from the Serravalian (10-14 Ma ago). The intra-continental convergence and N-S directed compressional tectonic regime remained at the end of Late Miocene and late Early Pliocene, in place along the BSZ (Koçyiğit et al., 2001). The N-S trending compression regime resulted from the collision of the Arabian and Anatolian plates and the break-off of the subducting front of the Arabian plate, which resulted in formation of extensive high plateau with an average elevation of 2 km asl., gave rise to the development of extensions and strike-slip fault systems in front of the BSZ (Keskin, 2005). The strike-slip faults are also observed at the eastern part of Van Lake that was affected by the October 23, 2011 earthquake. Koçyiğit et al. (2001) also indicate E-W trending, north-to-south vergent thrust faults and E-W trending folds (Figure 3.2). Volcanic activity initiated immediately after the rapid block uplift of Eastern Anatolia and became widespread all over the region, producing subaerial lava flows and pyroclastic products which are very variable in their composition and eruptive style (Pearce et al., 1990; Keskin et al., 1998; Yılmaz et al., 1998). In Early Pliocene, three major neotectonic structures, dextral North Anatolian (NAF) and sinistral East Anatolian (EAF) transform faults and then the Anatolian plate, which commenced to escape in WSW direction onto the oceanic lithosphere of the African plate due to the higher relative movement and anticlock-wise rotation of the Arabian plate developed (Hempton, 1987; Koçyiğit and Beyhan, 1998; Aydan, 1997).

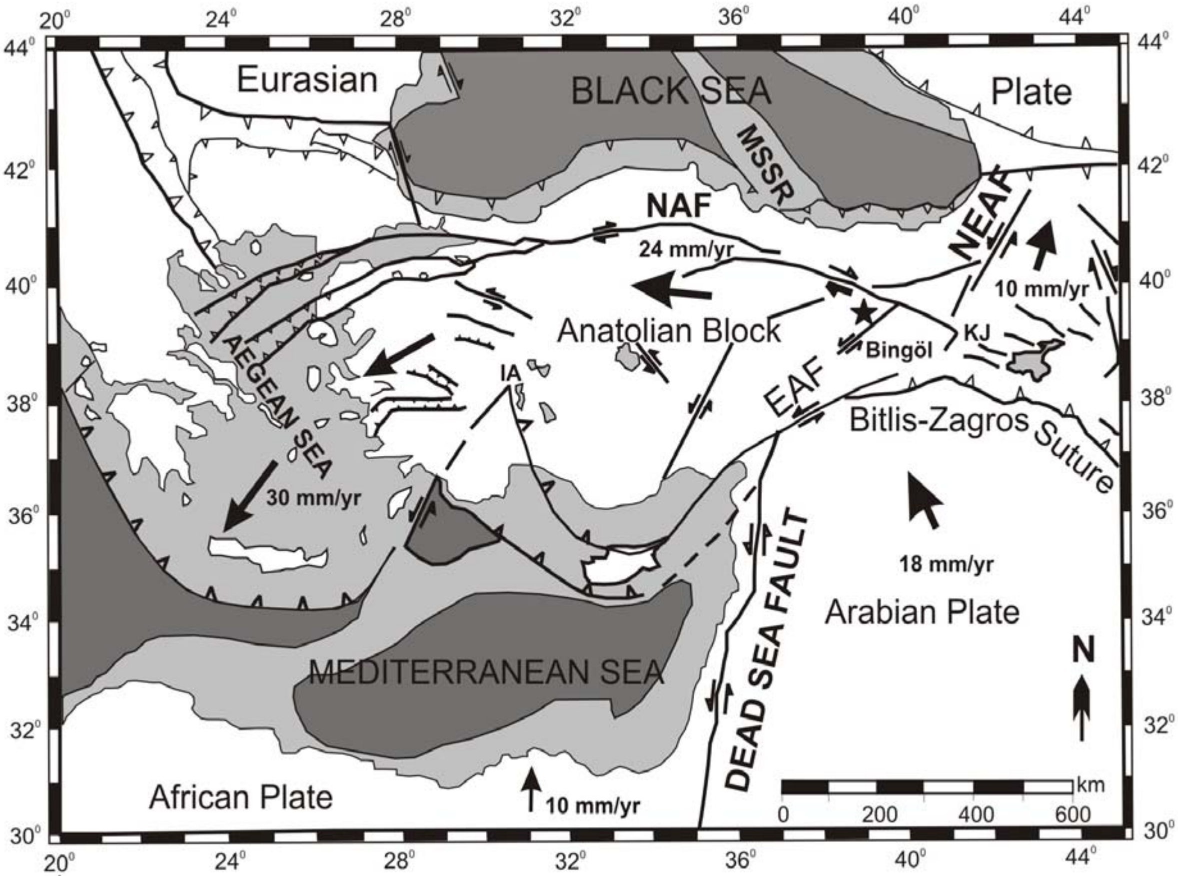


Figure 3.1. Main tectonic features of Turkey and surroundings (after Gülen et al., 2002).

The East Anatolian plateau, where the Van Lake Basin also takes place, and its boundary zones are the major structures of the Alpine-Himalayan convergent system. The intra-continental convergence, that is much more severe within and nearby the suture, is still continuing throughout these structures in NNW-SSE direction. It resulted in a series of E–W trending compressional features such as the WNW-trending thrust faults, folds and ramp basins with the reverse fault-bounded margins in the east Anatolian plateau during the Miocene time. The volcanism also accompanied the development of these compressional features during the Late Miocene–Early Pliocene transitional period that separates the pre-Serravalian palaeotectonic period from the Late Miocene–Early Pliocene transitional period that separates the pre-Serravalian palaeotectonic period from the Plio-Quaternary neotectonic period (Koçyiğit, et al., 2001).

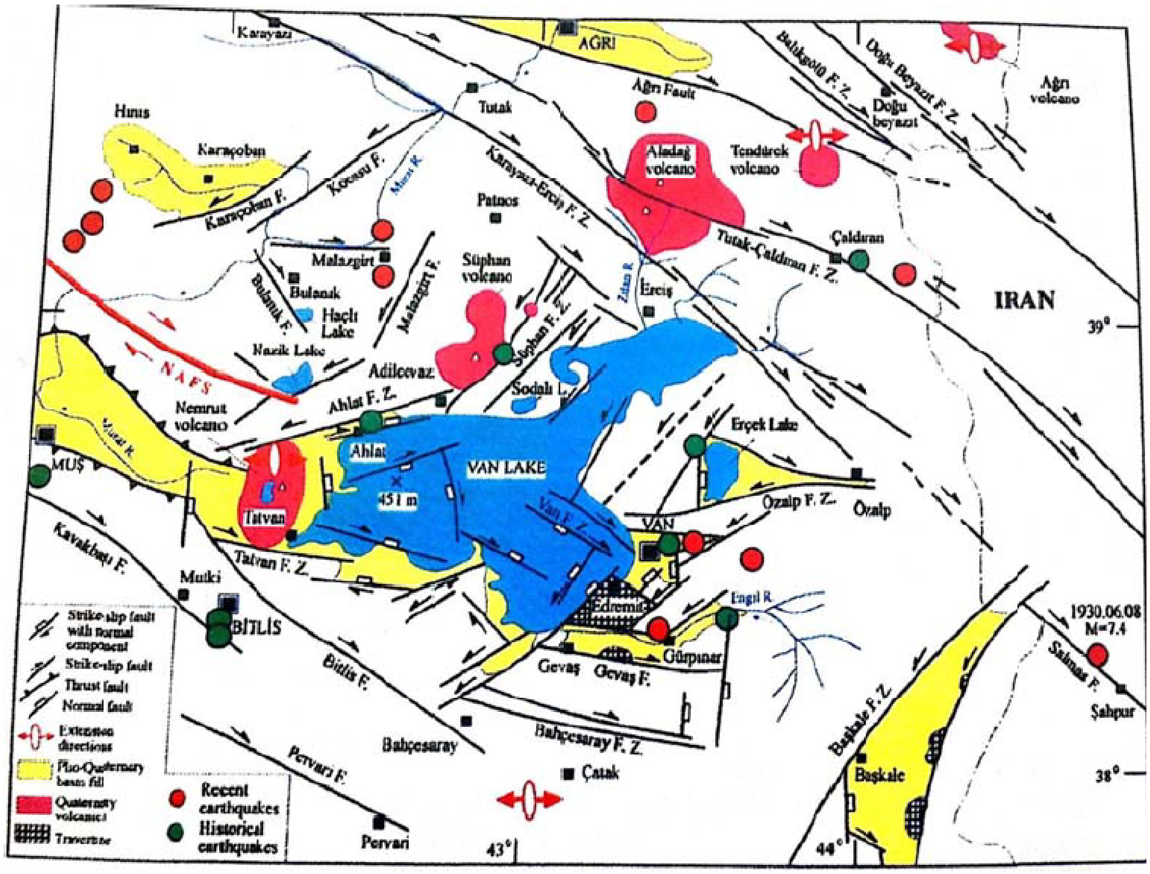


Figure 3.2. Seismotectonic map of the Van Lake Basin and its surroundings (modified from Koçyiğit et al., 2001 and Koçyiğit, 2002; KOERI, 2011)

3.2. Major Active Faults in the Earthquake Affected Area

The area affected by the 23 October and 9 November, 2011 earthquakes, is located in the tectonically controlled the Van Lake Basin. By considering the closeness of some faults in the earthquake region, brief descriptions of some major faults are given in the following paragraphs. From north to south, these faults are Çaldıran fault, Karayazı-Erciş fault zone, Özalp fault, Gürpınar fault, Gevaş fault and Bahçesaray fault. Although some of these faults are not shown on the active fault map of Turkey (Figure 3.3), they are all given in Figure 3.2.

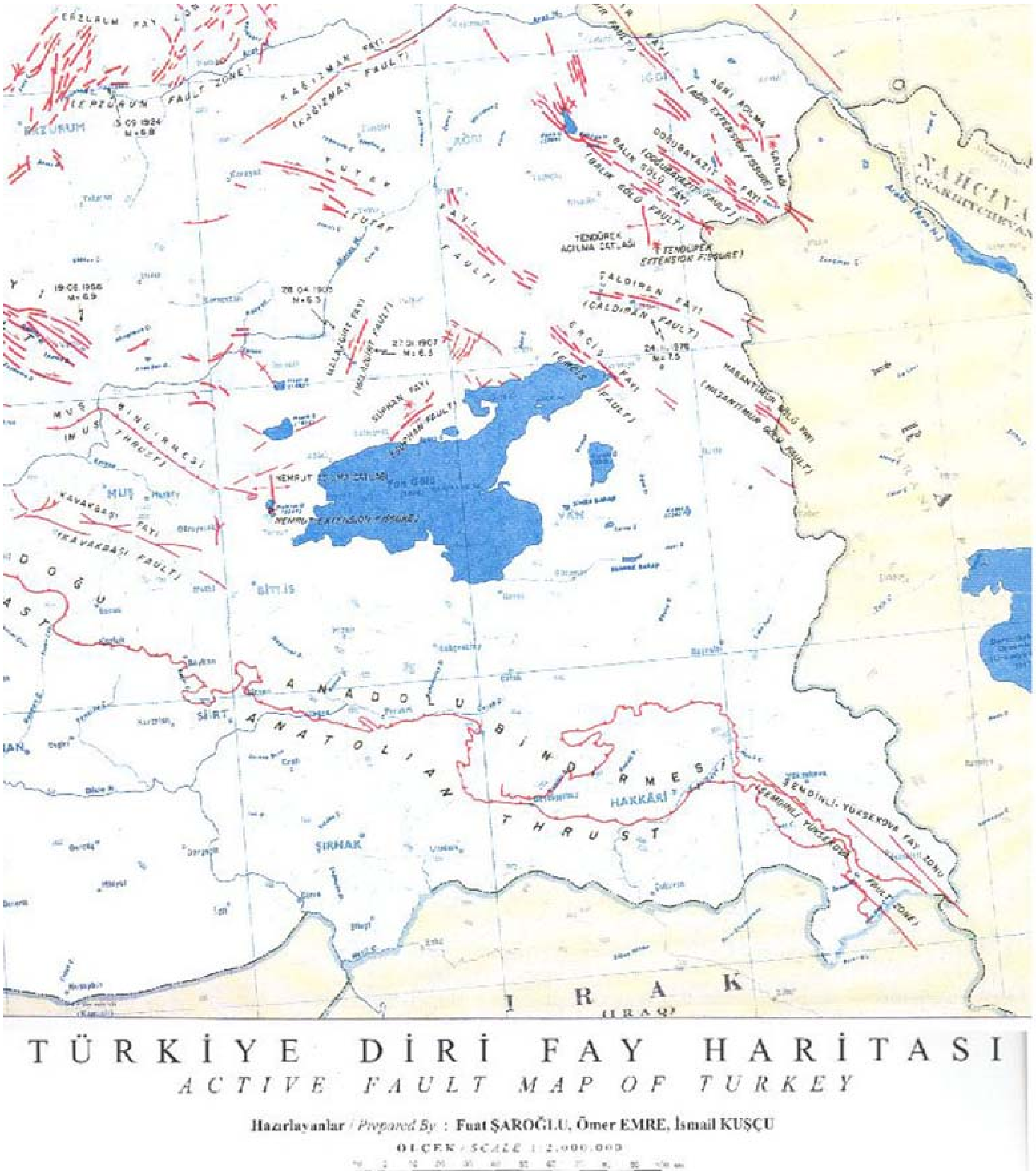


Figure 3.3. Active faults in the Van Lake Basin and its surroundings shown on the active fault map of Turkey (after Şaroğlu et al., 1992)

The Çaldıran fault trending in NW-SE and 60 km long is located 40 km NE of Van Lake (Figures 3.2 and 3.3). It is an active dextral strike-slip fault of 55 km long which caused the 1976 Çaldıran earthquake with a local magnitude of 7.2 (M_b: 6.9; M_s:7.3) (Toksöz et al. 1977). 0.5-1 km horizontal off-set stream channels (Deli and Bendimahi rivers), deepnarrow and long fault valleys developed across the Bemraz and Kösedağ volcanoes, and pressure ridges and pull-apart basins resulted from both its right step-over and bifurcation are the strong morphological evidences of its recent activity (Koçyiğit et al., 2001).

The Karayazı-Erciş fault zone, approximately parallel to the Çaldıran fault, is a dextral strike-slip fault located in the central part of the East Anatolian plateau (Figures 3.2 and 3.3). The northern block of the fault is 80 m morphologically higher than its southern block and consists of older rocks with respect to the southern block. Moreover along the western part of the fault, the reverse faults of Late Miocene age and some streams (Elmalı and Karasu Rivers) are cut and offset in dextral direction 3 km and 1 km, respectively, by the fault implying that the fault is younger than Miocene (Koçyiğit, 1985).

The Özalp fault is a left lateral strike-slip fault trending in approximately E-W between Özalp town and Lake Van (Figure 3.2). Its length is about 60 km and it reaches Van Lake about 10 km north of the campus of 100. Yıl University and can not be followed under the lake (Selçuk and Çiftçi, 2007).

The Gevaş fault is a right lateral strike-slip fault. It is located at the south of Van Lake and lies between Gevaş and Gürpınar towns (Figures 3.2 and 3.3). Its trace can be followed on the ground as much as 30 km (Selçuk and Çiftçi, 2007). The Gürpınar and Bahçesaray faults, approximately trending in E-W, are the other young fault systems in the region. Both faults have strike-slip characteristics (Figures 3.2 and 3.3).

In addition, Ketin (1977) distinguished four separate fault zones on the basis of his observations made in the region between Van Lake and Iranian border following the 1966 Varto and 1976 Çaldıran earthquakes and indicated that they could be active faults. These faults, trending approximately E-W (N75-85W) (Figure 3.4), were distinguished based on their morphological features and some evidences observed at some certain locations. The second part of Fault-I in Figure 3.4 starts from the northern tip of Van Lake and continues to the Iranian border. Based on the observations in streambeds, Ketin (1977) described that this fault is a right lateral strike-slip fault. Fault-II, starting from the shore of Van Lake, crossing

Lake Erçek and reaching to the Iranian border, indicated that the horizontal movements have also right lateral strike–slip characteristics. Fault-III, which closely locates to Van city center, was also classified by Ketin (1977) as a right lateral strike-slip fault based on the evident fault striations he observed. The last fault zone (Fault-IV) is located between Gevaş and Gürpınar towns and consists of E-W trending segments. Ketin (1977) also reported that travertine occurrences were observed along the fault zone. However, Ketin (1977) indicates that these faults should be considered as probable faults and further studies on these faults are needed.

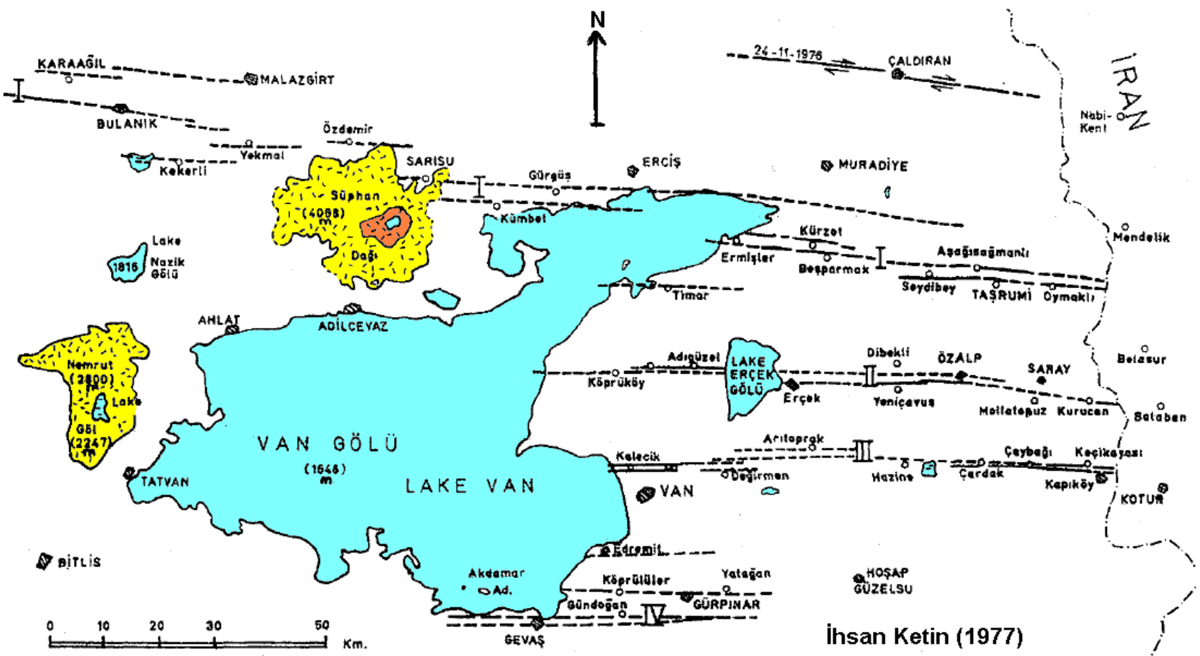


Figure 3.4. Principal fault zones of the eastern and northern parts of the region of Van Lake and the causative fault of the Çaldıran earthquake of November 24, 1970 (Ketin, 1977).

Most recent studies (Özkaymak, 2003; Özkaymak et al., 2004), which aimed to assess field observations of recent faulting in the eastern part of Van Lake, near the Van city, and to combine them with seismic data to discuss on the seismotectonic characteristics of the region, indicated the presence of some unknown faults. One of them is a thrust fault observed near the campus area of Yüzüncü Yıl University located at the NW of the Van city center. This fault shown in Figure 3.5 is a thrust fault trending N70E and dipping 45NW. It is observed to cut across the recent lacustrine deposits of Van Lake. The fault offset changes from about 90 cm in the older deposits to about 20 cm in the youngest sediments immediately below the soil horizon, suggesting that the fault surface was reactivated several times. In addition, a thrust fault trending in ENE-WSW and located at the north of Aşıt village was mapped (Figure 3.5). Although this fault doesn't continue to the lake shore (towards Bardakçı village where the evidents of the surface rupture of the Van-Erciş earthquake of 2011 were observed), its trend and type show a general agreement with those of the causative fault of the 23 October 2011 Van-Erciş earthquake which is discussed in Chapter 5 of the report. At different places of this area, the recent clastic units have been affected by N-S, NNW-SSE and NNE-SSW trending normal faults with offsets up to 1 m and minor thrust faults with centimetric offsets (Figure 3.5). In addition, the above-mentioned investigators reported that the shoreline between Van Lake and the Edremit travertines is a sinistral transtensional fault zone trending NE-SW and other NW-SE trending probable faults in this area may have accommodated dextral crustal displacements. Another most recent map, prepared by Koçyiğit et al. (2011), also shows the faults in the earthquake-affected region (Figure 3.6). In Figure 3.6, the Everek fault having thrust fault characteristics and located between Van Lake and Erçek Lake shows a general agreement with the causative thrust fault of the Van-Erciş earthquake of 23 October 2011.

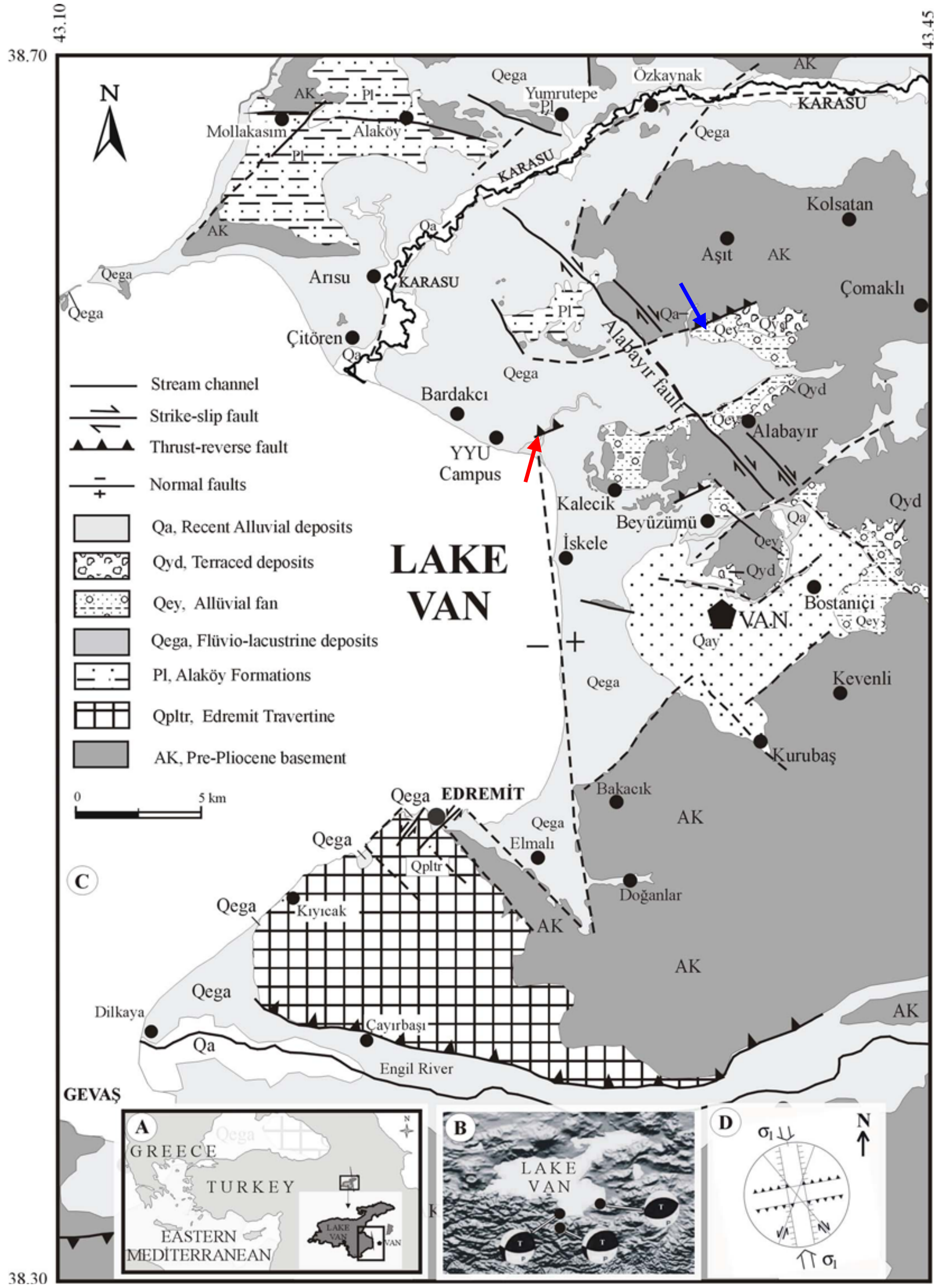


Figure 3.5 Simplified geological map also showing the faults in the close vicinity of Van (after Özkaymak et al., 2004) (Red and blue arrows show the thrust fault near the 100. Yıl Universtiy campus and the thrust fault having a general agreement with that of the causative fault of the 2011 Van-Erciş earthquake, respectively).

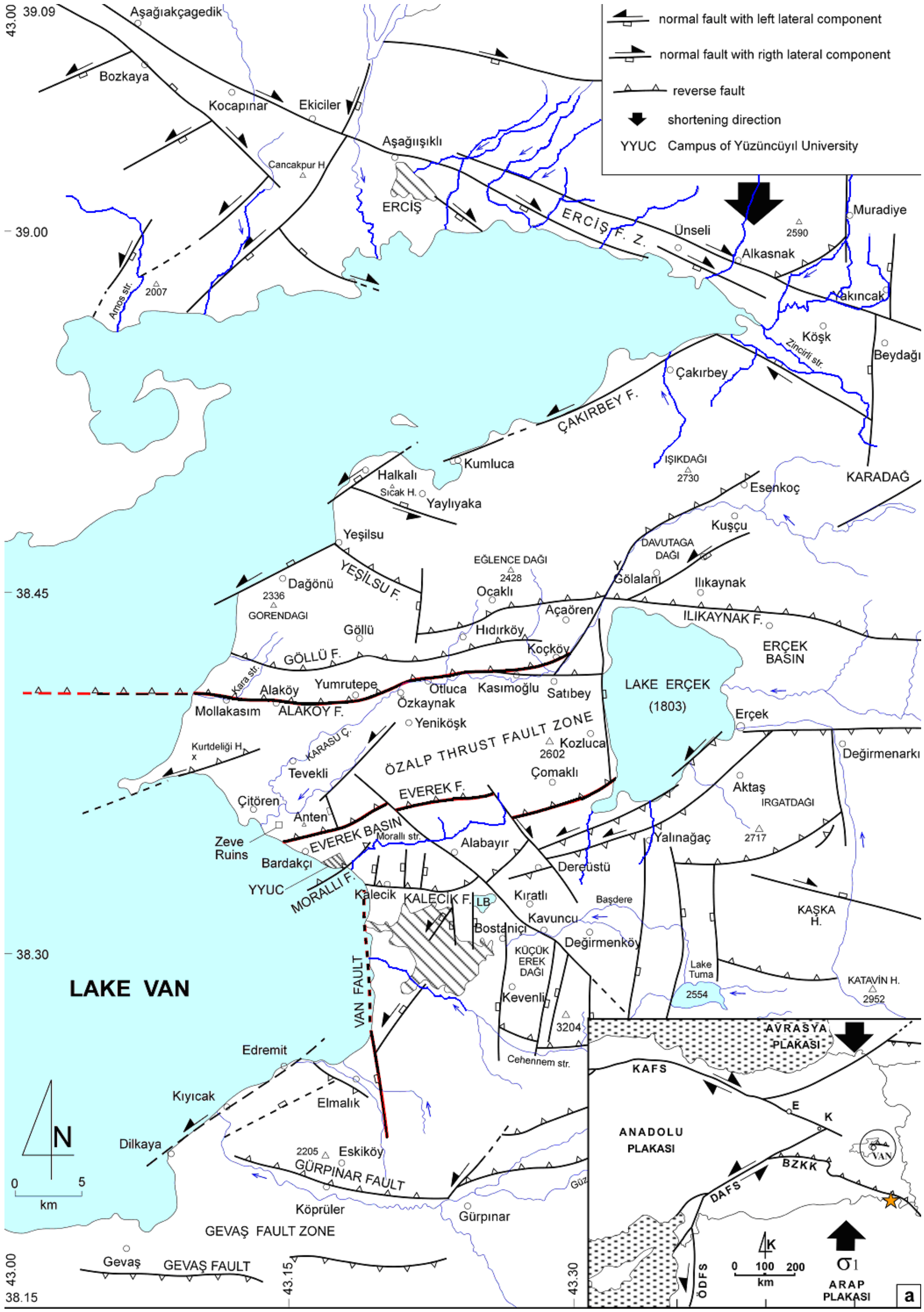


Figure 3.6. Most recent fault map of the area affected by the Van earthquakes of 2011 (arranged from Koçyiğit et al., 2011).

4. SEISMICITY OF VAN LAKE REGION

The tectonics of the region is influenced by the northward moving and subducting the Arabian plate beneath the Anadolu plate. The Anadolu plate squeezed between the the Arabian plate in the south and the Euro-Asian plate in the north. As a result of these crustal movements, there are EW trending thrust faults and major fold axis and NW-SE and NE-SW trending strike-slip faults. The Van Lake Basin is located at the northern front of Bitlis Sture Zone (BZF) formed as a result of neotectonic activity. Due to this ongoing tectonic activity in the region, strong earthquakes shook Van Lake Region from time to time. The seismicity of the region based on historical and instrumental periods are briefly given below.

4.1. Historical earthquakes

Historical earthquakes having different intensities occurred in the Van Lake Region were picked up from the cataloges compiled by Ergin et al. (1967), Soysal et al. (1981), Eyidoğan et al. (1991) and Uluçam (2000) are tabulated in Table 5.1 and the locations of their epeicentres are shown in Figure 5.1.

Ergin et al. (1967) report a devastating earthquake (I=IX) near Van city occurred in 1111, while the same event dated as 1110 by Soysal et al. (1981). It should be noted that the dates assigned to some events differ by one or two years depending upon the catalogues. In 1245 and 1246, earthquakes with intensities of VII and VI occurred and affected Ahlat, Bitlis, Muş and Erciş, respectively (Ergin, et al., 1967; Calvi, 1941; Uluçam, 2000). The 1276 earthquake caused heavy damage in Ahlat, Erciş and Van which was dated as 1275 by Uluçam (2000), according to Ergin et al. (1967) and Calvi (1941). It was reported that the 1439 and 1441 earthquakes were caused by the activity of Nemrut Volcano and resulted in some heavy damage and high casualties. In 1646 or 1647, a very strong earthquake (I=IX) caused heavy damage in Van, Tebriz, Bitlis and Muş. Another earthquake occurred (I=VIII) in the Hoşap-Van region in 1648 (Ergin et al., 1967; Soysal et al., 1981). It seems that several large earthquakes occur once the seismic activity starts and continues for several years. Another seismic activity up to an intensity of VIII occurred during 1701 and 1705 (Ergin et al., 1967; Soysal et al., 1981). Erciş experienced an earthquake with an intensity VII in 1715. The Van region was shaken by an earthquake with an intenisty of VIII in 1871. A very large earthquake with an intensity of IX-X occurred in the region and affected Van, Bitlis, Muş and Nemrut area in 1881 (Ergin et al., 1967; Soysal et al., 1981).

Table 4.1. Historical earthquakes occurred in the Lake Van Region.
Çizelge 4.1. Van Gölü havzasında meydana gelen tarihsel depremler

No	Date (AD)	N	E	Intensity (I)	Affected region	Source
1	1110 or 1101	38.5	43.4	IX	Van	Ergin et al. (1967)
2	1245 or 1246	38.7	43.3	VII	Ahlat, Van, Bitlis, Muş	Ergin, et al. (1967); Calvi (1941)
3	1275 or 1276	38.8	42.5	VII-VIII	Ahlat, Van, Erciş	Ergin, et al. (1967); Calvi (1941)
4	1439	38.6	42.3	VI	Nemrut area due to volcanic eruption	Ergin et al. (1967); Soysal et al. (1981)
	1582	38.7	41.5	VIII	Bitlis	Soysal et al. (1981)
5	1441	38.35	42.1	VIII-X	Bitlis, Muş, Nemrut area, Ahlat, Erciş, Van	Ergin et al. (1967); Öcal (1968); Soysal et al. (1981)
6	1647	39	44	IX	Bitlis	Ergin et al. (1967); Soysal et al. (1981)
7	1648	38.3	43.5	VIII	Hoşap-Van, Muş, Tebriz	Soysal et al. (1981)
8	1701	38.5	43.4	VIII	Van	Ergin et al. (1967); Soysal et al. (1981)
9	1704 or 1705	38.5	43.4	VI-VII	Van	Ergin et al. (1967); Soysal et al. (1981)
10	1715	38.95	43,65	IX	Van-Erciş	Ergin et al, (1967); Soysal, et al, (1981);
11	1871	38	43	VII	Near Van	Ergin et al, (1967); Soysal et al. (1981)
12	1881	38.5	43.3	IX, X	Van, Bitlis, Muş, Nemrut area	Ergin et al, (1967); Soysal et al. (1981)
13	1900	38.47	43.3	VI	Van	Ergin et al. (1967)

4.2. Earthquakes occurred in the instrumental period (1900-2011)

In addition to the catalogue published by Ergin et al. (1967), Eyidoğan et al. (1989) compiled a catalogue for the earthquakes occurred between 1900 and 1988, there are two major periods of earthquake activity between 1900 and1904, and 1941and 1945, respectively. The seismic activity initiated at Erciş with an intensity of VIII (M_s 5.9) in 1941 and, followed by several shocks lasted until 1945. In this period, the 1903 Malazgirt (M=6.3), 1930 Salmas (Iran)

(M=7.2), 1941 Erciş (M=5.9) and the 1945 serial earthquakes affecting the Van Region (the biggest one M=5.2) are the major earthquakes. The other major earthquakes in the close vicinity of Van Lake are 1966 Varto (M_s 6.8), 1975 Lice (M_s 6.6) and 1976 Çaldıran (M_s 7.3) earthquakes. The Varto and Lice earthquakes are of thrust type. While the Çaldıran (M_s 7.3) earthquake has a right lateral strike-slip character and the maximum displacements along the fault reached to 4 m close to the eastern end of the rupture, whereas the average slip was in order of 2 m. The 1976 Çaldıran (M_s 7.3) earthquake also induced some discussion on the continuity of the North Anadolu Fault Zone (NAFZ) to the east of Van Lake extending towards Iran. The çaldıran earthquake produced a 55 km long zone of surface rupture (Toksöz et al. 1977: Arpat et al. 1977). This earthquake caused 3840 fatalities demolishing about 10000 buildings. Arpat et al. (1977) and Ketin and Abdüsselamoğlu (1977) reported that the northern shore of Van Lake was uplifted for about 12-16 cm as a result of Çaldıran earthquake. Two moderate scaled earthquakes having moment magnitudes of 5.4 on June 14, 1988 and 5.7 on November 15, 2000 recently occurred in the eastern part of Van Lake. The faulting mechanisms of these earthquakes were all of thrust type.

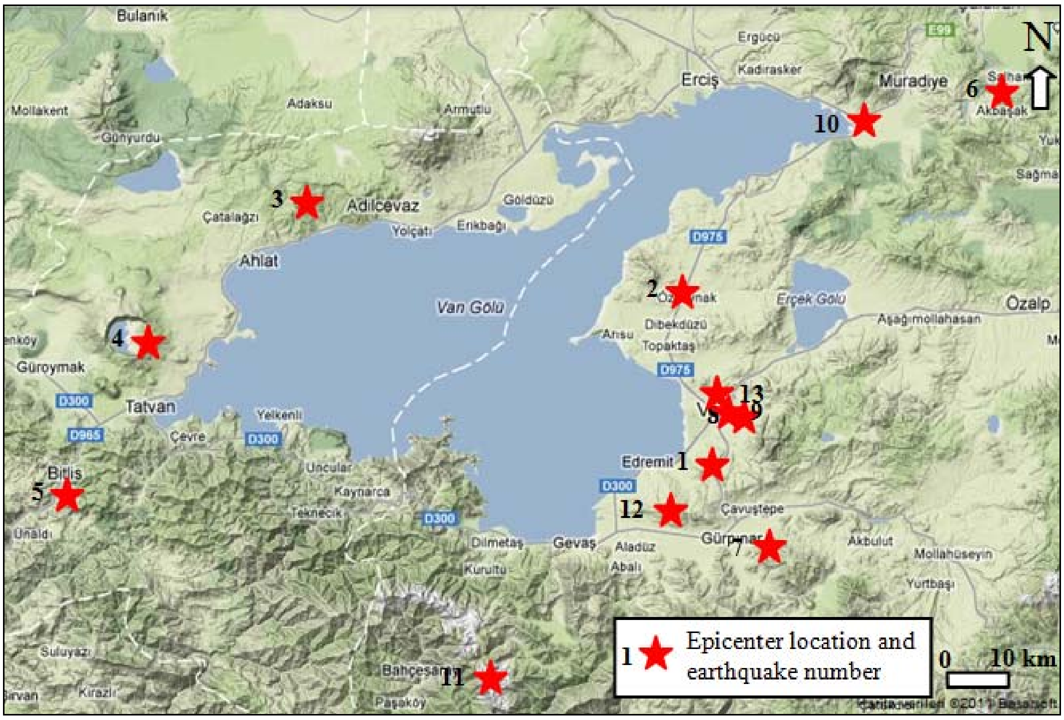


Figure 4.1. Epicenters of the historical earthquakes occurred in the Van Lake Region.given in Table 4.1.

The focal plane solution of the earthquake occurred in the vicinity of Edremit town, at the South of Van, on December 2, 2001 indicated a thrust fault and its strike was very similar to those of the thrust faults observed in the region (Özkaymak et al., 2004). Although this earthquake with a focal depth of 18 km didn't cause any loss of life, some cracks occurred on the walls of some buildings situated on loose sediments. Figure 4.2 shows that earthquake (M>4) activity of the region between 1900 and 2011.

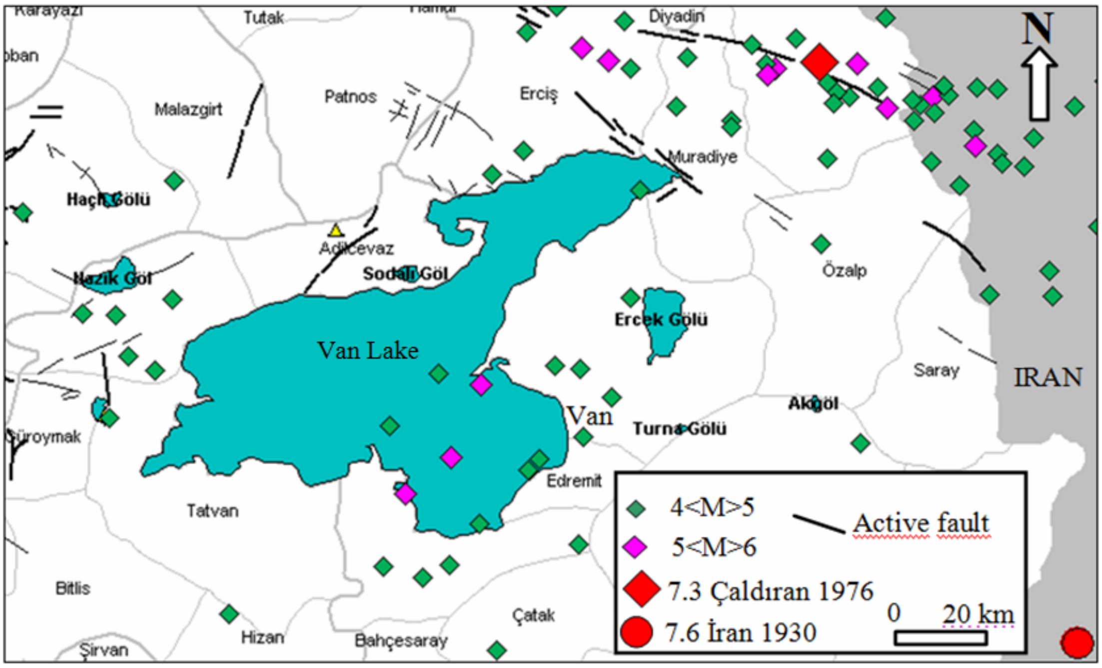


Figure 4.2. Seismicity of the Van Lake Region between 1900 and 2011 based on the earthquakes with magnitudes greater than 4 (Base map from MTA, 1998; arranged from Sayısal Grafik, 2011).

5 SEISMIC CHARACTERISTICS OF THE VAN-ERCİŞ EARTHQUAKE AND FAULTING

5.1. Earthquake Focal Mechanism and Faulting

The main shock occurred at 13:41 (10:41GMT) on Turkish standard time on October 23, 2011 in the Van province of Turkey. Various institutes in Turkey and other countries determined the epicenter of the earthquake and its faulting mechanism as shown in Figure 5.1. As noted from Figure 5.1 the locations of the epicenters predicted by various institutes such as KOERI, USGS, ERD, HARVARD and GFZ are scattered. Kandilli Observatory and Earthquake Research Institute (KOERI, 2011) estimated that the earthquake was centered about 30 km north of the Van city center near Tabanlı village.

The major energy release occurred within 20 seconds although the total duration of the rupture was about 50 seconds. KOERI estimated that the epicenter of the earthquake was near Tabanlı village (38.628N, 43.486E). The earthquake resulted from the movement of a 50 km long and 20 km wide thrust fault trending about E-W direction from Erçek Lake into Van Lake.

The rupture mechanisms released by different institutes (USGS, 2011; HARVARD, 2011; KOERI, 2011; ERD, 2011; GFZ, 2011) implied that the rupture was due to thrust type faulting as seen from Figure 5.1 and Table 5.1. The focal mechanism inferred from the striation of a fault observed in Topraktaş village based on the fault striation method developed by Aydan (2000) is also given in Figure 5.1. In view of the seismicity, the NW dipping faults may be assumed to be the causative fault with a slight sinistral component. The average inclination of this NW dipping fault may be about 40-60 degrees. Although the estimated average relative displacement of the fault is more than 2 m according to the empirical relation proposed by Aydan (2007), there was no clear fault scarp on the ground surface.

Regarding the active fault map of Turkey prepared by Şaroğlu et al. (1992), it was interesting to note that no active fault is recognized in the epicentral area. A more detailed tectonic map of the epicentral area has been released by Koçyiğit et al. (2011) following the earthquake as shown in Figure 5.1. They also attempted to relate the faults drawn in this map with the focal mechanism solutions of main and major aftershocks. However, this attempt is quite disputable in many aspects.

Table 5.1. Seismic parameters of the Van-Erciş earthquake of October 23, 2011 by USGS (2011), HARVARD (2011), ERD (2011), GFZ (2011) and KOERI (2011).

Institute	Lat. (N)	Lon. (E)	Depth (km)	M_L	M_s	M_w	NP1			NP2		
							Strike	Dip	Slip	Strike	Dip	Slip
GFZ	38.9	43.8	19			7.1	254	56	74	101	38	112
HARVARD	38.67	43.42	15			7.1	248	36	60	104	60	110
ERD	38.69	43.47	19	6.7		7.0	283	24	95	98	66	88
USGS	38.69	43.50	16		7.1	7.1	241	51	58	106	49	123
KOERI	38.76	43.36	5	6.6		7.2	292	61	125			

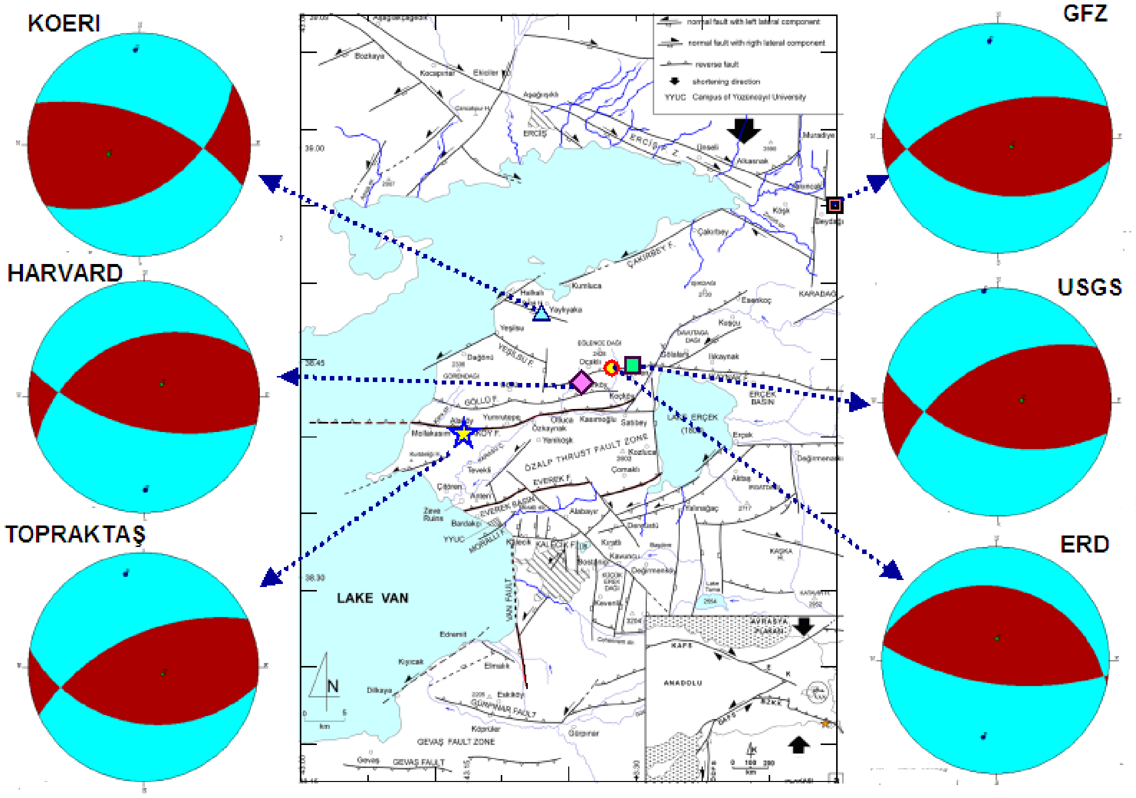


Figure 5.1. Faults mapped by Koçyiğit et al. (2011) and focal mechanism solutions by various institutes (Focal mechanism solution using the data measured in Topraktaş is derived from the method of Aydan, 2000).

5.2. Aftershock Activity

Figure 5.2 shows the locations of aftershocks following the October 23, 2011 earthquake just before the November 9, 2011 Van-Edremit earthquake. The aftershocks distributed over an area, which is about 50 km long and 20 km wide. This area extends from Erçek Lake into Van Lake. In the same Figure, projected seismicity with depth along NS and EW directions is also shown. It is also interesting to note that some pre-seismic activity is observed in the vicinity of the epicenter of November 9, 2011 earthquake.

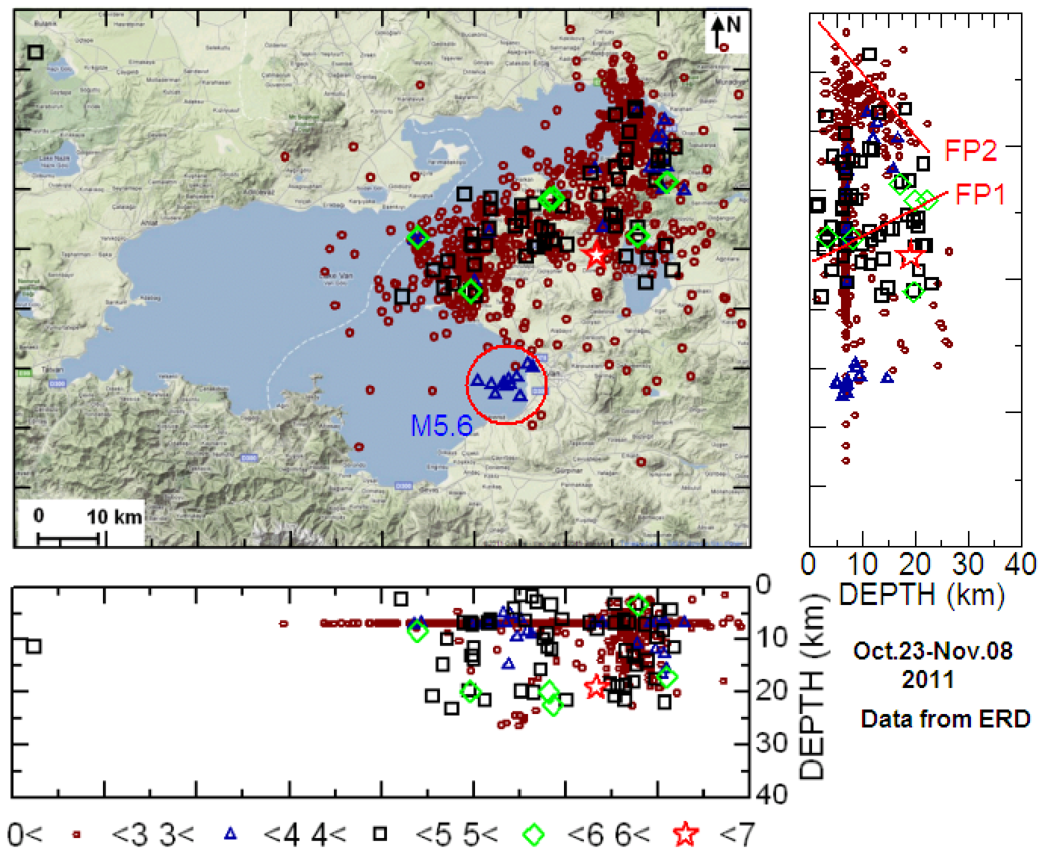


Figure 5.2. Aftershock activity following the main shock (aftershock data from ERD).

As noted from seismicity projected on “NS-depth” space, two distinct fault planes denoted by FP1 and FP2 can be inferred. The inclinations of inferred faults FP1 and FP2 are approximately 60 and 40 degrees, respectively. It seems that wedge-like body is undergoing a high seismicity.

5.3. Changes in the Shore Line of Van Lake

As the focal mechanism of the earthquake implies thrust faulting, it may be said that the body bounded by two planes may be undergoing uplifting. This uplifting also involves the Erçek Lake. The authors and Emre et al. (2011) noted that the shoreline of Van Lake was uplifted by 30-40 cm and it is in accordance with the inference of the seismicity (Figure 5.3). This uplift observed along the northern part of the causative fault, i.e. on the hanging wall block. Based on the measurements by the authors on the coast of the lake in Erciş town, the land uplifted about 30-33 cm. The authors also measured a withdrawal of about 45 cm on the lake shore near to Amik Castle and Yeşilsu villas and slight uplift along the shore line between Dağönü and Mollakasım villages. All these locations are shown by red stars in Figure 5.3. Emre et al. (2011) observed uplifts at ten locations on the shore of Van Lake between Adilcevaz at the NW and north of Van at southeast. These uplifts range between 10 and 40 cm and their locations are shown by purple stars in Figure 5.3.

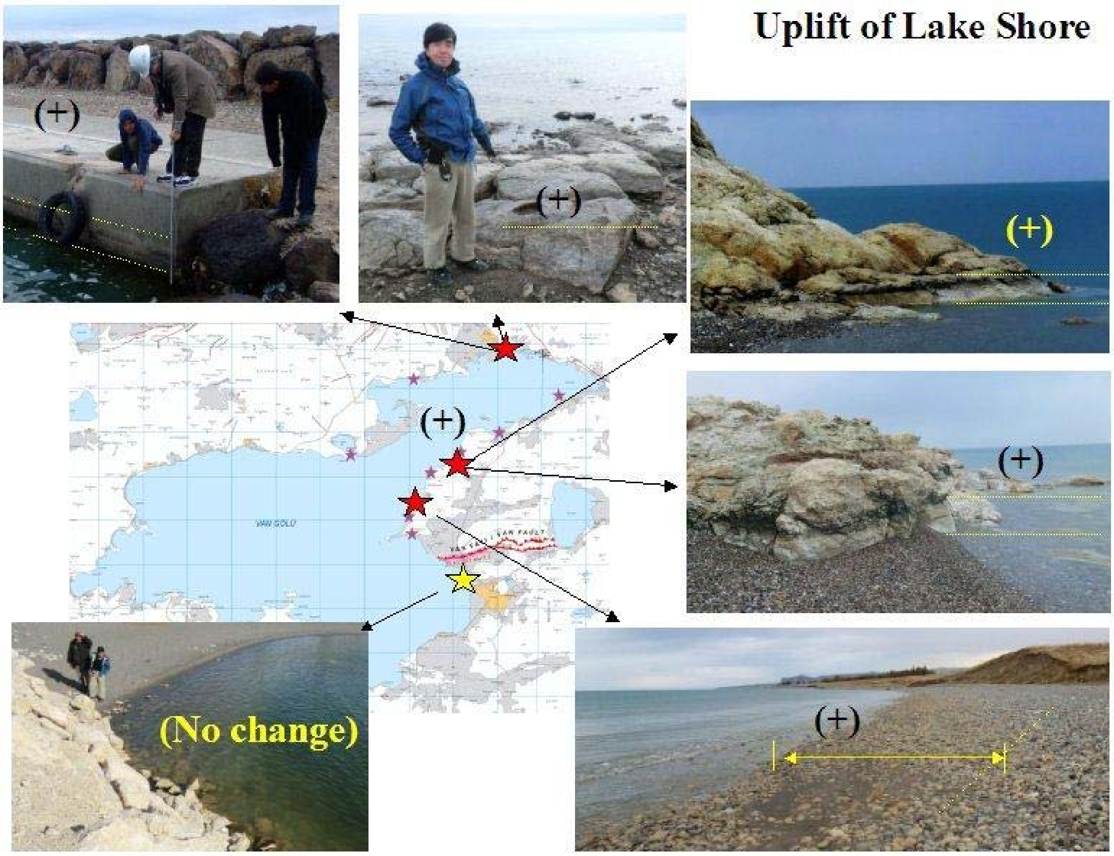


Figure 5.3. Views of uplift of the shoreline at several localities along the shore of Van Lake (Smaller purple and big red stars are the observations of uplifting reported by Emre et al., 2011 and by the authors of this report, respectively).

5.4. Surface Ruptures

Following the earthquake, many reconnaissance teams were dispatched to the epicentral area. The team dispatched by MTA (Emre et al., 2011) found traces of surface ruptures and they produced a fault trace map from Erçek Lake into Van Lake as shown in Figure 5.4a. The surface rupture could be traced from Bardakçı village located on the east shore of Van Lake at the north of Van towards east about 4 km (Akyüz et al., 2011).

Although there was no clear well-defined fault scarp along the fault trace, some uplift of ground, roadways, compression of bridges, canals slope failure and extensive liquefaction and associated lateral spreading over the fault front. The three locations, where the authors have observed the traces of the surface rupture, are also shown in Figure 5.4. One of them is located at east of the road between Bardakçı and Topaktaş villages (NW of Zeve Akademi Houses). At this location, a displacement about 5-6 cm was measured in a concrete water canal oriented perpendicularly to the surface rupture and it was observed that the part of the canal on northern block trusted towards south (Figure 5.4b). At the second location, a deformation trending in N50E was observed on the asphalt pavement of the Bardakçı-Topraktaş village and an uplift of 6 cm was measured on the northern block (Figure 5.4c). The deformation of Van-Ağrı Highway in the close vicinity of Yüzüncü Yıl University Campus at about 7 km north of Van City also implied slight sinistral lateral movement of the fault and this part of the highway was repaired (Figure 5.4d). Akyüz et al. (2011), who extended their reconnaissance towards east, reported that they observed very thin cracks trending N75E on a stabilized road close to Aşit village and the terraces trending in E-W direction at the south of Gedelova (near west of Erçek Lake) should be possible trace of the thrust fault causing the earthquake. According to Emre et al. (2011), the length of the fault on the land is 27 km and it consists of a single segment of 12 km long at its western tip, and two segments parallel to each other with a total length of 17 km in the east.

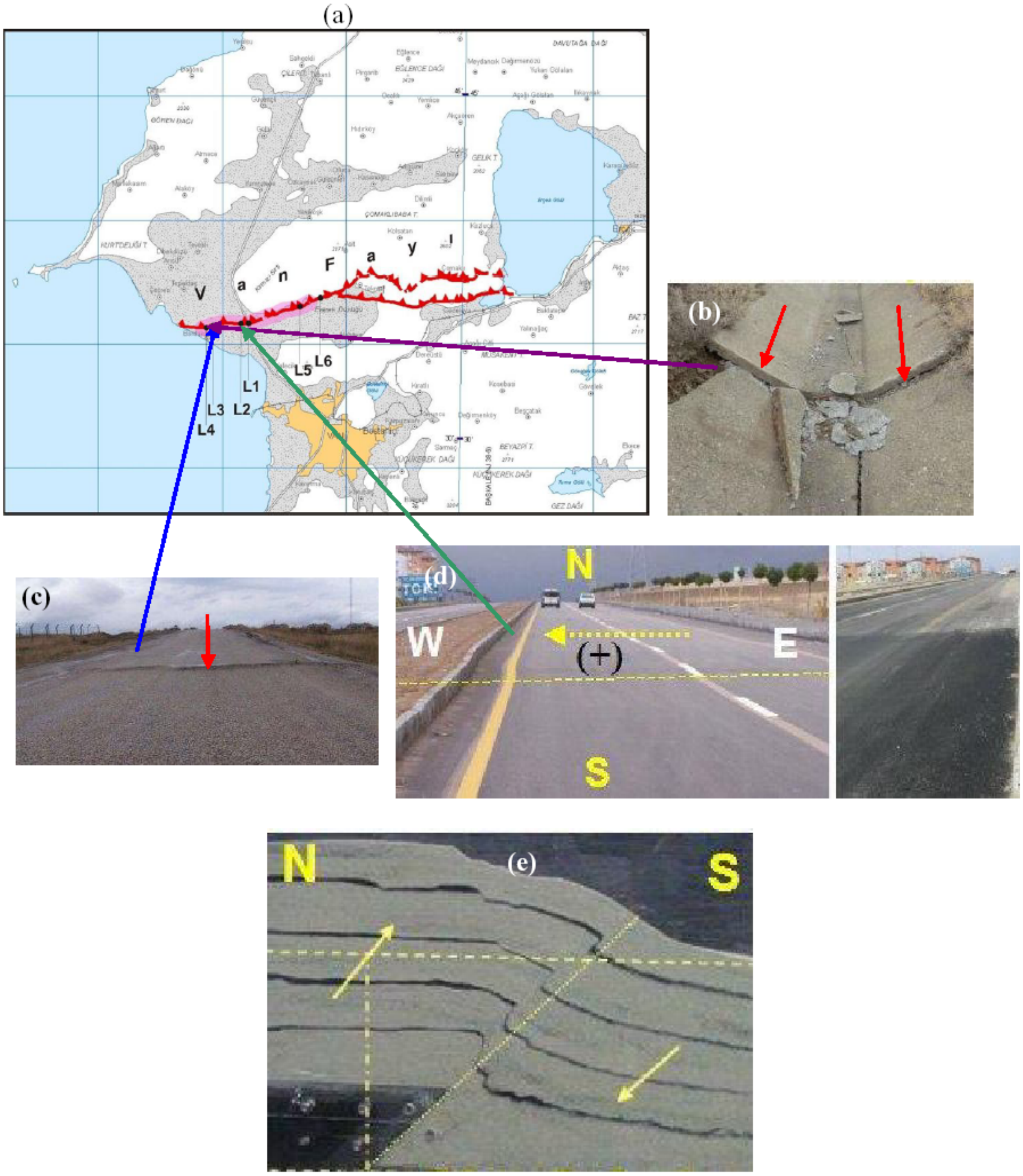


Figure 5.4. (a) Map showing the surface rupture of the October 23, 2011 earthquake (Emre et al., 2011), (b-d) locations of the surface rupture observed by the authors, (e) a model showing the deformation caused by thrust faulting by Ohta and Aydan (2004).

As there was no well-defined fault scarp, some researchers claimed that the earthquake was caused by a blind thrust faulting. When ground near surface is quite soft, the deformation caused by thrust faulting would be diluted over a great area as seen in the picture (Figure 5.4e) of a model faulting experiment performed by Ohta and Aydan (2007).

5.5. Comparisons with Other Turkish and Worldwide Earthquakes

Aydan (Aydan et al. 1996; Aydan 1997) developed some empirical relations among surface wave magnitude (M_s) and various fundamental parameters of earthquakes. He did not differentiate the fault type in his original relations. After about 10 years later, he revised his empirical relations and replaced the surface wave magnitude with moment magnitude of earthquakes as it has become quite rare that many seismological institutes report surface wave magnitude of earthquakes. The fundamental characteristics (i.e. displacement, length, area and duration) of this earthquake have been compared with empirical relations of Aydan (1997) and Aydan (2007). In converting M_s into M_w, the relation established by Aydan (2007) has been used for comparisons. The results are shown in Figure 5.5 with the consideration of fault type for Aydan's empirical relations published in 2007. The fault displacement is inferred from INSAR, and fault length and area were determined from seismic activity for about 10 days following the earthquake. The duration data comes from the data released by HARVARD (2011). As noted from Figure 5.5, the data of this earthquake (shown by a red star) is clearly on the estimated lines from the relations of Aydan (2007).

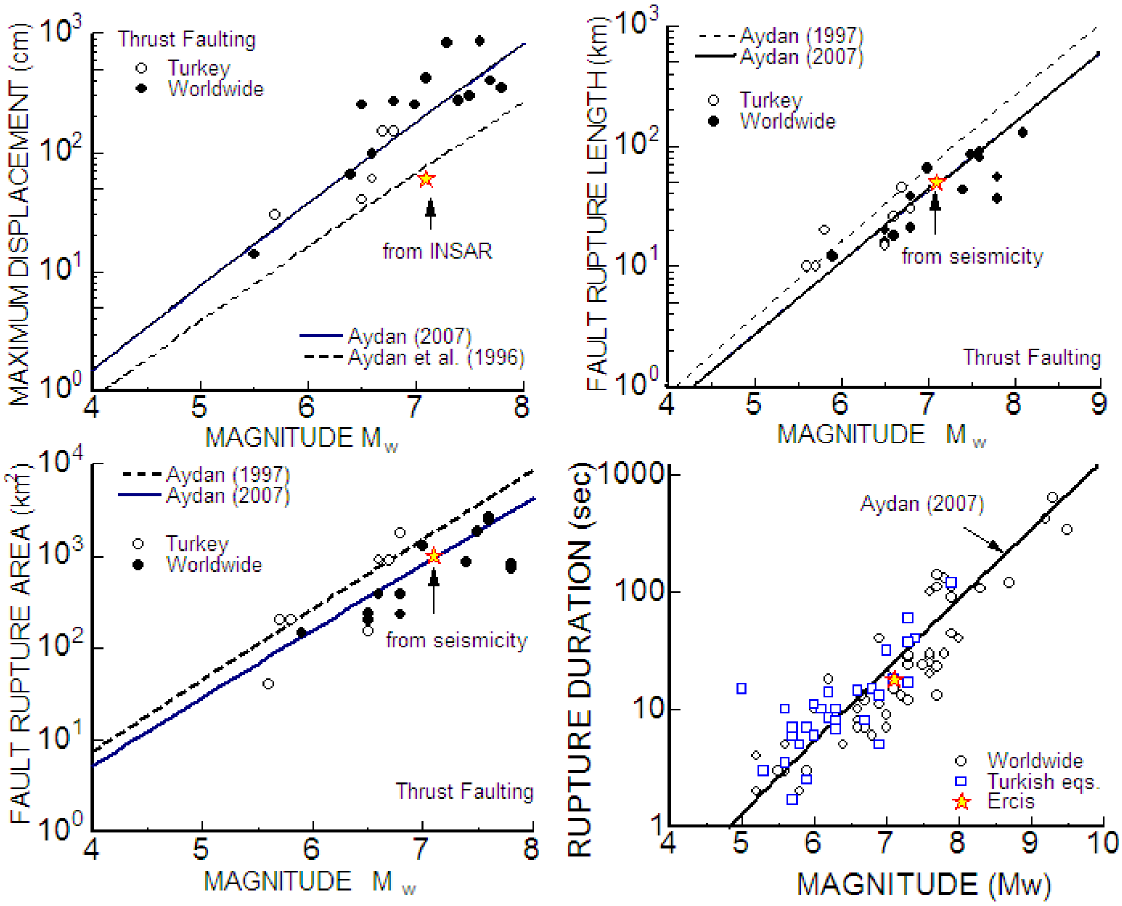


Figure 5.5. Comparison of fundamental parameters of the 2011 Van-Erciş earthquake with empirical relations proposed by Aydan (1997 and 2007).

6. STRONG MOTION CHARACTERISTICS

In the epicentral area, there are a number of strong motion stations operated by the national strong motion network of Turkey (Figure 6.1). Unfortunately, no strong motion was recorded in Van and Erciş, although Van and Erciş are equipped with strong motion devices. It seems that it did not record any strong motion data due to a technical malfunctioning.

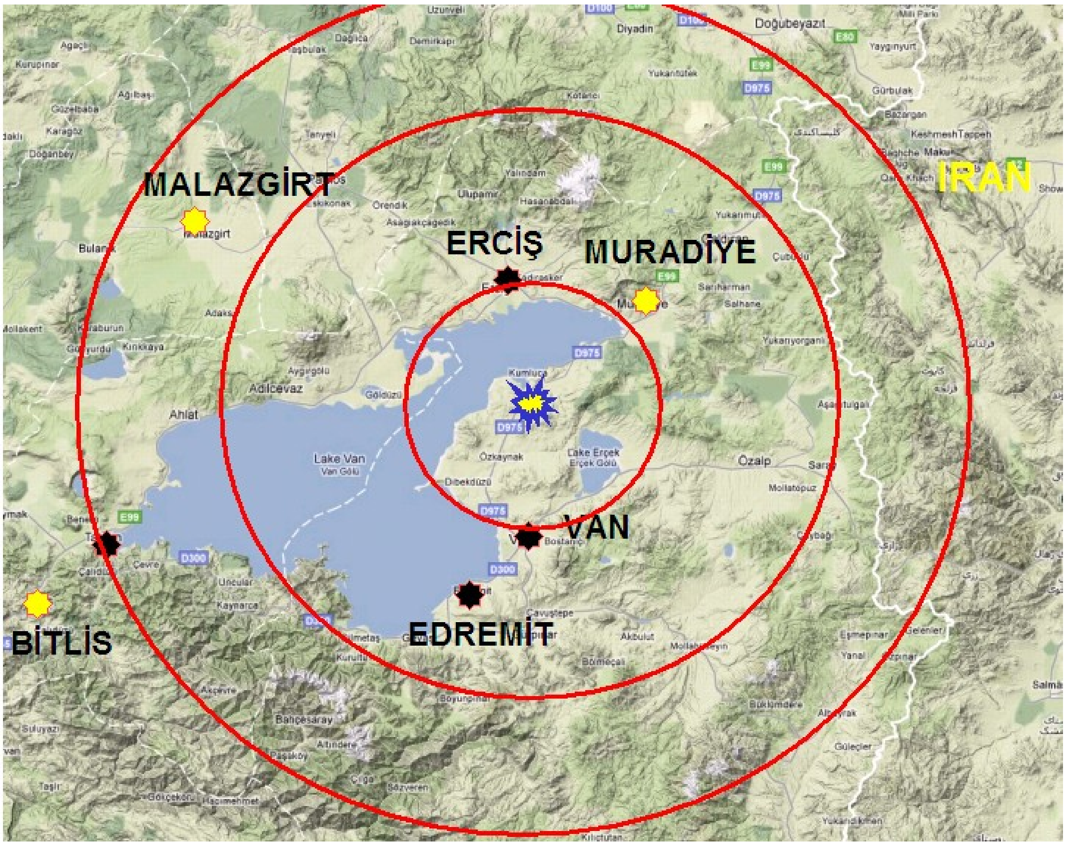


Figure 6.1. Locations of the strong motion stations in the vicinity of the earthquake epicenter (Black coloured stations have no records due to malfunctioning while yellow coloured stations have recordings).

6.1. Estimated and Measured Ground Motions and Their Attenuation

The nearest strong motion station to the epicenter of the main shock was located in

Muradiye (38.99011N-43.76302E) and the maximum ground acceleration at this station with a weighted shear velocity of 293 m/s was about 0.2 g (ERD, 2011). The distance of Muradiye station to the epicenter is almost the same as that of Erciş. Figure 6.2 shows the acceleration records taken at Muradiye and Bitlis (38.46600N-42.15000E). The N-S component of Muradiye station is the highest component, which probably reflects strong directivity effect.

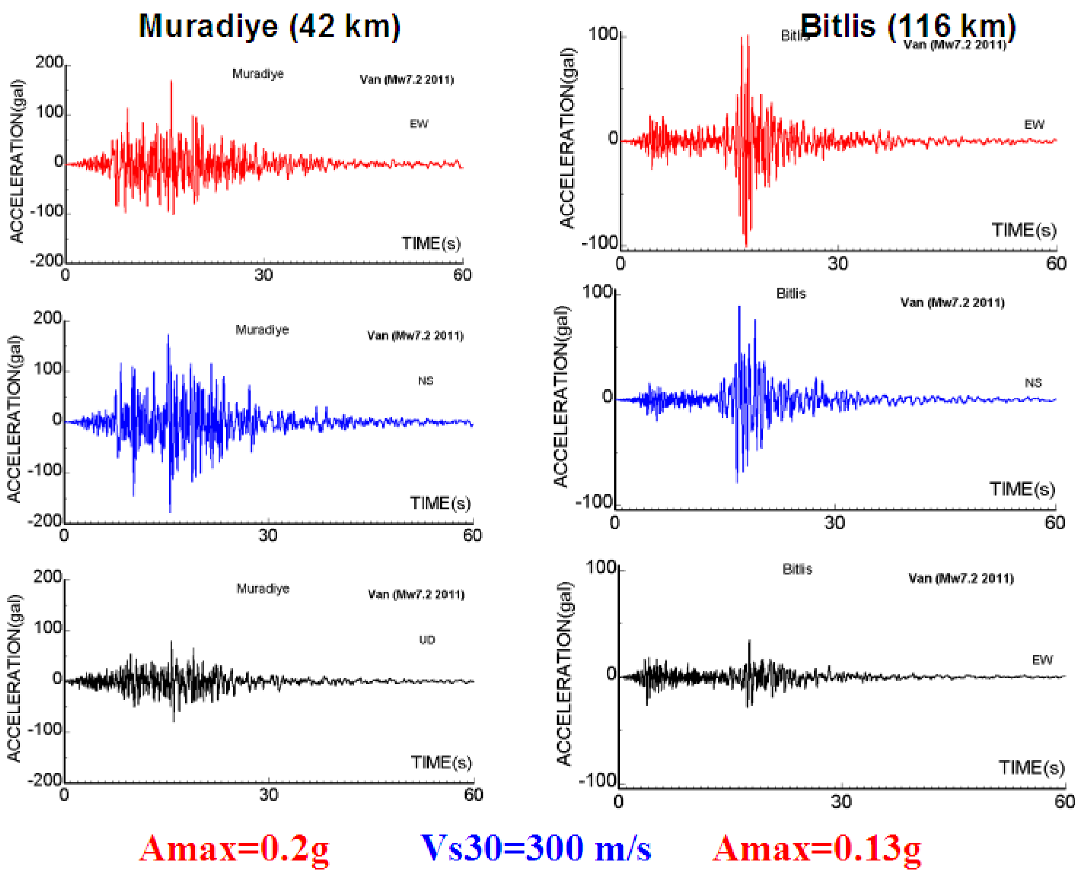


Figure 6.2. Acceleration records taken at Muradiye and Bitlis strong motion stations.

Figure 6.3 shows the acceleration records at Malazgirt and Muş strong motion stations. The shear wave velocity of ground at these stations is about 300 m/s. The accelerometers of Muradiye and Malazgirt stations are SMACH type while those at

Bitlis and Muş are CMG-5TD type. Therefore, some slight differences are noted particularly in the acceleration records of Malazgirt station.

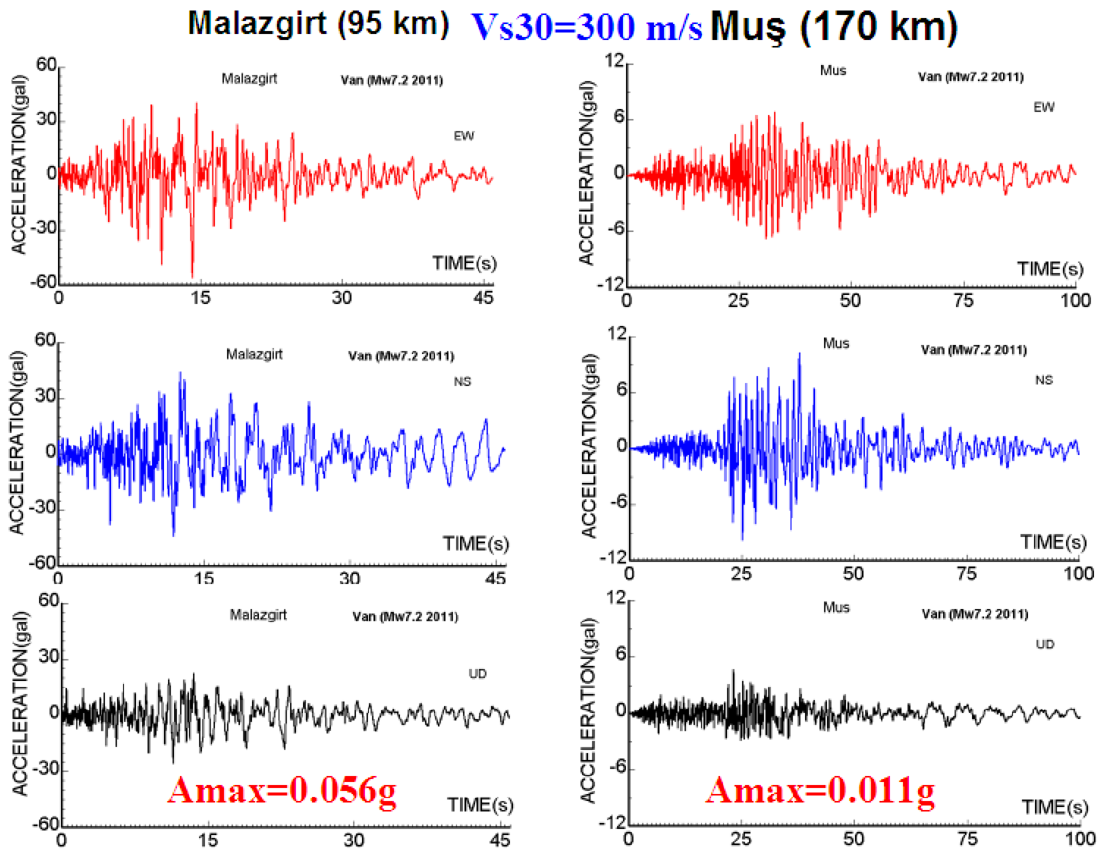


Figure 6.3. Acceleration records taken at Malazgirt and Muş strong motion stations.

The estimated contours of maximum ground acceleration and ground velocity using the method proposed originally by Aydan and Ohta (2006) and slightly modified by Aydan and Ohta (2011a) to include the effect of length and dip angle of the earthquake fault in addition to the effect of the fault strike, hangingwall and footwall effects are shown in Figures 6.4 and 6.5 for a uniform distribution of shear velocity of ground. It should be noted that the actual ground motions should differ from estimations if shear wave velocity of ground is different. Furthermore, it should also be noted that this type of estimations does not include topographic and basin effects yet. In the same observed maximum ground acceleration and velocity values at Muradiye, Bitlis and Malazgirt stations are also shown. It can be said that the observations are generally close to estimations. In addition, we plotted inferred maximum ground motions from toppled simple structures (see Section 6.4 for details) in the same figure. As there was no strong motion data in the epicentral area, the inferred ground motions may provide some information on the likely strong motions. The inferred results implied the maximum ground acceleration and velocity could be 500 gals and 38 cm/s at least, respectively.

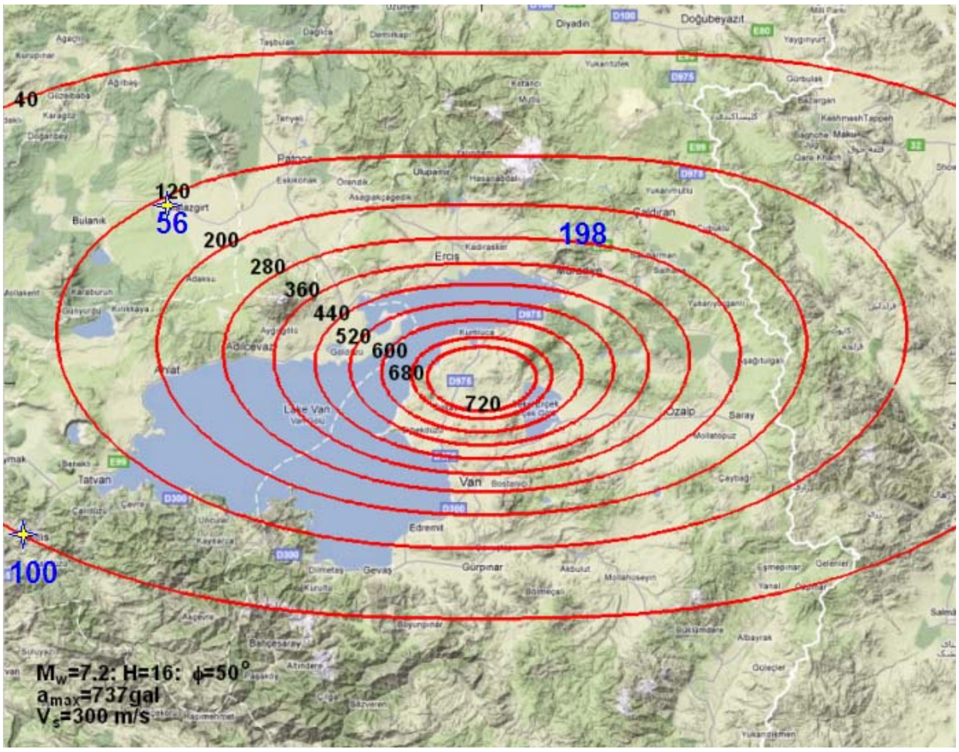


Figure 6.4. Contours of maximum ground acceleration.

Figure 6.6 compares the estimations by several attenuation relations proposed by Aydan (2001), Aydan and Ohta (2006, 2011a) and Ulusay et al. (2004) for maximum ground acceleration and maximum ground velocity with observations. The observed data are within the bounds proposed by Aydan (2001) and Aydan and Ohta (2011a).

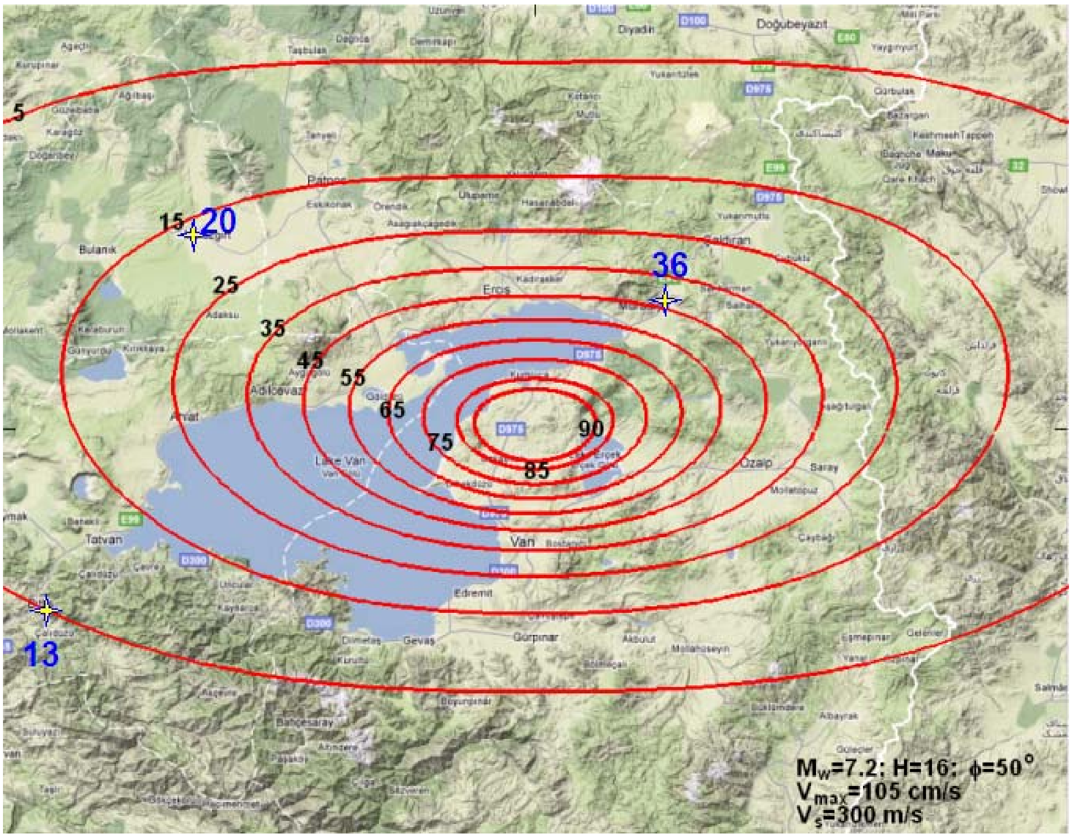


Figure 6.5. Contours of maximum ground velocity.

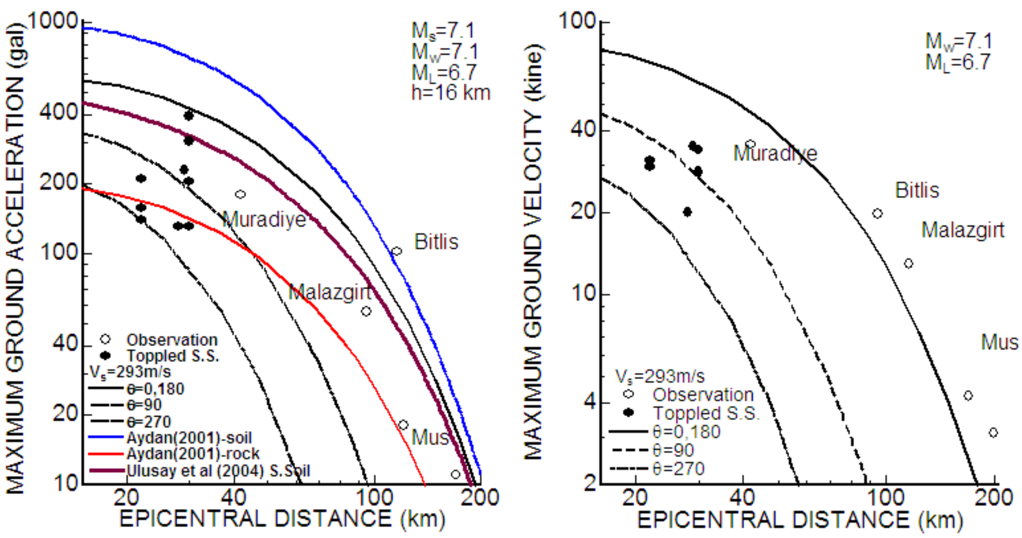


Figure 6.6. Comparison of estimations by several attenuation relations with observations.

6.2. Spectral Characteristics of Ground Motions

The acceleration spectra of the Muradiye, Bitlis, Malazgirt and Muş strong motion stations for a mass-proportional damping ratio of 5% are shown in Figure 6.7. Maximum spectral accelerations are observed for a natural period of 0.3-0.5 seconds for Muradiye record with a peak around 0.4 second for N-S component. The acceleration response of Bitlis is quite similar to those of Muradiye records. As for the acceleration of strong motion stations such as Muş, Malazgirt and Bitlis away from the epicenter, the effect of long period components appear as expected. For example, the collapse of minarets in Muş and Malazgirt can be explained by long period components for strong motion records. Furthermore, the acceleration spectra of Muş station, has a distinct peak between 1.2 and 1.3 s. This may be related to a basin effect.

6.3. Natural Periods of Structures in Turkey

Figure 6.8 shows the natural periods of various structures for the first mode together with formula provided by the Turkish Seismic Codes (Ministry of Public Works and Settlement of Turkey, 1998). In converting the period of RC towers (water tanks), the height is divided by a common story height of 3.3 m. In addition, a linear function based a theoretical model of a simple structure is fitted to the data set. The coefficient of 0.065 seems to be the best fit to the data set. The number of story of many collapsed RC buildings particularly in Erciş ranges between 5 and 8. In view of natural periods common to reinforced concrete (RC) structures in Turkey, the acceleration response of 6 story RC buildings should have been must vulnerable to high ground shaking in view of their natural periods in addition to other structural problems. This result may also explain why 5–8 story RC buildings collapsed or heavily damaged during this earthquake.

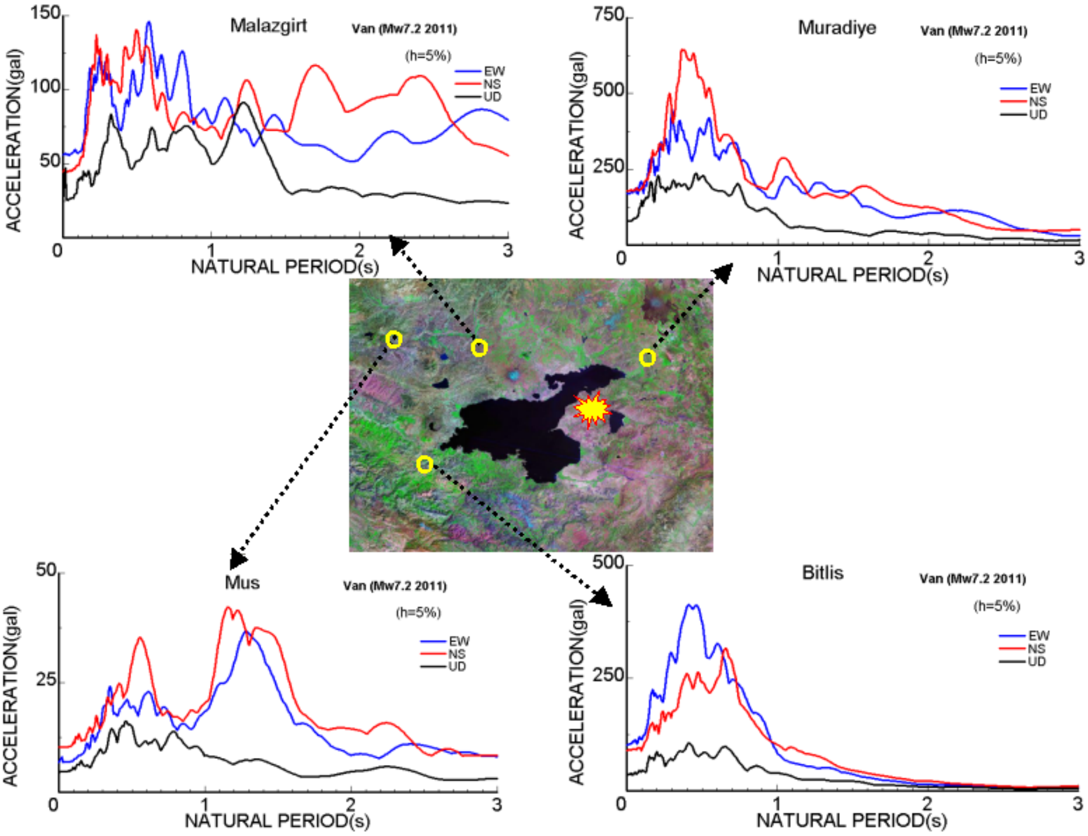


Figure 6.7. Acceleration response spectra for a damping ratio of 5% at different strong ground motion stations.

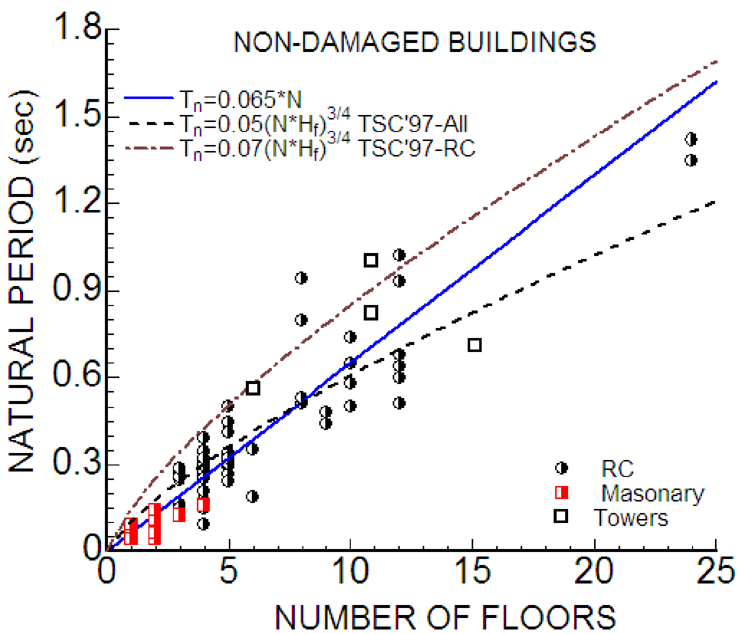


Figure 6.8. The relation between natural periods of various structures in Turkey.

6.4. Permanent Ground Motions from GPS and INSAR

Turkey has recently improved its global positioning system (GPS) network (Turkish CGPS). Following this earthquake, the displacement of the GPS stations were released as shown in Figure 6.9. The largest displacement was observed at Muradiye station on the hangingwall side of the fault and it had amplitude of 56 mm. This station moved in the S20W direction. Başkale GPS station, which is on the footwall side of the earthquake fault, moved in N30W direction with an amplitude of 29 mm. Malazgirt station moved westward with an amplitude of 13 mm. The measured uplift at many stations is very small and may be related to the resolution problem of the GPS in vertical direction. In any case, it should be noted that the measured displacement by the GPS may not correspond to actual crustal deformations due to the possibility of plastic deformation of ground at surface.

Several INSAR techniques have been also applied to the surface deformation caused by the October 23, 2011 earthquake. Figure 6.10 shows the fringes of inferred crustal deformation in the epicentral area processed by Eric Fielding of JPL-Caltech. As noted from this figure, there are clear indications of surface deformation particularly at the north of Van and the highest deformation is observed near the epicenter. The colour contours in the direction of the radar line sight (28 degrees from vertical and roughly west) is 20 cm. However, one of the major problems with this technique is that the surface deformations caused by liquefaction induced lateral spreading and slope failures can not be differentiated. This is often the case as observed in previous large-scale earthquakes such as 2005 Kashmir earthquake (Aydan et al., 2006). Therefore, the processed results from INSAR techniques should be interpreted with caution.

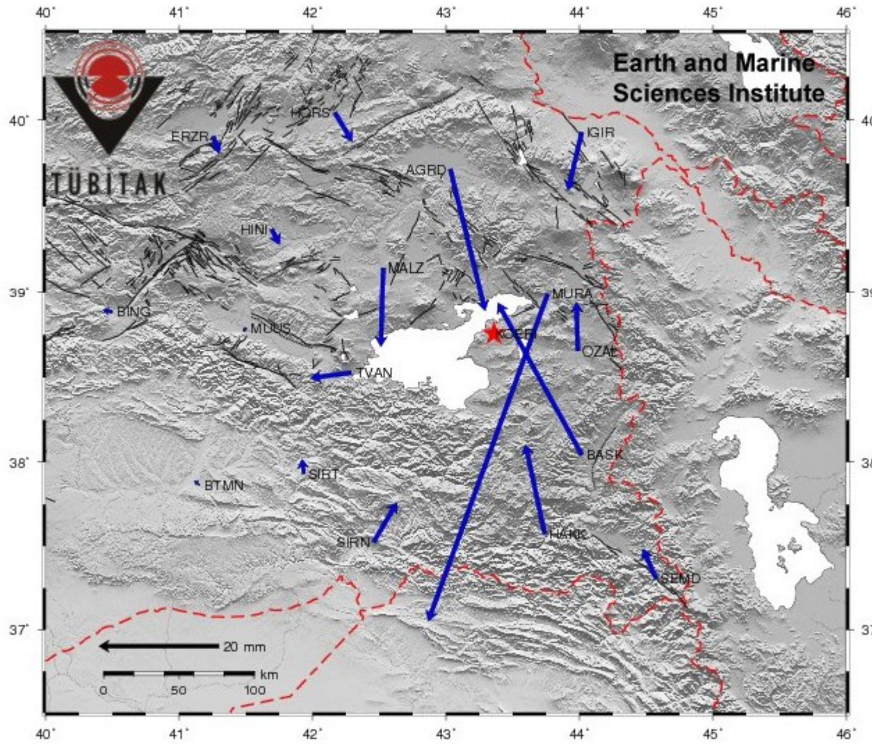


Figure 6.9. Measured displacements at the GPS stations of the national GPS network of Turkey. (http:supersites.earthobservatory.org/)

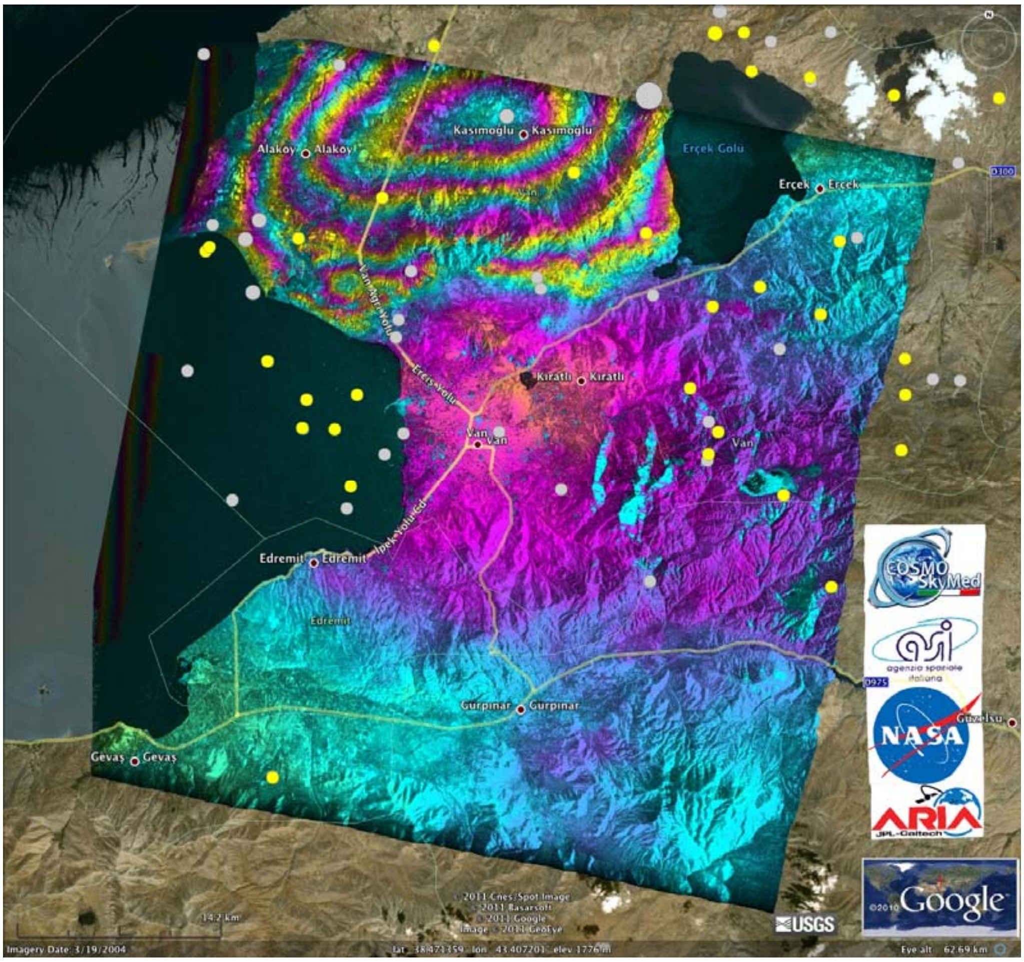


Figure 6.10. Inferred fringes of surface deformations from INSAR techniques by COSMOS-Med (http:supersites.earthobservatory.org/CSK-20111010-1026-20 cm).

6.5.Collapse Directions of Simple Structures and Estimated Strong Motions

Collapse directions and inferences of ground motions from simple structures may also give some indications of possible strong motions in the epicentral area. As there were no strong motion records in heavily damaged areas, such inferences may provide some insights to the strong ground motions in the affected areas. Some available techniques in literature (i.e. Aydan, 2002; Aydan et al., 2004) may be used. Figures 6.11 and 6.12 show inferred maximum ground acceleration and velocity for the sliding and toppling modes of failure of some simple structures. The inferred maximum ground accelerations and ground velocity are more than 200 gals and 30 cm/s, respectively in Erciş. Some typical examples of collapses are shown in Figure 6.13.

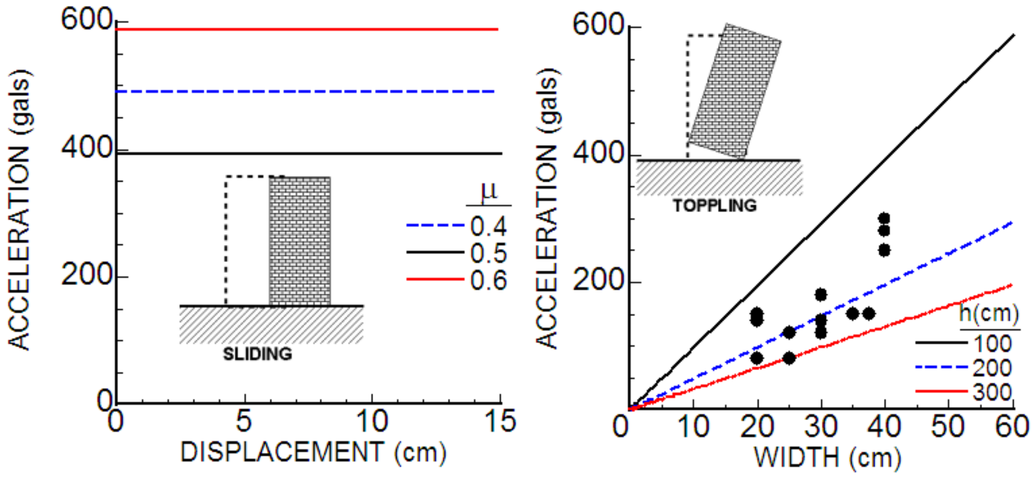


Figure 6.11. Maximum ground acceleration for sliding and toppling modes.

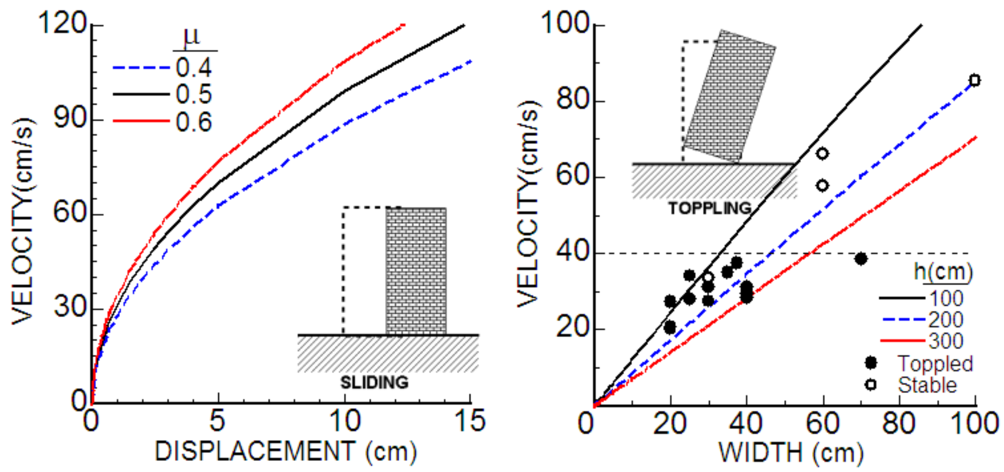


Figure 6.12. Maximum ground velocity for sliding and toppling modes.

Collapse directions of buildings, minarets, garden walls and chimneys were measured by the authors during the reconnaissance in the earthquake affected area (Figure 6.13). Distribution of collapse directions in the epicentral area is generally concentrated in north and south directions (Figure 6.14).

Figure 6.13. Views of failed, toppled and displaced some structures in the epicentral area

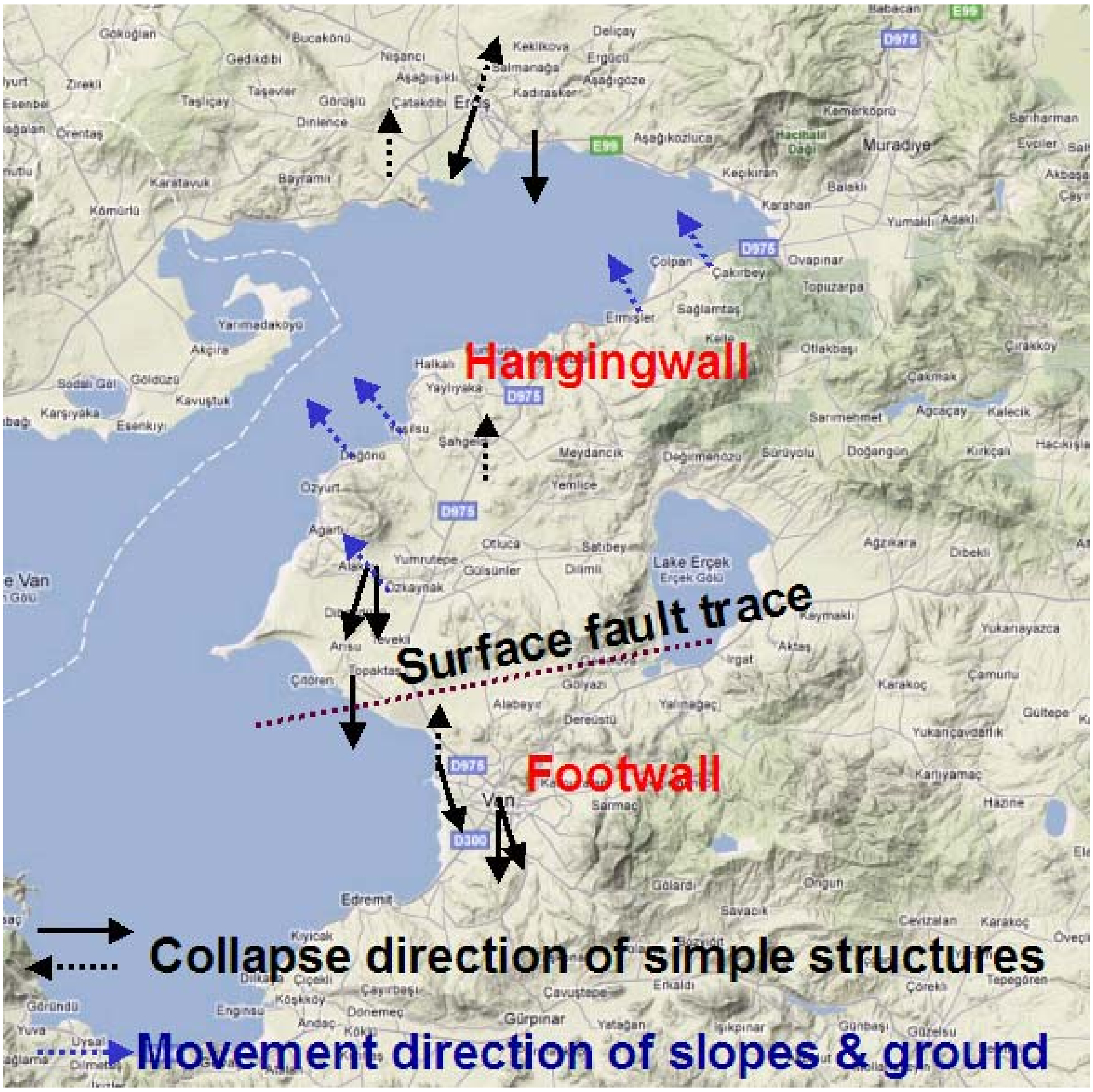


Figure 6.14. Collapse direction of simples structures and movement direction of slopes and ground in the epicentral area

7. DAMAGE TO STRUCTURES

The distances from the earthquake epicenter to Van and Erciş were approximately the same. However, the damage was quite heavy in Erciş as it was on the hanging-wall side of the causative fault while the damage in Van city was relatively less probably because it was on the footwall side of the causative fault. In this chapter, the characteristics of the damages to various structures are explained.

7.1. Mosques and Minarets

Most of the main compounds of mosques in the earthquake-affected region were generally intact or suffered very slight damage (Figure 7.1). The damage was generally concentrated at corners as observed in the previous earthquakes of Turkey (i.e. Aydan et al., 2000a, 2000b). The main compounds of mosques generally have single dome or multiple semi-spherical domes and they are structurally symmetric. For this reason, the main compounds remain intact during shaking. Furthermore, the domes of mosques are made of very light materials. The main compounds of the mosques either failed or damaged when the falling minarets hit them. Such examples were observed in Erciş.

The height of minarets in the region ranges between 10 and 25 m. While recently constructed minarets are mainly reinforced concrete structures, the minarets of old mosques are stone masonry. The stones are generally made of sandstone and/or andesite. Failures of minarets occurred at the junctions where the cross-section configuration of the structure changes by toppling as seen in Figure 7.1

Figure 7.1. Views from damage to mosques and their minarets.

7.2. Reinforced Concrete Structures

The earthquake resulted in heavy damage to buildings and significant casualties in this province, particularly in Erciş. A number of 5-8 stories RC buildings collapsed particularly in Erciş and Van (Figures 7.2 and 7.3). The major causes of the heavy damage to reinforced concrete buildings were basically similar to the observations in previous earthquakes such as poor quality of construction materials, lack of implementation of design codes, existence of soft-floor (weak-floor), pounding, lack of ductility, poor integrity of RC frame with in-fill walls, poor quality of workmanship and poor ground conditions (i.e. Aydan et al., 2000a, 2000b). It should be added that site effects most likely contributed to alteration of frequency characteristics of the ground motions to adversely affect the buildings.

Figure 7.2. Views of collapsed or heavily damaged RC buildings.

Figure 7.3. Views of constructional problems causing the collapse or heavy damage.

In recent years, TOKİ, which is a state owned construction company specialized in buildings, have constructed buildings in Van, Edremit and Erciş. These buildings are like honeycombs utilizing shear walls as the shear load bearing elements. This earthquake probably is the major event to test their structural performance during earthquakes. The story number of TOKİ buildings in Erciş is 5 while it is 8 stories in Van. They are generally built on a firm ground. Although the authors could not inspect these buildings in detail, the visual inspection indicated that there was almost no damage to the buildings (Figure 7.4).

Figure 7.4. Views of non-damaged TOKİ buildings.

The authors noticed during their reconnaissance that some buildings were repaired by cosmetic non-structural methods such as re-plastering of cracked beams, columns, infill-walls and beam column connections, which had disastrous effects in the November 9, 2011 earthquake (Figure 7.5). Similar problem was observed in buildings damaged by the 1999 Kocaeli earthquake in Düzce during the 1999 Düzce earthquake (i.e. Aydan et al., 2000a and 2000b).

Figure 7.5. Cosmetic repairs apllied to a damaged RC building in Van on November 5, 2011 after the Van-Erciş earthquake.

This earthquake also damaged some low story reinforced concrete buildings constructed along the shore of Van Lake as villa houses. The major cause of damage was the permanent deformation of sloping ground towards the lake. Figure 7.6 shows views of these damaged villa-type houses. These examples also indicated the vulnerability of buildings to the permanent deformation of foundation ground along the lake shore.

Figure 7.6. Damaged low story villa-type buildings constructed on sloping ground along the shore Van Lake.

7.3. Masonry Structures

Buildings in rural areas and villages are of brick masonry or stone masonry type. Timber houses (hımış in Turkish) are quite rare due to lack of forests in the earthquake affected area. This earthquake damaged many such buildings as seen in Figure 7.7. In addition to poor quality construction and inappropriate construction materials, the damage was caused partly by the settlement and lateral spreading of liquefied ground to buildings. Figure 7.8 shows some examples of geotechnically induced structural damage at Çelebibağı village of Erçiş.

Figure 7.7. Views of heavily damaged brick masonry buildings.

Figure 7.8 Lateral spreading induced damage to buildings in Çelebibağı village (Erçiş).

When these buildings are constructed with the consideration of having a mat concrete or firm base, light roof, hatıl (timber or conrete confining beams) at certain intervals, lime (cement)-based bonding, utilization of saman (straws) in kerpiç (adobe) bricks and plastered walls, the damage was none or slight. Such buildings performed very well even some permanent ground deformation occurred beneath their foundations as seen in Figure 7.9. There are some golden rules how to construct masonry buildings in earthquake-prone areas, which are outcomes of experiences gained from the long-history of seismicity of Turkey. These rules can be summarized as follow:

(a) Built on a base-mat concrete or firm base (if ground condition is poor)

(b) Roof should be light (toprak dam (earthen roof)) is not desirable)

(c) Use hatıls (timber or concrete beam) at each 1 m interval at the top of the wall.

(e) Use lime (cement)-based mortar with saman (straws) in kerpiç (adobe) bricks (original idea of fiber-reinforced concrete/shotcrete comes from this concept)

(h) Plaster walls in order to prevent water diffusion into kerpiç (adobe) bricks

Figure 7.9. Views of non- or slightly-damaged masonry buildings in several localities.

7.4. Elevated Water Towers and Silos

Elevated water towers are commonly used in when ground is quite flat. There were some reinforced concrete water tanks in Van. Water towers are RC structures and their height generally ranges between 25-30 meters. The towers have 6 columns and they are symmetric structures. Figure 7.10 shows a water tower belonging to the General

Directorate of Highways (TCK) of Turkey in Van city. No damage was observed at this water tower. The visual inspection of water tanks at other localities indicated that there was no damage. The water in this type of elevated water tanks may act as an active damper during ground shaking. As noted from Figure 6.8, the natural period of these structures are generally long. This may be additional factor why such structures are not affected by earthquakes in this earthquake as well as in previous earthquakes in Turkey.

Figure 7.10. Non damaged elevated water tank owned by the General Directorate of Highways (TCK) in Van city.

Although some silos observed by the authors were intact and did not suffer any damage (Figure 7.11a), KOERI (2011) reported that many cement and wheat silos, which were full at the time of the earthquake, either fully collapsed or were seriously damaged (Figure 7.11b-c). Some of silos ruptured at their base due to bending or insufficient seating width of the supporting concrete.

(a) (b)

Figure 7.11. (a) Non-damaged silos in Van and (b) collapsed cement silo in the Van Industrial complex (KOERI, 2011).

7.5. Dams

There are several rock-fill dams up to 65 m high and earth-fill water reservoirs in the epicentral area. These dams are Sarımehmet Dam (4 km from the epicenter), Koçköprü Dam (39 km from the epicenter) and Bostaniçi Dam. Koçköprü Dam and Sarımehmet Dam are a 75 m high clay core rock fill dam with reservoir capacity of $110x10^6$ m^3 and a 62 m high clay core rock fill dam with reservoir capacity of $115x10^4$ m^3, respectively. Based on the reconnaissance reports at dam sites in the earthquake region (DSİ, 2011; Çetin et al., 2011), the earthquake did not cause any damage to the dams, for example, even the Sarımehmet Dam (Figure 7.12) was very close to the earthquake epicenter.

(a)

(b)

Figure 7.12. Views from (a) crest and (b) spillway of the non-damaged Sarımehmet Dam (after Çetin et al., 2011).

7.6. Pre-cast (Prefabrik) Reinforced Concrete Structures

Structures utilizing pre-reinforced concrete columns and beams are widely used for factories and large ateliers. The first devastating damage to these structures occurred in the 1992 Erzincan earthquake and since then, there were very similar type damage to these structures in almost every earthquake having a magnitude greater than 6 (Aydan and Kumsar, 1996 ; Aydan et al., 1998; Aydan et al., 2000a, 2000b; Ulusay et al., 2002; Aydan et al., 2003). It was also observed that such damage could even occur in earthquakes having a magnitude of 5.3-5.6 as seen in the 2003 Buldan earthquakes (Kumsar et al., 2008). Following the heavy damage to these structures in the 1999 Kocaeli and Düzce earthquakes, the seismic design codes of pre-cast structures have been revised. Although the authors could not visit such structures due to the limited duration of their investigation, the information provided by the reconnaissance teams of KOERI (2011), METU/ERRC (2011) and Özden et al. (2011) reported severe damage to those structures in the Van Industrial Complex. Figure 7.13 shows a commonly observed damaged to an old pre-cast concrete structure. Especially, the damage always occurs at the connection of the reinforced concrete beam to the short cantilever of the column. The beams are attached to the column with two thin reinforcing bars and the beams become dislodged during shaking either due to rupture of the column end or rupture or sliding of bars from their anchorage and they fall on the floor, subsequently.

As seen in Figure 7.14, the total collapse of one part of the precast concrete structure under construction strongly implies that there is no improvement to their seismic design despite the revision of the code in practice since 1999. It seems that the old practice still continues. Figure 7.15 shows the details of the beam-column connection the collapsed pre-cast reinforced concrete structure shown in Figure 7.14.

Figure 7.13. A typical damage to a pre-cast reinforced concrete structure in Van Industrial Complex (from KOERI, 2011).

Figure 7.14. A view of heavily damaged pre-cast reinforced concrete structure in Van Industrial Complex (from KOERI, 2011).

Figure 7.15. The details of poorly constructed beam-column connection of the pre-cast structure shown in Figure 7.14 (pictures arranged from KOERI (2011)).

7.7. Damage to Historical Structures

Karakoyunlu Türkmen State governed Azerbaijan and Iraq during a period between 1375 and 1468. Erciş served as the capital of Karakoyunlu Türkmen State and there are many historical remains from that period in Erciş and Provinces of Van and Bitlis. There are a number of several mausoleums (Kümbet in Turkish) built for the khans (king) and/or their aristocratic families. They are dodecahedral or cylindrical built on a cubic base. Two kümbets were damaged by this earthquake. Particularly the Kara Yusuf Pasha Kümbet (also locally known Zortul), which was built near Çatakdibi village of Erciş during the period of Cihan Şah, suffered very heavy damage by the earthquake as seen in Figure 7.16.

(a) before (b) after

Figure 7.16. Heavily damaged Kara Yusuf Pasha Kümbet (pictures from Erciş Municipality and TRT-Haber, 2011).

The second kümbet damaged by the earthquake is Kadem Pasha Hatun Kümbet. This kümbet is about 1–2 km to the east of Erciş, at the junction of the Erciş–Van and Patnos–Van roads. It was also built in 1458 for the wife (hatun) of Kadem Pasha during the period of Cihan Khan (Shah). The damage was due to relative movement among blocks, which caused the opening of vertical joints between stone blocks of the structure as seen in Figure 7.17.

It was also reported that some stone monuments with cuneiform (originally developed by Sumers, who are of Central Asian origin) inscriptions of Urartu (probably related to Ural-Altaic origin) period in the Van Museum toppled as seen in Figure 7.18. The museum building also suffered some damage, some clay tablets were broken and some collections belonging to Urartu period were also damaged.

(a) (b)

Figure 7.17. Damaged Kadem Pasha Hatun Kümbet: (a) before and (b) after the earthquake (pictures from Erciş Municipality and Çetin et al., 2011).

Figure 7.18. Stone monuments (toppled) Van Museum (Anadolu Ajansı, 2011).

In Çelebibağ village, a stone wall of castle remains from the Urartu period collapsed towards South (Figure 7.19).

Figure 7.19. Toppled wall of Urartu castle in Çelebibağ village (Erciş).

The Van Castle, which was built in Urartu period in 9th BC, did not suffer any damage during the October 23, 2011 and the November 9, 2011 earthquakes. It is built over a rock ground consisting of limestone (Figure 7.20). There are also some historical mosques and other historical structures to the south of the castle. There are three historical mosques, namely, Kayaçelebi, Hüsrevpaşa and Süleyman Han mosques, Hüsrevpaşa mosque was built in 1567 by the famous Turkish architect Mimar Sinan. The Kayaçelebi mosque was built in 1660 and lost its minaret during the October 23, 2011 earthquake (Figure 7.21). The November 9, 2011 earthquake caused more damage to the main compounds and minarets and the inner plastering of walls were fallen down. Süleyman Han mosque is on top of the hill within the castle and built by Magnificient Sultan Süleyman of Ottoman period and the earthquake did not damage it.

Figure 7.20. A view of Van Castle after the earthquake.

(a) (b)

Figure 7.21. Views of Kayaçelebi mosque (a) before and (b) after the earthquake (pictures from Ministry of Culture and Tourism of Turkish Republic and Özden et al. 2011).

8. DAMAGE TO TRANSPORTATION FACILITIES

Van province is served by major highways and railways connected to Tatvan through a ferryboat line. Turkish Airlines Company and other major Turkish airline companies serve between Van and other major cities of Turkey as shown in Figure 8.1. Van province also neighbors Iran and transportation facilities connect the province to Iran also. This chapter is concerned with damage to transportation facilities by the October 23, 2011 earthquake.

Figure 8.1. Major highways, railways, ports and airports in Van province and its close vicinity.

8.1. Roadways and Roadway Bridges

The major highway connecting Van to Ağrı (D975 & D280) pass through the epicentral area. In addition, some local roadways run along the shoreline of Van Lake and connect villages and towns to the major D975, D300 and D280 highways. The D975 and D280 highways run almost parallel to the east shoreline of Van Lake at a higher elevation. This highway passes over some major rivers such as Karasu, Zilan, İrşat, Çaldıran and

Deliçay. The damage to highways and its bridges by the earthquake was basically quite light and it did not cause any major obstruction to traffic. The damage to highways and roadways was observed as

- failure of shoulder embankments,
- settlement of approach embankments and piers of bridges,
- failures of slopes adjacent to highways and roadways and
- rock falls from adjacent slopes and high mountains.

In the followings, the major damages are described.

Embankment failures at several localities, the major ones were observed on the Van-Ağrı Highway. The embankment (highway itself), seen in Figure 8.2, settled and slightly moved towards Van Lake. Nevertheless, it could be used without any hindrance to traffic following some repairs the settled and fractured asphalt surfacing of the highway.

Figure 8.2. Embankment failure on the D975Van-Ağrı Highway

Figure 8.3 shows the damage to shoulder embankments on the roadway between Dağönü and Özyurt villages and D975 Van-Ağrı Highway near Gedikbudak. The repair works were implemented as seen in Figure 8.3 and the roadway was re-asphalted

Figure 8.3. Failure of shoulder embankment of roadway and D975 Van-Ağrı Highway.

There were many slope failures and rock falls from adjacent slopes or high mountains along the section of Van-Ağrı Highway between Gedikbudak and Keçikıran as seen in Figure 8.4. Some of these rock falls from high mountains reached to the Van-Ağrı Highway. Nevertheless, they did not result in any casualties.

Roadway bridges are generally constructed using cast-in place technique. The earthquake caused very little damage to bridges. The damage to bridges was due to the settlement of piers and settlement and lateral deformation of their approach embankments. These type damages of bridges were observed along Van-Ağrı Highway and other roadways at Karasu and Zilan Rivers (Figures 8.5-8.8). The settlement of piers was probably caused the partial liquefaction in the vicinity of bridge piers.

Another interesting slight damage was observed at a small roadway bridge between Topraktaş and Yüzüncü Yıl University Campus. The approach embankments of the bridge were subjected to ground deformation due to thrust faulting as seen in Figure 8.9. Vertical bending cracks were observed at wing walls of this small bridge.

Figure 8.4. Slope instabilities and rock falls along Van-Ağrı Highway.

Figure 8.5. Views of damaged Tirleşin bridge over Karasu on Van-Ağrı Highway.

Figure 8.6 Damage to a bridge near Göllü village due to lateral spreading.

Figure 8.7. Settlement of piers and lateral deformation of embankments of Zilan Bridge.

Figure 8.8. Settlement of piers of the bridge near Topraktaş village over Karasu River.

Figure 8.9. Cracking of wing-walls of a small bridge due to ground deformation caused by the thrust faulting.

8.2. Railways

A major railway line of Turkish Railways (TCDD) connects Van Port to the railway line of Iran. This railway line connected to the rest of railway network of Turkey through a ferryboat line between Tatvan and Van ports. The ferryboat transports the entire train between Tatvan and Van. The railway line in Van province starts from Van Port and passes along the southern shore of Erçek Lake and exits Turkey at Kapıköy border gate. The earthquake caused no major damage to the railway and its bridges. However, ground liquefaction occurred at the Van port and railways were slightly deformed by ground liquefaction and its associated ground deformation (Figure 8.10). The interviews with the railway authorities at the railway station of Van Port informed the authors that the slight damage to railways at the port did not cause any disruption of train services.

The damage to the station building was almost none, except some cracking related to the ground liquefaction induced ground deformation.

Figure 8.10. Views of deformed railways and liquefaction at Van Port.

8.3. Ports and Breakwaters

Some ground liquefaction occurred at Van Port and there were some slight cracking of RC components of quay walls and anchorages as seen in Figure 8.11. Nevertheless, the port was functional. The captain of the ferryboat informed the authors that he was sailing to Van when the earthquake hit. Although the earthquake caused a jolt on the ferryboat, there was no major problem of huge wave causing the vibration of the ship.

Figure 8.11. Views of slightly damaged Van Port.

Breakwaters at the Van Port and Yüzüncü Yıl University (YYU) Port made of large stone blocks settled and deformed laterally as seen in Figure 8.12. The main reasons for such deformations may be related to the settlement of large rock blocks into lake-bottom due to ground liquefaction.

(a) Van port (b) YYU port

Figure 8.12. Settlement and spreading of breakwaters of Van and YYU ports due to liquefaction of foundation ground.

Aydan and Ohta (2009) performed some shaking model experiments on breakwaters on a liquefiable ground following the 2009 West Sumatra Earthquake in Indonesia and observed that breakwaters can sink into the ground and it may even completely disappear as seen in Figure 8.13. Similar phenomenon was also observed in 2011 Christchurch earthquake and 2011 Great East Japan earthquake in much large scale.

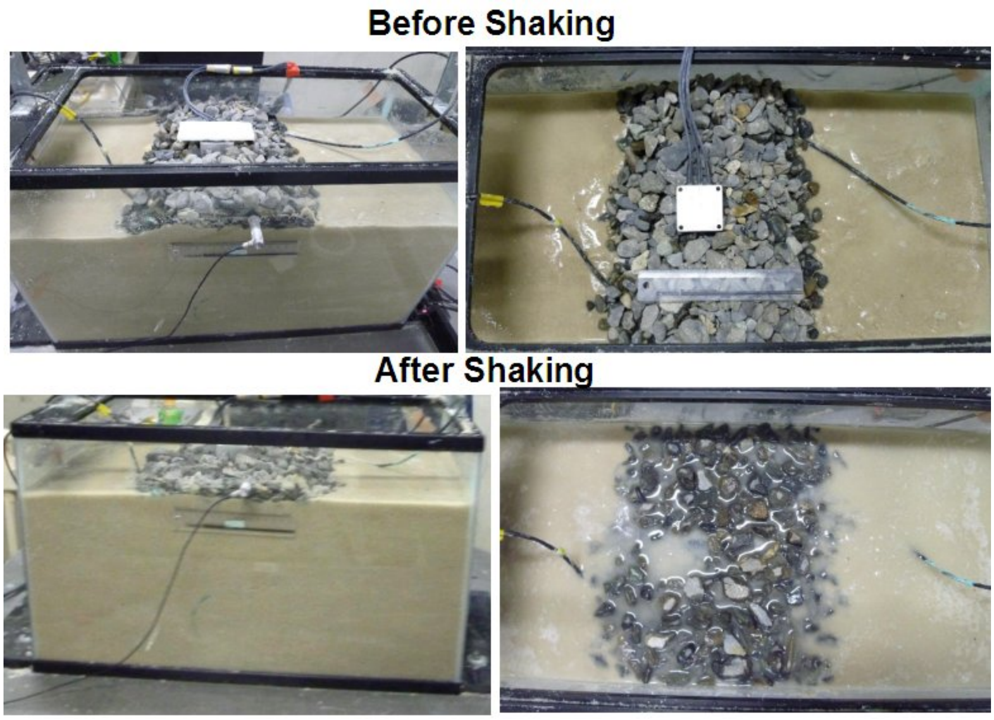


Figure 8.13. Views of a breakwater model before and after shaking experiment (after Aydan and Ohta, 2009).

8.4. Airports

The Van airport, also known as Ferit Melen Airport, has a 2750 m long runway along the shore of Van Lake. The airport is served by Turkish Airlines Company and other Major Turkish airline companies. In addition, there are also international flights to Iran and Azerbaycan. The earthquake did not cause any damage to its runway and it can be used for emergency operations immediately. However, some structural damage was caused to the old terminal building especially to its infill walls and window glasses were broken. Despite it was pointed out that ground liquefaction might be induced in the vicinity of lakeshore, there was no observation of any ground liquefaction in the premises of Van Ferit Melen Airport.

Figure 8.14. Views of runway and old and new terminal buildings of Van Airport suffered slight damage (note that the façade of the old terminal building thorn down before earthquake).

9. DAMAGE TO LIFELINES

The October 23, 2012 earthquake caused damage to lifelines particularly in Erciş. In this chapter, the damage to lifelines are briefly summarized as the duration of reconnaissance was too short for a detailed investigation.

9.1. Electricity

The electricity of Turkey is produced and distributed to main transformation stations by TEİAŞ. From these main transformation stations, the electricity is distributed to the cities and industrial facilities by TEDAŞ. These two originally state companies are now privatised owned. Figure 8.1 shows the electricity system of Turkey and the electricity network in the epicentral area.

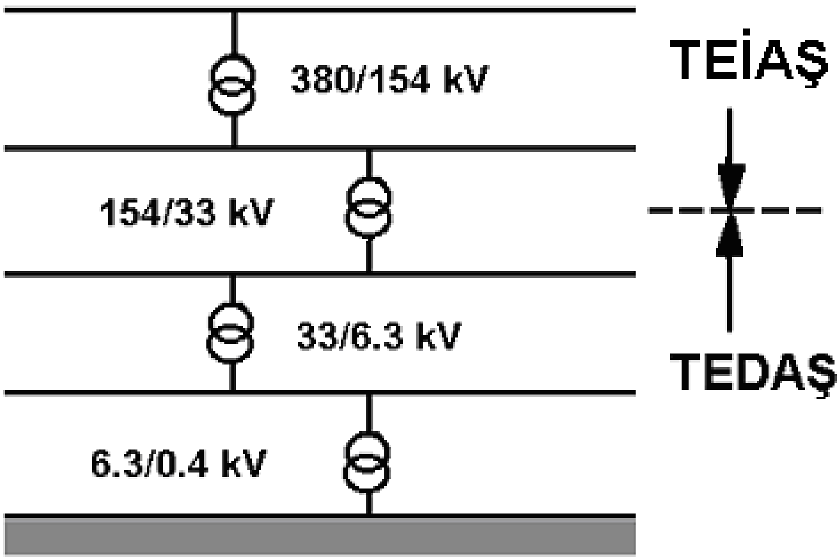


Figure 9.1. Electricity system of Turkey and the functions of TEİAŞ and TEDAŞ.

The major electricity producing facility is the Zernek1-2 Hydro-electric Power Plant. The region lost power shortly after the earthquake since it is customary to shut off the power as soon as a large earthquake happens. After some preliminary checks on the location of the earthquake, the power was gradually supplied to the region in order to prevent fires due to short circuits, which could be caused by the collapsed or heavily damaged structures. The power supply in Erciş was restored in 2 days for 70% and fully restored in 4 days after the earthquake except heavily damaged areas.

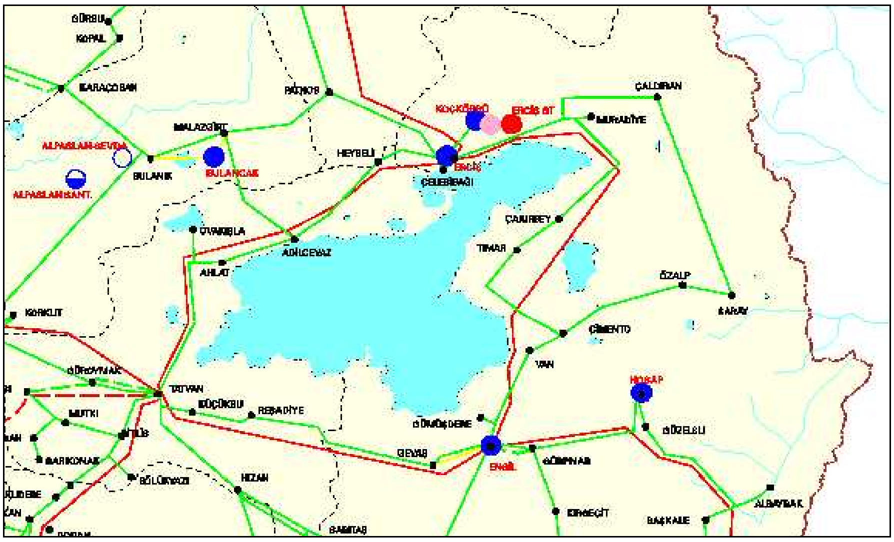


Figure 9.2. Electricity network in the epicentral area.

The earthquake did not cause the collapse of any of the sub-stations although some damage to some transformers of sub-stations occurred during shaking (Figures 9.3 and 9.4). A total of damaged 44 transformers were replaced and 12 transformers were added to the network in the epicentral area. However, the effects were minimal to these substations and they could be easily handled within a short period of time. Although most of transformers on the elevated utility poles were intact (Figure 9.5), some elevated transformers on pylons in the towns and cities were dislodged/fallen from their locations. An example of transformer damage by dislodging in Erciş is shown in Figure 9.6.

Figure 9.3. Non-damaged sub-stations in Erciş.

Figure 9.4. A non-damaged sub-station in Van.

(a) Alaköy (b) Van

Figure 9.5. Non-damaged elevated transformers.

Figure 9.6. Dislodged transformer on a utility pole in Erciş.

Some of poles and pylons of the electricity distribution system in Erciş and some villages were damaged as a result of ground shaking or foundation failure. Figure 9.7 shows some damage to a utility pole in Van and a utility pole with a transformer in Yeşilsu.

Figure 9.7. Tilted and bended utility poles in Van and Yeşilsu.

The electricity was back in the evening of the same day in Van city while it was back in the severly hit Erciş 4 days (26 October 2011, 90%) after the earthquake, except the regions where there were heavily damaged buildings. The 95% of the Erciş town had electricity restored on November 21, 2011 (Press Release of Van Province Governorship, 2011).

9.2. Water Supply and Water Distribution Networks

Water supply was stopped due to pipe damage in Van city following the October 23, 2011 earthquake. However, the damage to water supply network was quite limited by this earthquake. The November 9, 2011 earthquake caused more damage. The Van municapility had to change some major pipes with a diameter of 800 mm for a 225 m long connecting to No. 2 water reservoirs. This repair work was done on December 27, 2011 and water supply was shut-down for about 36 hours as a result (Figure 9.8) (Press Release of Van Municipality, 2011).

Figure 9.8. Repair work of water network of Van City (from Van Municipality, 2011).

The water supply system of Erciş was the most severely hit by the earthquake. Besides the damage to the pipe network in the downtown of Erciş, the pumping facilities at the source area near Işıklı village (5km away from Erciş) could not be operated due to the power blackout. The pump station pumps the spring water over a hill and then the distribution system runs under the gravity. The diameter of the main pipe with a total length of 10 km is 500 mm and it branches to 300 mm pipes along major distribution lines and then to 100 mm pipes beneath streets.

For an immediate supply of water to Erciş, first water tanks, provided by İstanbul Municipality Water Department *(İSKİ)*, were used with a set-up of smaller distribution systems (Figure 9.9). Later on, the fire department of İstanbul Municipality laid out a temporary network of a hose network, which could stand up to 3.5 MPa internal pressure, to supply clean water to the major distribution points until October 26, 2011 (Figure 9.10). The supplied water was chlorified for sanitation purposed at the major distribution points. The 95% water supply was achieved in to Erciş by November 28, 2011, except areas of collapses and heavy damages according the press release of the Van Province Governorship.

Figure 9.9. Emergency water supply in Erciş.

In some villages, there are some facilities to pump up the groundwater. Figure 9.11 shows such a facility in Alaköy village. The inspection of this facilities showed that there was no sign of damage to the facility.

Figure 9.10. Temporary water supply system set up by İstanbul Municipality Water Department .

Figure 9.11. A view of pumping facility in Alaköy.

9.3. Natural Gas Network

Aksa Van Gas company is the main supplier of natural gas to the region. No damage occurred in the of natural gas supply pipe network of Van City due to the October 23, 2011 earthquake. However, it was stopped as a result of power supply blackout following the earthquake.

The November 9, 2011 earthquake caused a disruption to the natural gas supply in Van City. The total number of natural gas household in Van city is 7153 in Van city. But they were reduced to 5440 households due to some slight damage to distribution network and the shutdown of 7 sub-units in areas where rescue and debris cleaning operations were underway due to the damage caused by the November 9, 2011 earthquake. The system is fully restored on November 21, 2011 according to the press release by the Van Province Governorship.

9.4. Seewage

The diameters of sewage pipes are 1600 mm and 1000 mm beneath boulevards and streets of large cities, respectively. The sewage system of Erciş was damaged due to severe ground shaking and lateral spreading (Figure 9.12), while the sewage system of Van City was almost non-affected. The damage assessment of the sewage system is the most difficult item in the overall damage assessment of lifeline facilities as they are buried. The systems were checked systematically through water flow states at manholes in the cities, towns and villages. If there was any blockage, they were repaired. However, some damage may undergo unnoticed unless an indication of damage in the form of ground cave-in takes place or material or smell leaks out of the ground.

Figure 9.12 Repair work of sewage in Erciş

9.5. Telecommunications

The TÜRK-TELEKOM and other private companies run the telecommunication system in Turkey. During the earthquake, the main buildings of the TÜRK-TELEKOM were lightly damaged as seen in Figure 9.13. However, the relay towers of the system were almost non-damaged. Nevertheless, some telephone lines were damaged as a result of toppling of the poles of the system caused by the collapse of nearby buildings. The telephone service was not quite well functioning for three days due to the congestion of phones to the region as expected. Mobile units and first aid telephone lines were set up by the TÜRK-TELEKOM and other private telephone companies and they were free of charge soon after the earthquake, including all public telephones (Figure 9.14).

Figure 9.13. Slightly damaged main building of the TÜRK-TELEKOM in Erciş.

Figure 9.14. A view of a mobile telecomunication unit of TÜRKCELL in Erciş.

10. GEOTECHNICAL ASPECTS OF THE EARTHQUAKE AND ASSOCIATED GROUND FAILURES AND DAMAGES

The 2011 Van-Erciş earthquake caused an extensive liquefaction and associated ground failures particularly on the plains along the eastern shore of Van Lake and between Van and Erciş, and in the close vicinity of Erciş town. The liquefaction and associated ground failures resulted from lateral spreading, particularly, close to river beds and lake shore led to damage to some residential houses, embankments and some bridges. In addition, slope instabilities in different sizes also occurred at some locations. In this chapter, first, local site conditions, which have important effects on liquefaction and associated geotechnical damages, were briefly outlined based on the findings in the previous geotechnical studies performed in Van city, Erciş town and their close vicinities. Then observations performed by the authors at different parts of the earthquake-affected region, evaluations on grain size distributions of the samples collected from ejected sands and silty sands and the lateral spreading induced by ground liquefaction, slope instabilities and associated geotechnical damages observed after the earthquake are given and discussed.

10. 1. Local Site Conditions

As mentioned in Chapter 2, the Holocene deposits in the region mainly consist of alluvial fan deposits, lacustrine-fluviatile deposits and debris material including loosely-to-moderately cemented gravel, sand, silt and unconsolidated clay horizons, and groundwater table is generally shallow-seated (Selçuk and Çiftçi, 2007; Özvan et al., 2005, 2008).

Selçuk and Çiftçi (2007), who investigated the liquefaction potential of the Plio-Quaternary soils in the Yüzüncü Yıl University campus area located at the north of Van city center, classified these soils into for units such as lacustrine, lacustrine-fluviatile, shore-sand and recent fluviatile sediments with very low p-wave velocities (V_p) varying between 120 and 516 m/s. The lacustrine sediments (phase-1 soils) mainly consist of silty and clayey soils of CL and CH classes. Lacustrine-fluviatile soils (phase-2 soils) are composed of fine-grained soils including silty sand layers and thin gravel layers. The shore-sand sediments (phase-3 soils) are poorly graded sands with N_{60} values ranging between 13 and 41. These soils with a maximum thickness of 9-10 m observed in the central part of the campus area have fine-grained material less than 5% and the groundwater level is near the surface making them susceptible to liquefaction. The recent alluvial soils (phase-4 soils) along the ancient and recent rivers and streams are mainly composed of well and poorly graded gravel with sand and silt layers. Typical grain size distribution curves of sandy soils in this sequence together with the boundaries of lower and upper limits for liquefiable soils are shown in Figure 10.1. It is clear from this figure that these sandy soils are generally susceptible to liquefaction in terms of their grain size distributions. This condition was also confirmed by the factors of safety against liquefaction calculated (an earthquake scenario based on M=6.5 earthquake and a peak ground acceleration of 400 gal) by Selçuk and Çiftçi (2007) as shown in Figure 10.2. These investigators also prepared liquefaction potential map of the campus area using the liquefaction potential index (I_L) and I_L classification proposed by Iwasaki et al. (1982). This map (Figure 10.3) suggests that the soils in the central part of the campus area have high liquefaction potential.

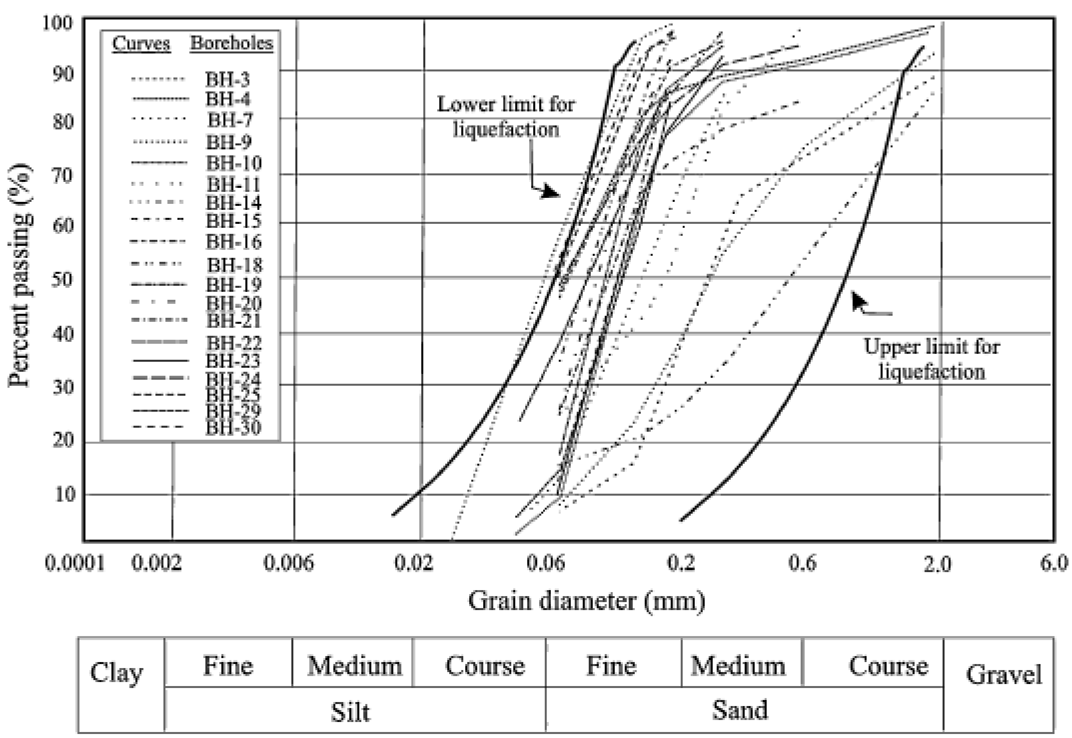


Figure 10.1. Typical grain size distribution curves of sandy soils in Yüzüncü Yıl University campus area and the upper and lower bounds for liquefiable soils (Selçuk and Çiftçi, 2007).

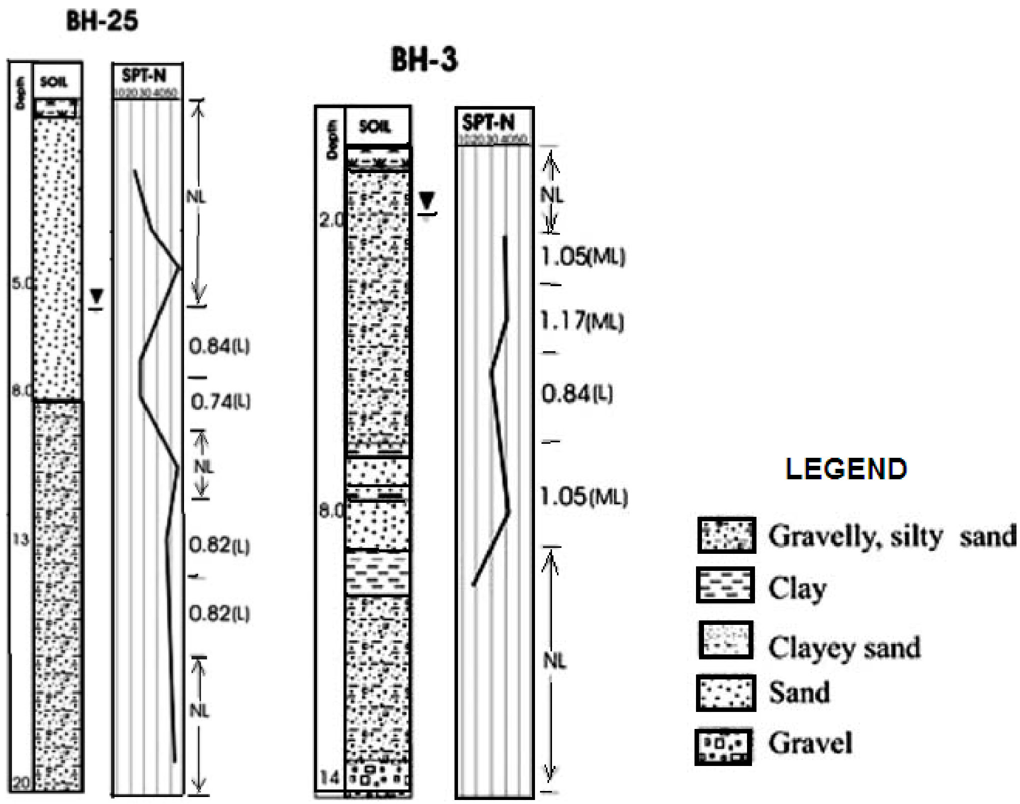


Figure 10.2. Results of liquefaction analyses of two selected boreholes at the Yüzüncü Yıl University campus area (L: Liquefiable, NL: Non-liquefiable, ML: Marginally liquefiable) (Selçuk and Çiftçi, 2007).

A preliminary evaluation by Ulusay (2000), based on the data from 12 boreholes drilled at the Yüzüncü Yıl University campus area in 1984 and grain size distribution curves, the presence of some loose and fine sand layers at depths between 5.5 and 12.5 m was found. The thickness of the sand layers increases towards west to the lake shore. In addition, the data from the boreholes also indicated some dense sand pockets between clay layers. According to the limited number of boreholes, the SPT-N values generally range between 10 and 20, however, at some depths they reach up to 30-35. The grain size distribution curves of the samples taken from sandy layers suggest that they have low amount of fines and fall between the upper and lower bounds of the grain size curves for liquefiable soils. The depth of groundwater measured in 12 boreholes ranges between 2.55 and 14 m, however, it is generally between 5.5 and 9 m. Figure 10.4 shows the locations of liquefaction sites observed during historical and instrumental periods in Turkey. This map, which has been constructed based on the records, observations and the data from literature (Aydan et al., 2000; Ulusay et al., 2000), shows that liquefaction has also occurred at the eastern part of

Van Lake during the historical earthquakes and the soils in this region are prone to liquefaction.

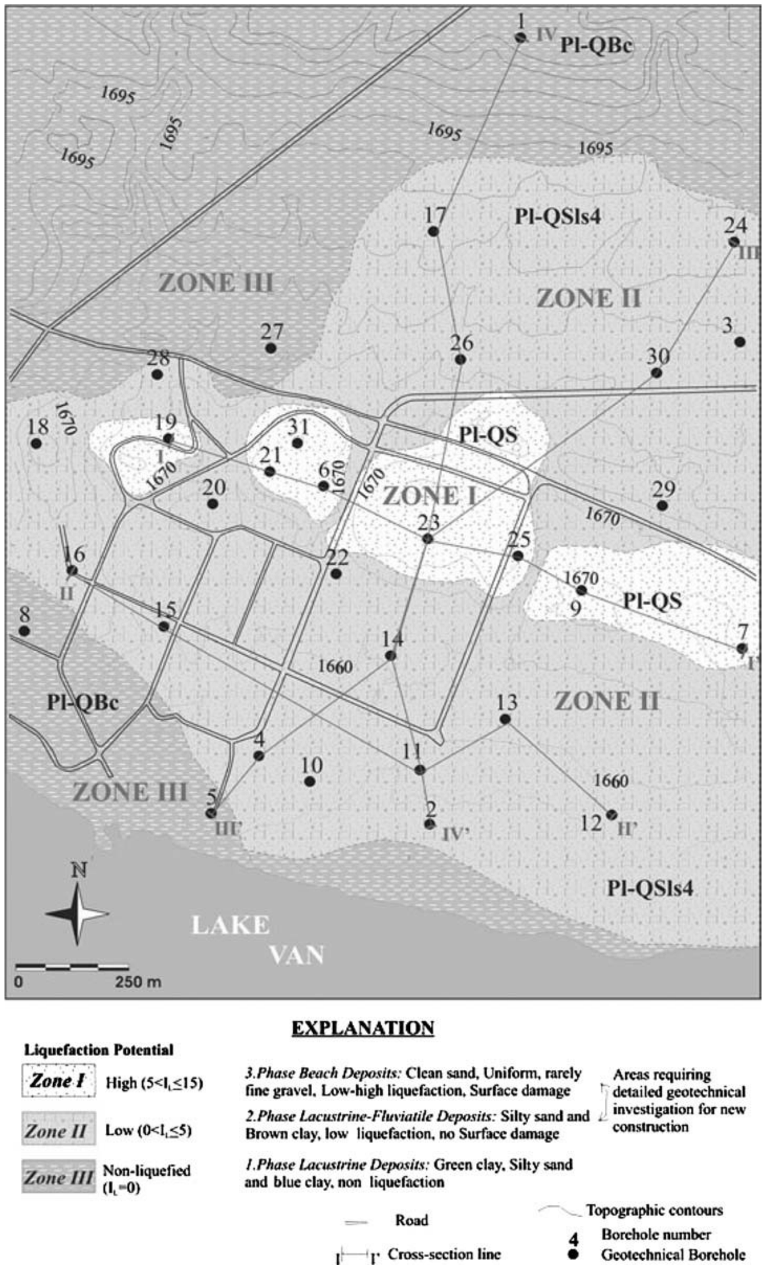


Figure 10.3. Liquefaction potential map of the Yüzüncü Yıl University campus area (Selçuk and Çiftçi, 2007).

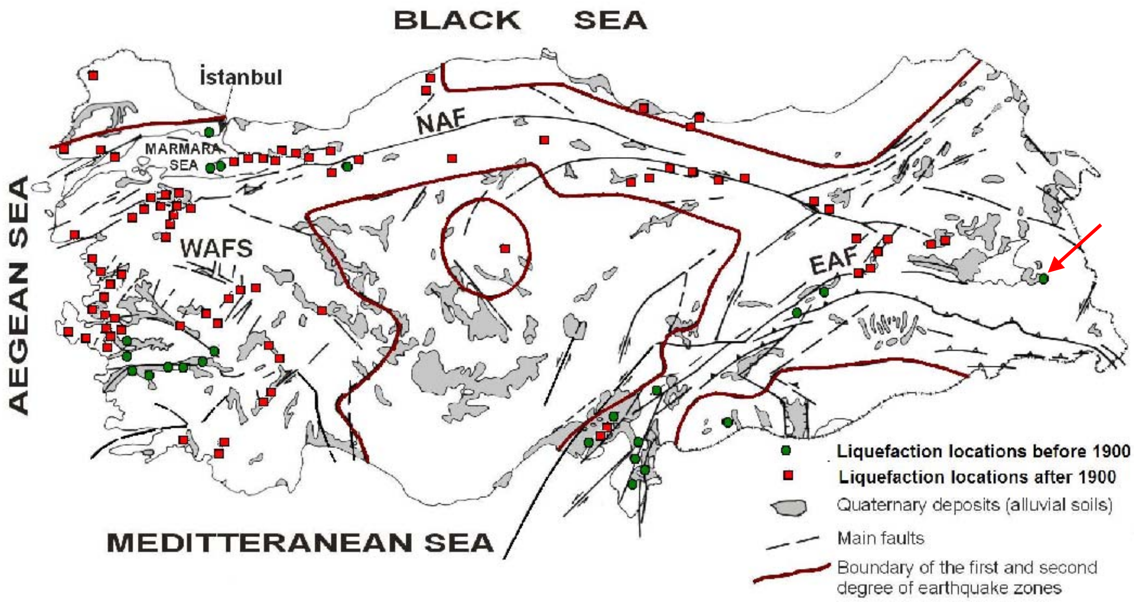


Figure 10.4. The locations where liquefaction has been observed in Turkey during historical (before 1900) and instrumental (after 1900) periods (Aydan et al., 2000; Ulusay et al., 2000).

The geotechnical boreholes drilled in the settlement area of Van city by Özvan et al. (2005) showed that this area also takes place on the Quaternary lacustrine and fluviatile sediments. A view from these deposits taken by the authors of this report during the reconnaissance after the Van-Erciş earthquake in the city centre of Van is given in Figure 10.5.

Figure 10.5. A view from the Quaternary sediments in the city centre of Van.

These loose sediments have aquifer characteristics and their thickness reach up to about 45 m at the central part of Van city center. Based on this study, the SPT N_{60} values are between 20 and 46, 18 and 40, and 14 and 28 between the depths of 3 and 3.45 m, 6 and 6.45 m, and 9 and 9.45 m, respectively, indicating that the soil sequence is moderately dense. These investigators also mentioned that some sand layers in this area seem to be susceptible to liquefaction in terms of their grain size distributions (Figure 10. 6). The P-wave velocities (V_p) measured in the Van settlement area are low and range between 182 and 551 m/s and 384 and 1024 m/s for the upper and second layers involved in the Quaternary sequence, respectively. Particularly towards the lake shore, the values of V_p show a clear tendency to decrease (Figure 10.7). Due to this, Özvan et al. (2005) concluded that shaking will be considerably felt in this settlement during an earthquake.

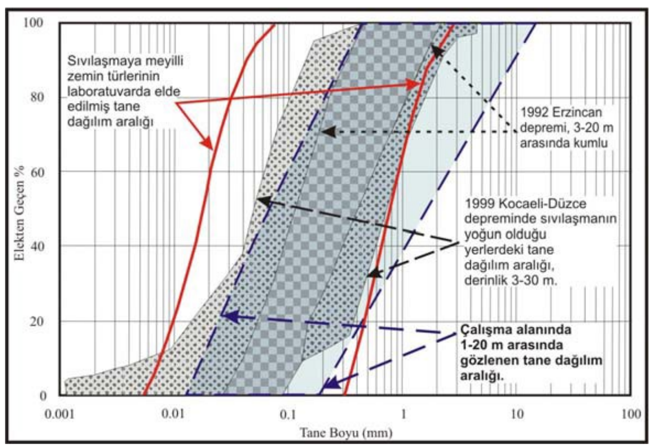


Figure 10.6. Comparison of the grain size distribution curves of the soils in Van city with the upper and lower bounds for liquefiable soils (Özvan et al., 2005).

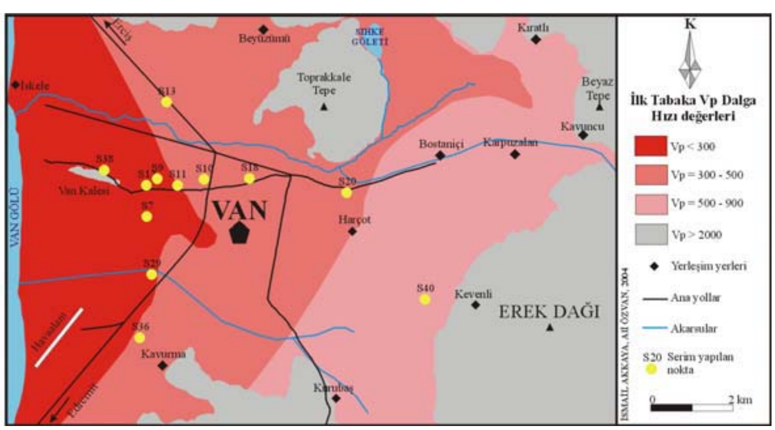


Figure 10.7. P-wave velocity map of the city of Van (Özvan et al., 2005).

Geotechnical properties and liquefaction susceptibility of soil grounds in Erciş town and its close vicinity, which are located in the Erciş Plain at the northern shore of Van Lake, were also investigated by Özvan et al. (2008). As explained in Chapter 2, depth of groundwater in this plain is between 0 and 12 m and artesian conditions prevail in some wells. The average thickness of the Quaternary and Plio-Quaternary sequence varies between 10 and 240 m and it increases towards the central part of the plain. The values of N_{60} obtained from sandy and silty layers penetrated by 18 geotechnical boreholes are less than 20 in the areas close to Van Lake and about 25 at the northern part of the area (Figure 10.8). The coarse grained soils in this area are generally represented by poorly graded sands and silty sands falling in SM soil class indicating that they have liquefaction potential in terms of their grain size distributions (Figure 10.9). The factors of safety against liquefaction (F_L) for this area calculated by Özvan et al. (2008) were smaller than unity indicating that liquefaction potential of the soils in Erciş town and its close vicinity seems to be high (Figure 10.10).

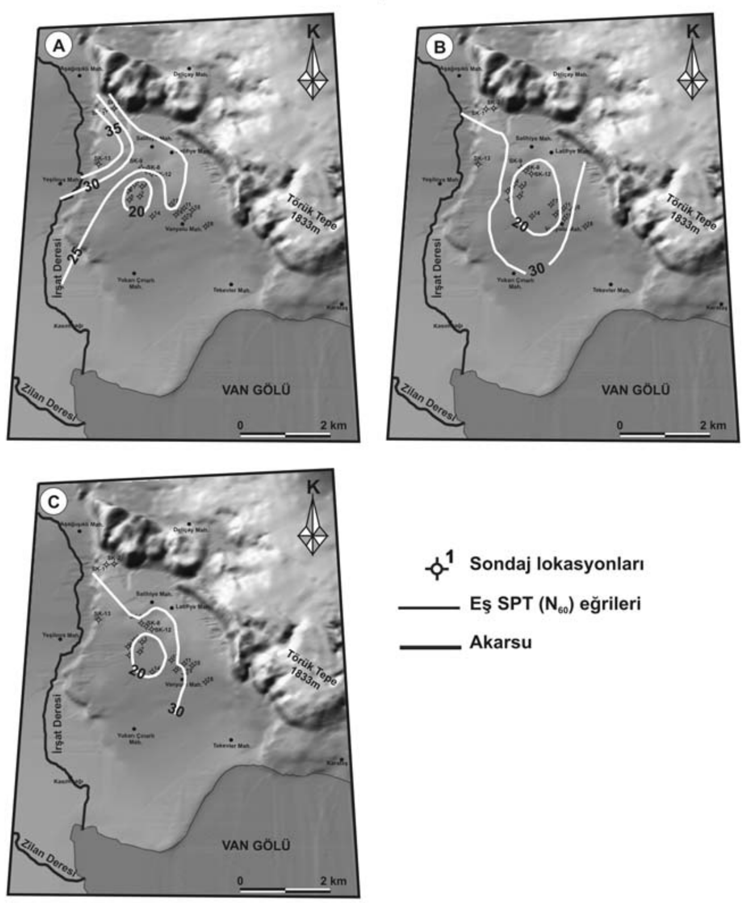


Figure 10.8. SPT N_{60} contour map of the Erciş Plain for the depths between (A) 3.00-3.45 m, (B) 6.00-6.45 m and (C) 9.00-9.45 m (Özvan et al., 2008).

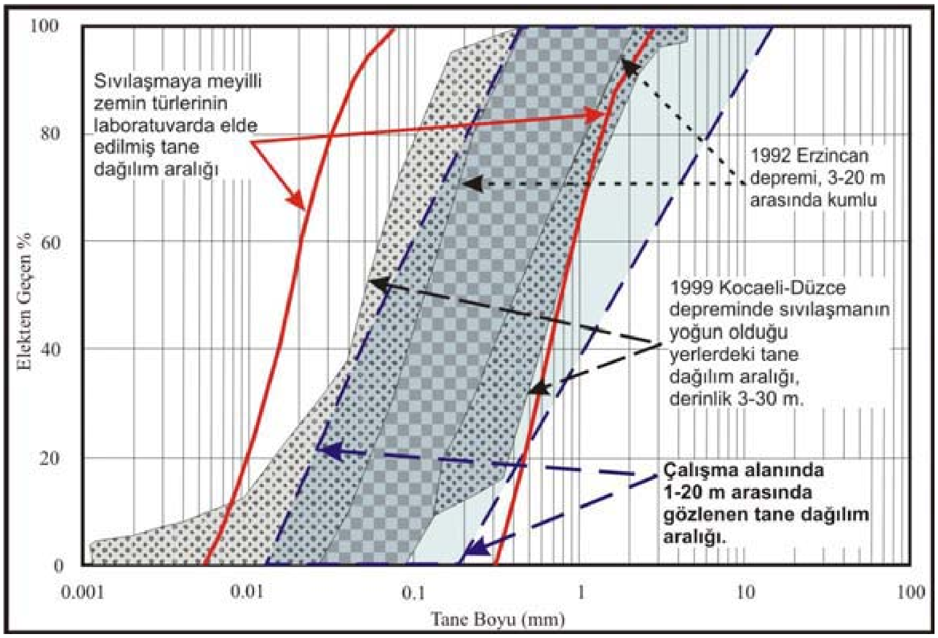


Figure 10.9. Comparison of the grain size distribution curves of the coarse grained soils in Erciş and its close vicinity with the upper and lower bounds for liquefiable soils (Özvan et al., 2008).

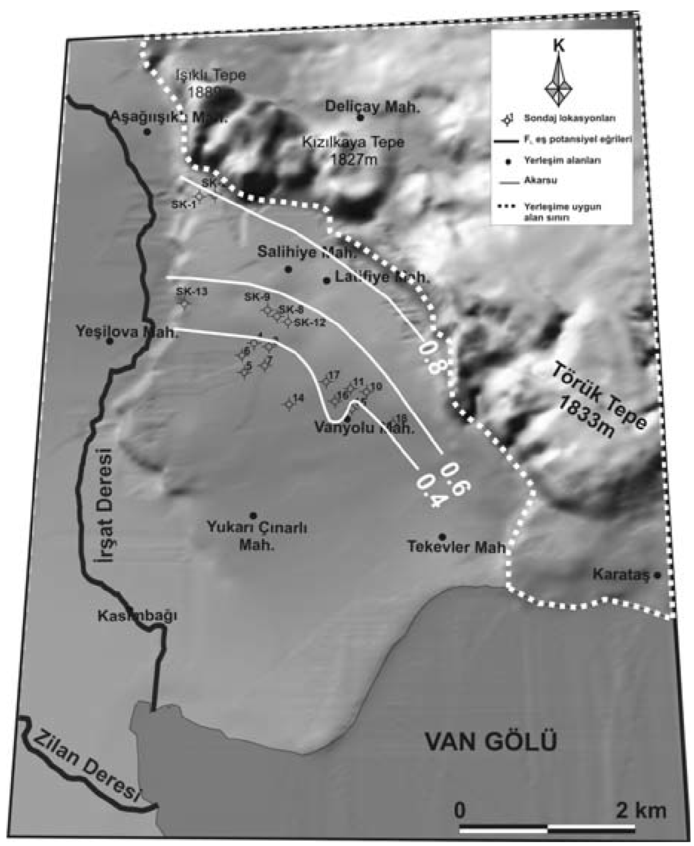


Figure 10.10. Contours of factor of safety against liquefaction for Erciş town (Özvan et al., 2008).

The local site conditions briefly mentioned above indicate that the Holocene deposits of the earthquake-affected region seem to be susceptible to liquefaction under dynamic loads generated by earthquakes

10.2. Liquefaction and Associated Ground Failures

10.2.1 Liquefaction and its effects on structures

In this earthquake, liquefaction and associated ground deformations were evident and widespread sand boils and liquefaction fissures were observed particularly in Erciş Plain (Çelebibağı and Kasımbağı villages, and along Zilan stream) at the northern part of Van Lake and the flood plain of the Karasu River (Topraktaş, Arısu, Göllü, Tevekli, Çitören, Mollakasım Güvençli and Alaköy villages), Van Port and Esenkıyı at the north of Van city, and alluvial shore plains. Lateral spreading was quite extensive at Çelebibağı (west of Erciş) and Topraktaş (at NW of Van city) villages. Some of these liquefaction locations were visited by the authors during the reconnaissance and the information for the other liquefied sites were compiled from the quick reports of various investigators. The locations of the liquefied sites and associated lateral spreading are shown in Figure 10.11.

One of the sites, where widespread liquefaction was observed, is the Van Port (Figure 10.12a). In this area, there were evident sand boils with different diameters, reaching up to a maximum value of 160 cm, and fissures (Figure 10.12b). Ejected sands were also commonly observed along the contacts of the pavement stones between the rails (Figure 10.12c). Clear evident of liquefaction-associated settlements with a vertical displacement of about 5 cm are also observed at the station and quay wall (Figure 10.12d).

Settlement of a bridge at the southern entrance of Topraktaş village (Figure 10.13a) and sand boils and fissures and lateral spreading along the Karasu (Evlengaz) Stream flowing under this bridge were the clear evidences of liquefaction (Figure 10.13b,c). In addition, common liquefaction sand boils were also observed on a flat area about 1 km far from this village, between the stream and road (near Topraktaş-Arısu road).

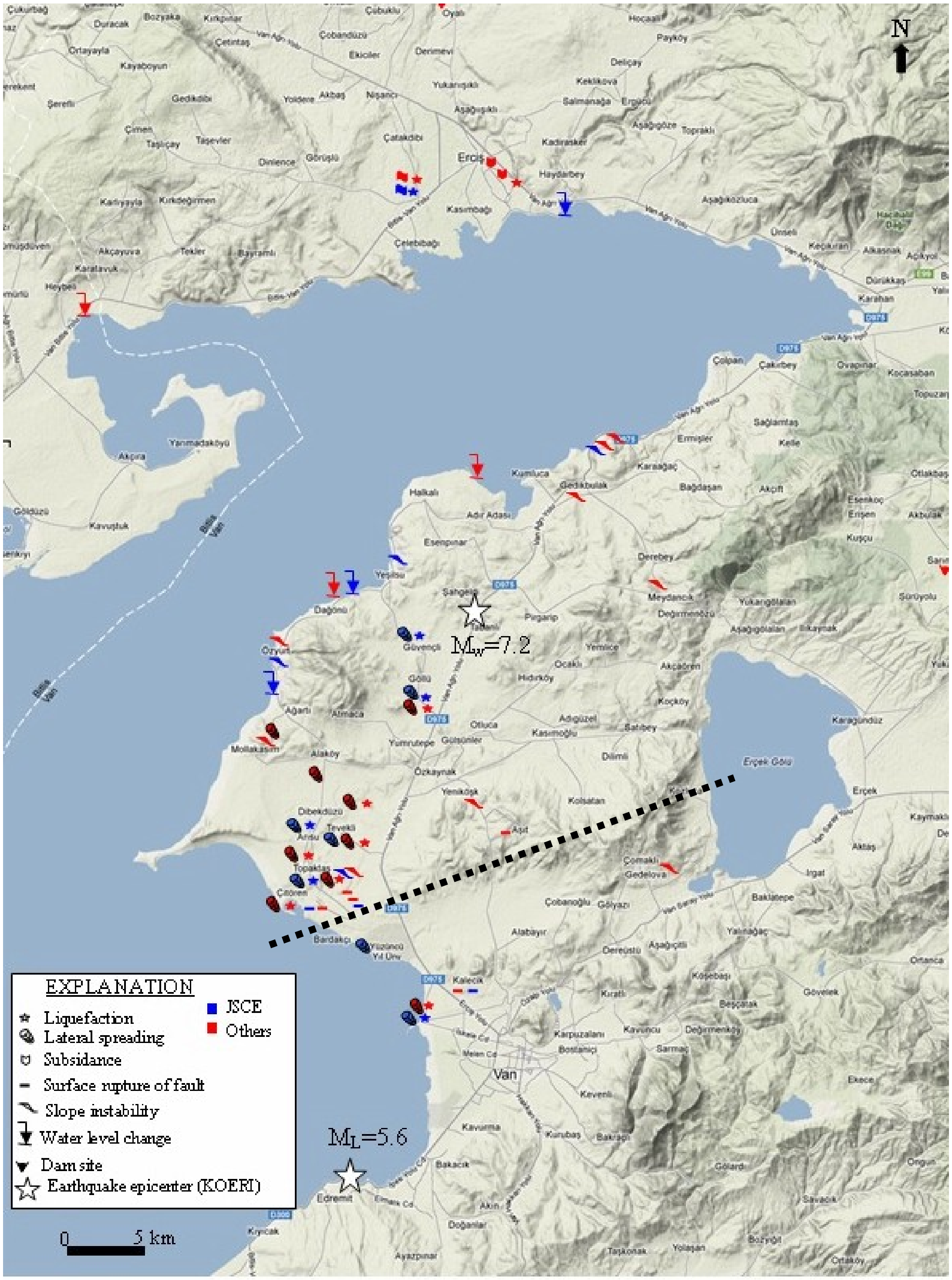
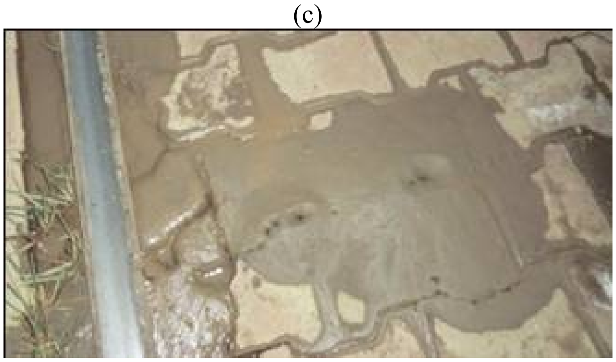


Figure 10.11. Map showing the geotechnical aspects, surface rupture of the Van-Erciş earthquake with water level changes in Lake Van.

(a)

(b)

(c)



(d)

Figure 10.12. (a) A view from Van port, (b) liquefaction fissures and sand boils, (c) settled station building and (d) ejected sand along the contacts of pavement stones between rails (Van Port).

(a)

(b) 

(c)

Figure 10.13. Views from liquefaction in Topraktaş village: (a) a bridge settled due to liquefaction, (b) liquefaction fissures parallel to the Evlengaz Stream, (c) sand boil.

In this area, the sand boils and fissures were oriented parallel to the stream (Figure 10.14). The local people emphasized that ejected soil and water raised up to 4-5 m to the surface during the earthquake at this flat area. Based on visual inspections, the ejected sands in this area have similar characteristics with those observed at the southern entrance of Topraktaş village and also involve very small-sized pebbles. Since there is no any structure located in this area, liquefaction-induced damages did not occur.

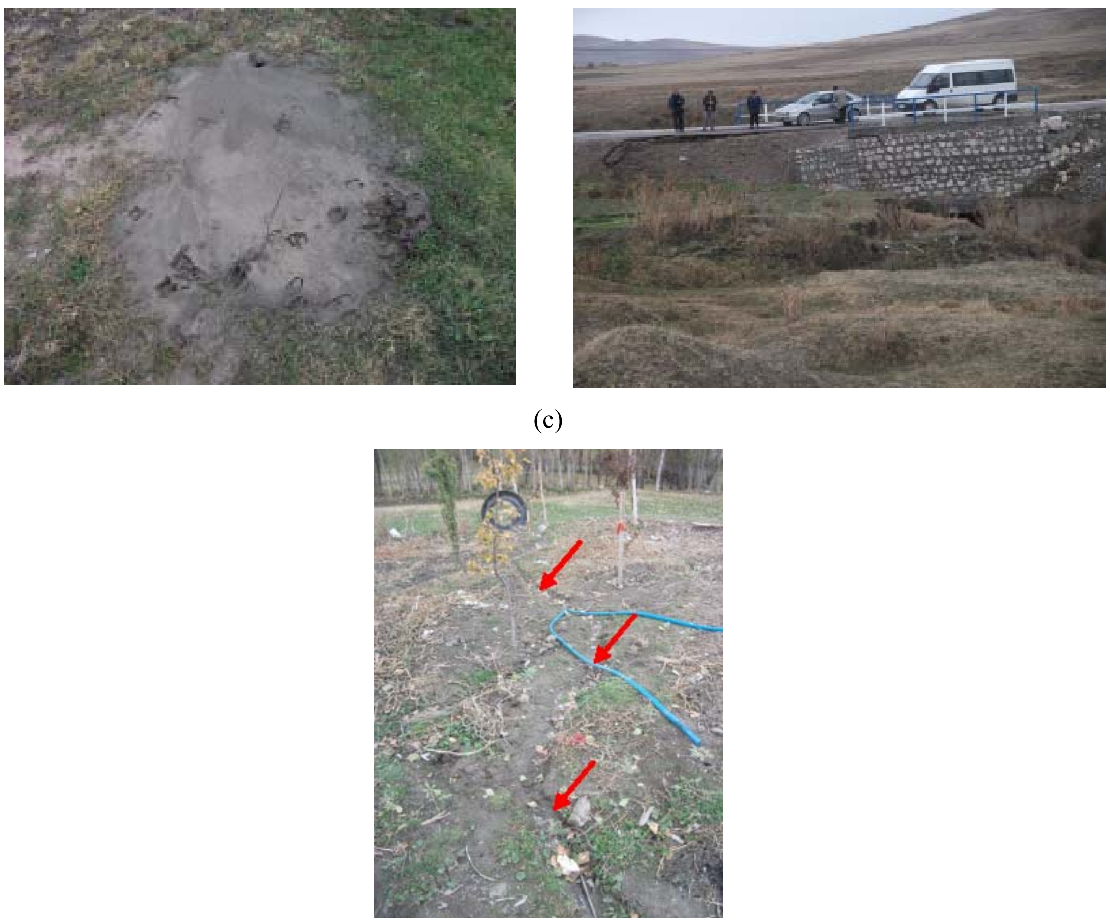
(a) (b)

Figure 10.14. (a) Liquefaction and (b) liquefaction fissures occurred near the road between Topraktaş and Arısu villages.

One of the other important liquefied sites is located about 1 km south of Göllü village (near the road between Göllü and Güvençli villages). At this location, in addition to sand boils (Figure 10.15a), the bridge on the road and the water canal were affected by liquefaction (Figure 10.15b). Although sand boils are not observed, ground cracks parallel to the water canal also indicate liquefaction in Güvençli village (Figure 10.15c).

Çelebibağ village, particularly its İnönü district, which is located in the Erciş Plain at the west of Erciş town, is the location considerably affected by liquefaction. Although some ejected sands filling the fissures are observed at limited number of locations, widespread lateral spreading cracks and associated ground movements were the main evidents of liquefaction at this site (Figure 10.16). Based on the information from local people and surface observations by the authors, Çelebibağ village is situated on a soil sequence consisting of a sand layer at the top which is underline by a clay layer and a second sand layer. But the order of the layering changes at some locations and the clayey soil represents the cap soil. Probably due to the presence of a clayey cap soil and probably the occurrence of liquefaction in the underlying sand layer, sand boils are not commonly observed in this site. In addition, a crack and settlement on the right abutment of the bridge on the İrşat Stream crossing the road between Erciş and Adilcevaz indicate liquefaction (Figure 10.17). Sand boils in the alluvium of this stream near to the bridge was also reported by Çetin et al. (2011).

(a) (b)



(c)

Figure 10.15. (a) Sand boil and (b) a bridge damaged due to liquefaction on the road between Göllü and Güvençli villages, (c) liquafaction in Güvençli village.

(a)

(b)

Figure 10.16. (a) Lateral spreading crack filled by ejected sand, (b) sand boil (Çelebibağ village).

Figure 10.17. Crack and settlement on the right abutment of the bridge on the İrşat Stream between Erciş and Adilcevaz indicate due to liquefaction.

As mentioned in Section 10.1, Özvan et al. (2008) considered the maximum ground acceleration as 0.35 g and evaluated the liquefaction potential of Erciş town and its close vicinity using the borehole data. They found that the ground, on which Erciş town is located, would liquefy entirely (Figure 10.10). On the contrary to their findings, no widespread liquefaction has been experienced in Erciş during the Van-Erciş earthquake. It is also very difficult to verify the estimations by Özvan et al. (2008) as there was no strong motion record at Erciş. As the maximum ground acceleration recorded in Muradiye town (at the east of Erciş) was 0.2g, it is expected that some partial liquefaction might occur. The settlement of some buildings (Figure 10.18), reported and observed in Erciş town, may imply partial liquefaction did occur. İTÜ (2011) also conclude that some settlements observed in the vicinity of Clock Tower in Erciş town are probably due to softening and collapsing of the soil ground.

Figure 10.18. Settlement of a building probably due to liquefaction in Erciş town (after JMO, 2011).

Selçuk and Çiftçi (2007), who evaluated the liquefaction potential of the soils in the campus area of Yüzüncü Yıl University, estimated that the central part of the campus has high liquefaction potential, and the area between the central part and the lake shore line has low liquefaction potential based on an earthquake scenario (M=6.5 and a_{max}= 400 gal) (Figure 10.3). Except a limited area at the University Port, no evidences of liquefaction were observed in this area. As there was no strong motion record for Van, it is extremely difficult to verify the estimations by these investigators. However, some movements probably due to lateral spreading on the breakwater of the University Port on the lakeshore (Figure 19) indicate that some partial liquefaction might have occurred which may partly confirm the liquefaction estimations by Selçuk and Çiftçi (2007). In addition, pipe breaks at many locations in the water transmission system of Yüzüncü Yıl University due to ground settlement were reported by KOERI (2011).

(a) (b)

(c)

Figure 10.19. Movements probably due to lateral spreading on the breakwater of the University Port.

Some pictures from the other liquefied sites, to which the authors of this report couldn't visit due to limited time, were compiled from the reports of various reconnaissance teams and are shown in Figure 20. İTÜ (2011), Akyüz et al. (2011) and JMO (2011) reported liquefaction and lateral spreading occurred in an area 3 km far from Alaköy village (Figure 20a). Based on the interview by the ITÜ reconnaissance team (İTÜ, 2011) with local people, at this locality, liquefied soil and water raised up to a few meters above the surface during the main shock.

10.2.2. Lateral spreading and its effects on structures

In this earthquake, most important effect of liquefaction was the lateral spreading of the ground, particularly along river and streambeds and partly lakeshore. Lateral spreading cracks and resulted ground deformations are generally observed at most of the liquefied sites mentioned in sub-section 10.2.1. Lateral spreading was particularly quite extensive in

Çelebibağ and Topraktaş villages and their close vicinities. The locations of the lateral spreading sites were also shown in Figure 10.11.

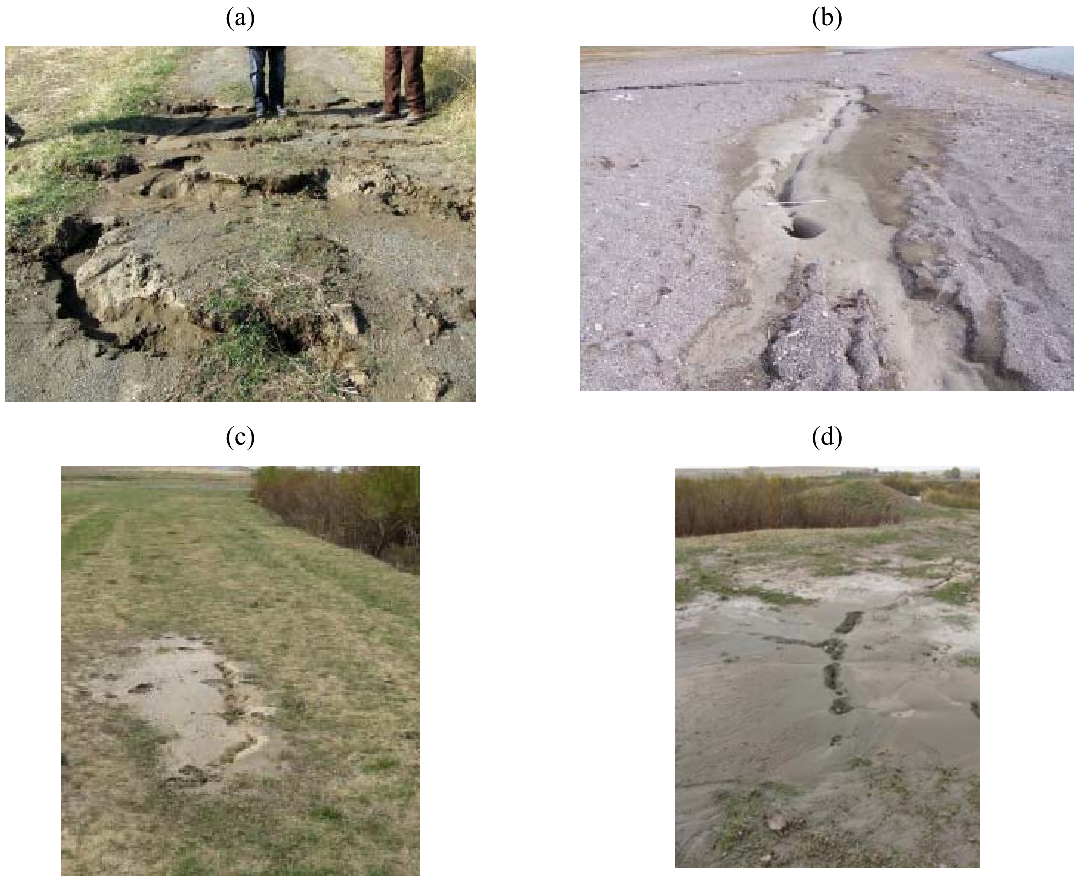


Figure 10.20. The some other sites where liquefaction observed: (a) Alaköy (JMO, 2011), (b) Esenkıyı (Göldüzü) (Emre et al., 2011), (c-d) Tevekli (Akyüz et al., 2011).

The ground cracks resulted from lateral spreading at the Van Port were in N-S direction parallel to the lake shore, and as also confirmed by the port personnel, a relative movement on the quay wall was observed (Figure 21a, b). The length of some cracks reached up to 70 m and the separation of the cracks were between 1 and 5 cm (Figure 10.21c). At the Van Port, lateral spreading also caused separation between the rails about 15 cm (Figure 10.21d).

(a)

(b)

(c)

(d)

Figure 10.21. (a-b) Evidences of relative movement of the quay wall (c) separation of 5 cm lateral spread crack, (d) separation between rails due to liquefaction at Van Port.

Lateral spreading occurred particularly along the left bank of the Evlangaz Stream near Topraktaş village resulted in ground cracks filled by the ejected sand with a direction of N75E parallel to the stream (Figure 10.22a). Based on the measurements by the authors between these cracks, a total displacement of 1 m due to lateral spreading was found at this locality. The lateral spreading cracks on the plain at the southern entrance of Topraktaş village occurred between the Topraktaş-Arısu road and the stream (Figure 10.22b). The total displacement at this location was measured about 80 cm and the trend of the cracks was N70W parallel to the stream. Except the bridge on the Evlangaz Stream (Figure 10.13a), fortunately, since there is no any settlement and structure in this area, no geotechnical damaged occurred.

(a) (b)

Figure 10.22. Lateral spreading cracks parallel to Evlangaz Stream; (a) Topraktaş village and (b) near the road between Topraktaş and Arısu.

The bridge and water canal on the road between Göllü and Güvençli villages were damaged by lateral spreading. The ground cracks resulted from lateral spreading were in N-S direction and caused failures on both banks of the water canal and damage (cracks on the culvert) to the bridge (Figure 10.23). The separation between the lateral spreading cracks was about 20 cm. The bridge suffered more damage due to settlement and rotation and more tilting of its abutments, as well as the extensive cracking and settlement of approach abutments due to ground liquefaction.

Çelebibağ village, at the west of Erciş town, is the most important site where widespread lateral spreading occurred and resulted in heavy damages to residential houses, a concrete water canal (Figure 10.24a-c). The area affected by lateral spreading is approximately 350 m long and 150 m width. The trend of lateral spreading cracks was in N-S and/or N20S direction. In this area, the total displacement, which was induced by lateral spreading approximately towards south and measured from the ground cracks by the authors, was 1.5 m and inclination of the ground was 3^0 (Figure 10.24d). In addition, some localized damages to buried water pipes in Çelebibağ village due to lateral spreading were also reported by KOERI (2011). On the other hand, the piers and abutments of the Evlangaz Bridge, on the road between Van and Ağrı cities (100 m west of Van E-type prison), was slightly damaged due to settlement and lateral spreading of ground (Figure 10.24e).

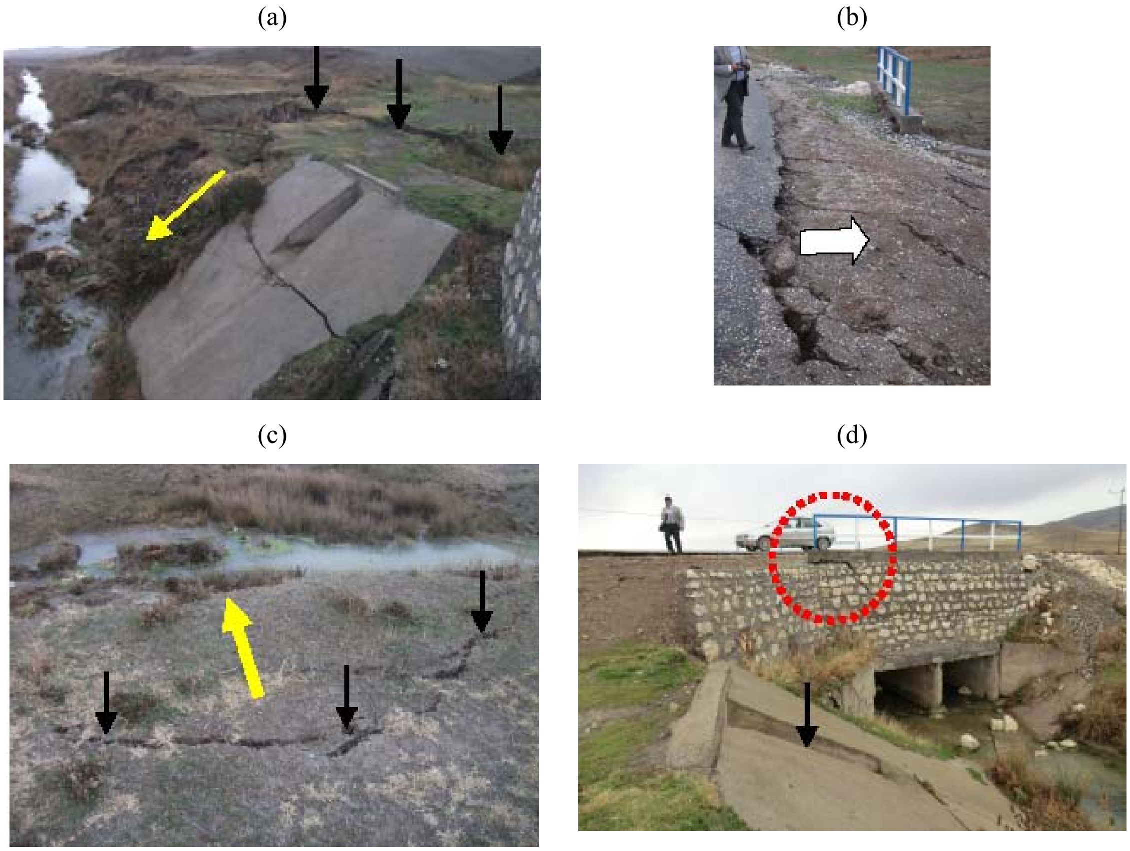


Figure 10.23. Damages to the road bridge and water canal between Göllü and Güvençli due to liquefaction and lateral spreading.

10.2.3. Evaluation of liquefaction and lateral spreading

The authors have gathered some samples from sand boils observed during the reconnaissance (Figure 10.25a). Generally the ejected soils were in gray color and composed of sand, silty sand and sand with low amount of small pebbles. These samples were collected from Van Port, Çelebibağ, Topraktaş and Göllü villages. Besides, additional ejected sand samples were obtained from Dibekdüzü and Mermit meadow by Dr. Onur Köse of Yüzüncü Yıl University to be used in this study. Their grain size distribution analyses, using sieve and hydrometer methods, were carried out in the soil mechanics laboratories of Hacettepe and Pamukkkale Universities. It is clear from Figure 10.25b that, although some samples have high fine content, they are still within the easily liquefiable bounds.

Figure 10.24. Lateral spread and resulted damages in Çelebibağ village: (a) damaged canal, (b-c) damaged residential houses and (d) movement and cracks due to lateral spreading, and (e) damage to piers and abutments of the Tirleşin Bridge due to settlement and lateral spreading of ground.

(a)

(b)

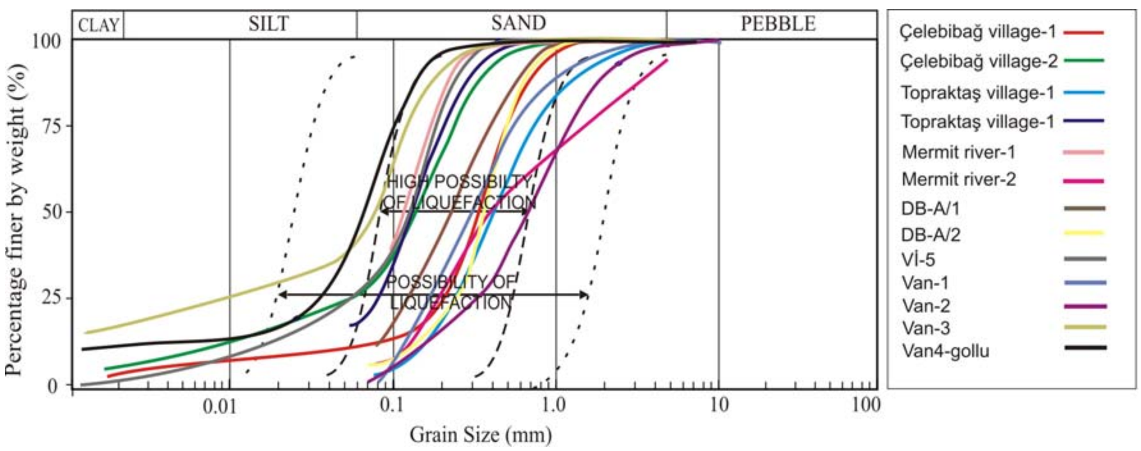


Figure 10.25. (a) Sampling from ejected sand (Van Port), (b) comparison of grain-size distributions of the samples obtained from liquified soils in various sites of the erathquake-affected region with known bounds for liquefiable soils (Port and Harbour Research Institute, Japan, 1997).

Aydan et al. (1998) compiled some data on the locations of earthquakes and developed some empirical relationships between magnitude of earthquake and hypocenter distance for liquefaction and non-liquefaction sites. These relationships are given in Fig. 10.26. The empirical lines in this figure may also be regarded as non-liquefaction to light, light to moderate to severe liquefaction boundaries in Turkish earthquakes. Figure 10.26 shows empirical relations for the magnitude and hypocenter limit distance for liquefaction with observations carried out by the authors after the Van-Erciş earthquake. The observations fall into the domain of liquefaction predicted by empirical relations proposed by Aydan et al. (1998) and Aydan (2007). It should be noted that the relations by Aydan (2007) considers the position of observation point with respect to the earthquake fault.

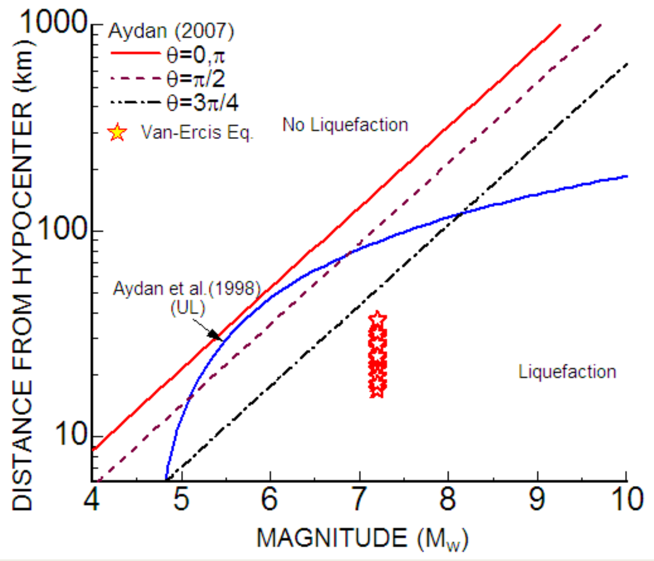


Figure 10.26. Comparison of empirical relations for magnitude and liquefaction limits with observations at liquefied sites performed in the earthquake region.

Aydan et al. (2008) proposed an approach to estimate amount of lateral spreading using the strong motion records. A sample computation was carried out for different base inclination of liquefiable layer using the records at Muradiye strong motion station and results are shown in Figure 10.27. The amount of lateral spreading is about 69 cm for an inclination of 3% while it becomes about 19 cm for the inclination of 1%. As the inclination of liquefiable layer was probably more than 3% at Çelebibağı (Erciş) (Figure 10.24d), these computational results can explain the possible reason for large deformation at that locality.

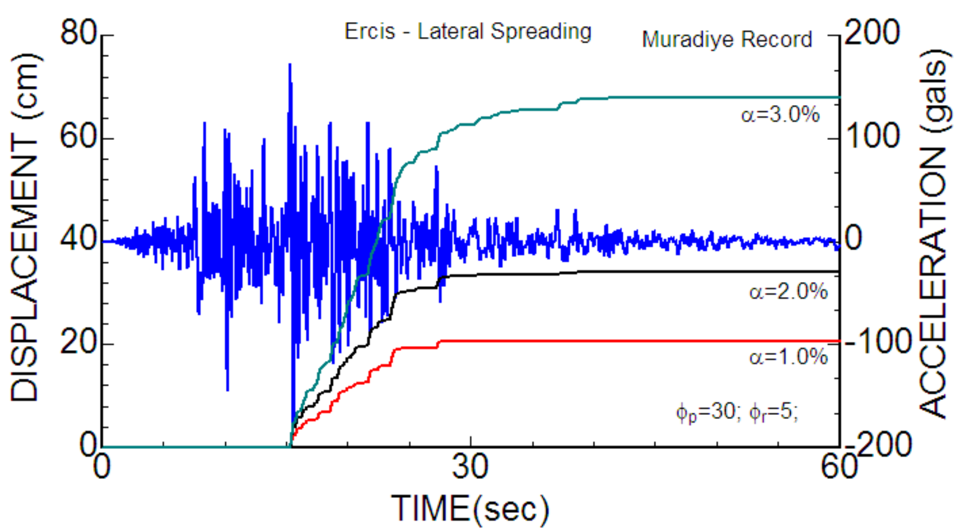


Figure 10.27. Computed lateral spreading for three inclinations using the records taken at Muradiye.

10.3. Slope and Embankment Failures

Many slope failures were observed in the epicentral area. Most of the slope failures occurred on the hanging wall-side of the earthquake fault (Figure 10.11). The dominant types of slope failure were rock falls and flows. Some slope instabilities were recognizable only from the tension cracks observed at their crests, rather than fully displaced mass movements.
One of the largest slope failures occurred in the vicinity of Topraktaş village on the right bank of the Karasu Stream. This instability developed in a relatively weak slope forming material (Figure 10.28a) and the height of the failed slope was greater than 30 m. Figure 10.28b shows numerous rock falls from basaltic slopes near Keçikıran which is close to the northern shore of Van Lake. Local rock falls from the road cut between Topraktaş and Arısu villages also occurred (Figure 10.28bc. Some of the rock falls from the road cuts in Van formation at the north of Gedikbulak village reached to the Van-Ağrı highway (Figure 10.28d). Nevertheless, they did not result in any casualties.

Typical earthquake-triggered and large-scale slope instability was observed on a hilly topography between Yeşilsu village and Amik Castle on the eastern shore of Lake Van (Figure 10.29). The slope failed is composed of weak, weathered and partly soft material. The villas under construction on this slope subjected to heavy damage due to slope movement. Bending cracks on the columns of these buildings and tension cracks on the crest of the slope were evident. Model experiments on rock slopes (Aydan et al., 1991, 2003) clearly show that accelerations are larger at the top of the slope and they are amplified near the slope crest. This situation suggests possible ground amplification at the cliff sides due to topographical effects. This effect was clearly observed in the city of Bingöl and a village during the 2003 Bingöl earthquake (Ulusay and Aydan, 2005). Probably amplification effect due to earthquake and sloping ground might be the main reasons of the damage to these villas.

At some locations along the eastern lake shore at the north of Van, some slope instabilities, generally in the form of rock falls, also occurred. One of them is the local rock falls observed near to Özyurt village (Figures 10.11 and 10.30a). The other instability occurred in the lacustrine terraces on the road between Dağönü and Mollaksım villages (Figure 10.30b). However, these instabilities did not affect the road parallel to the lake shore. In addition to these, some instabilities in old landslide areas at the east of Çomaklı and Meydancık villages which were identified from the tension cracks by Emre et al. (2011) and rock falls from the crown of the Özyurt landslide complex (YTÜ-DBAM, 2011) were also reported.

(a)

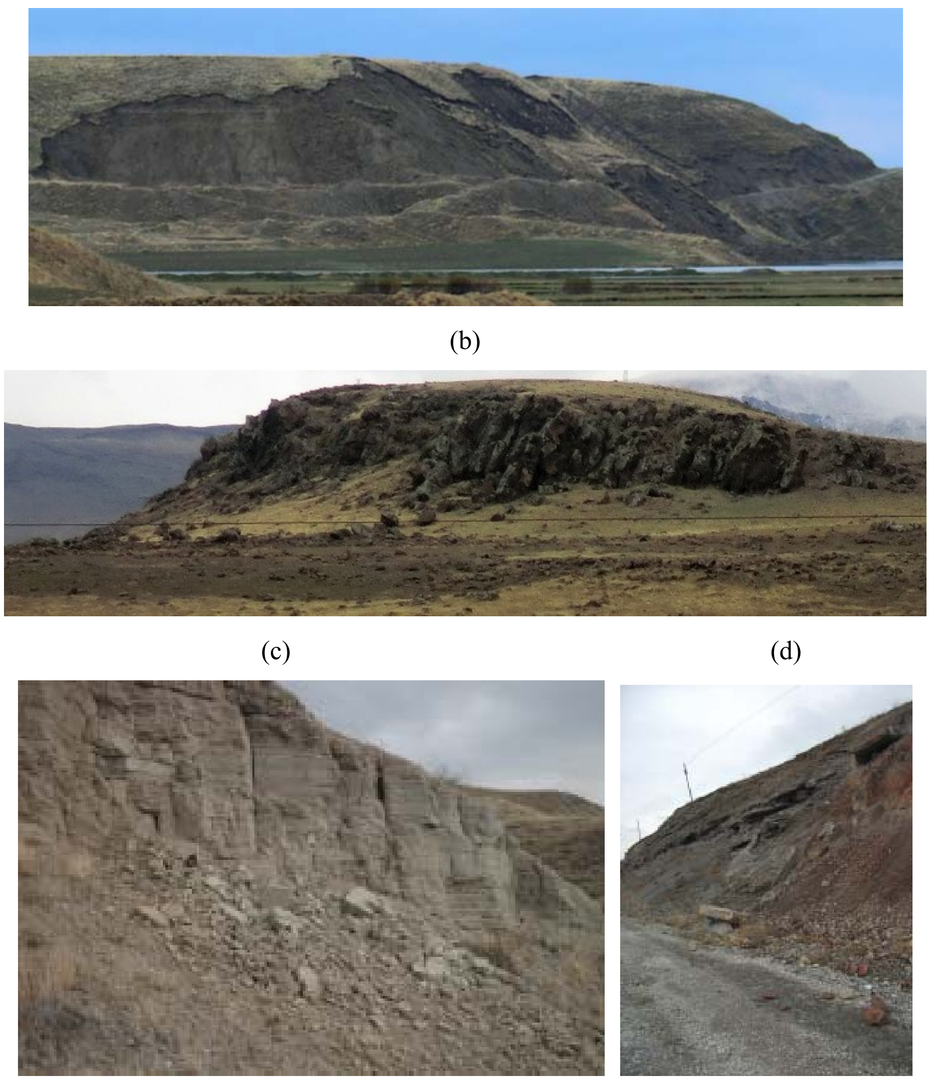


Figure 10.28. Slope failures trigerred by the Van-Erciş earthquake: (a) slope failure near Topraktaş, and rock falls. (b) near Keçikıran and (c) between Topraktaş and Arısu, and (d) along the slope of the road cut (Van-Ağrı highway).

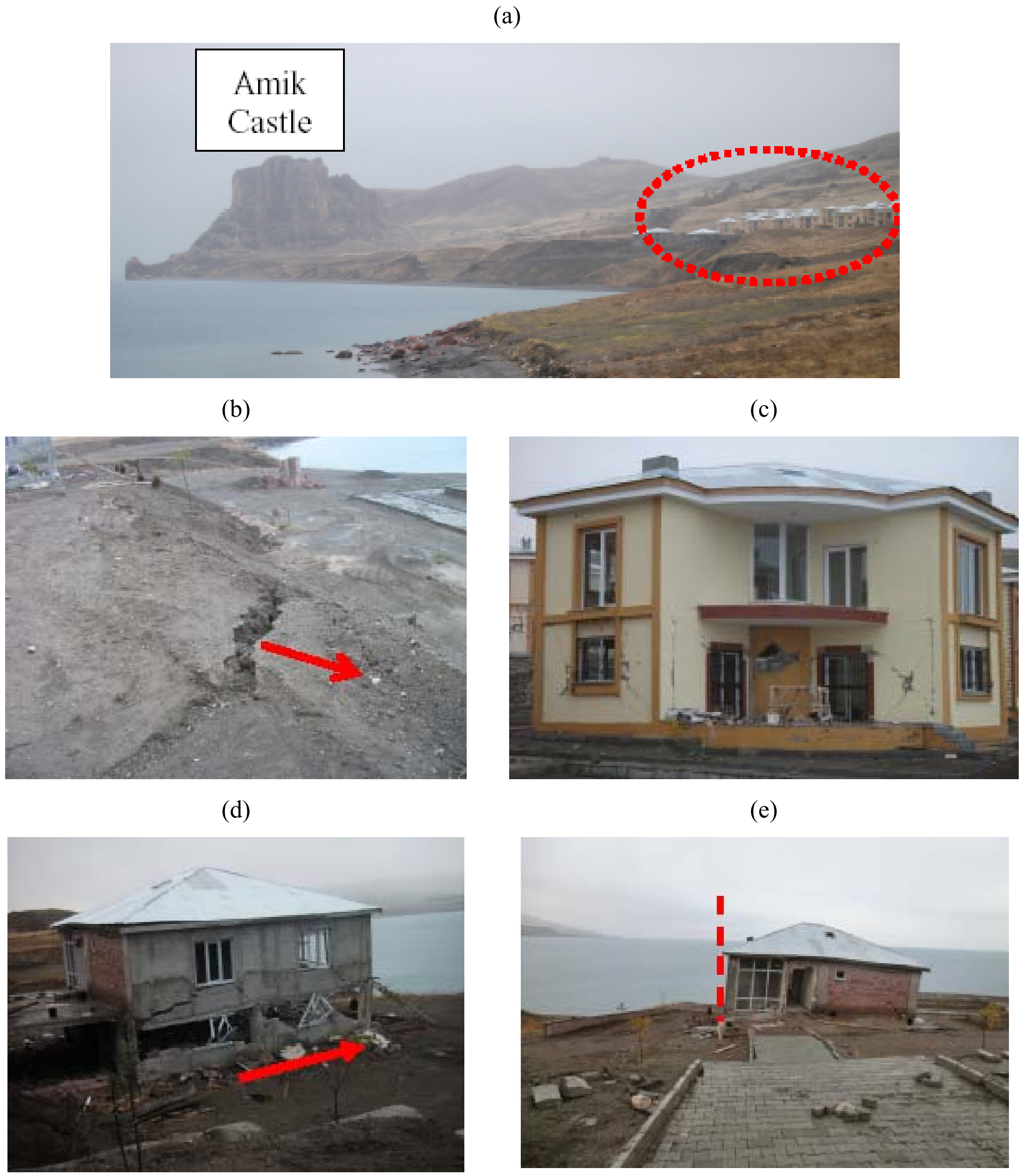


Figure10.29. Natural slope failure between on the coast of lake shore between Amik Castle and Yeşilsu village and damaged villas under construction.

Figure 10.31 compares the empirical relations between the earthquake magnitude and limits of slope failures for coherent and disrupted states. The observations from the Van-Erciş earthquake region are within the bound of the empirical bounds proposed by Aydan (2007) and empirically drawn line by Keefer (1984). The relations proposed by Aydan (2007) considers the effect of fault orientation with respect to the observation point

Figure 10.30. (a) Rock falls near to Özyurt village, (b) sliding between Dağönü and Mollakasım

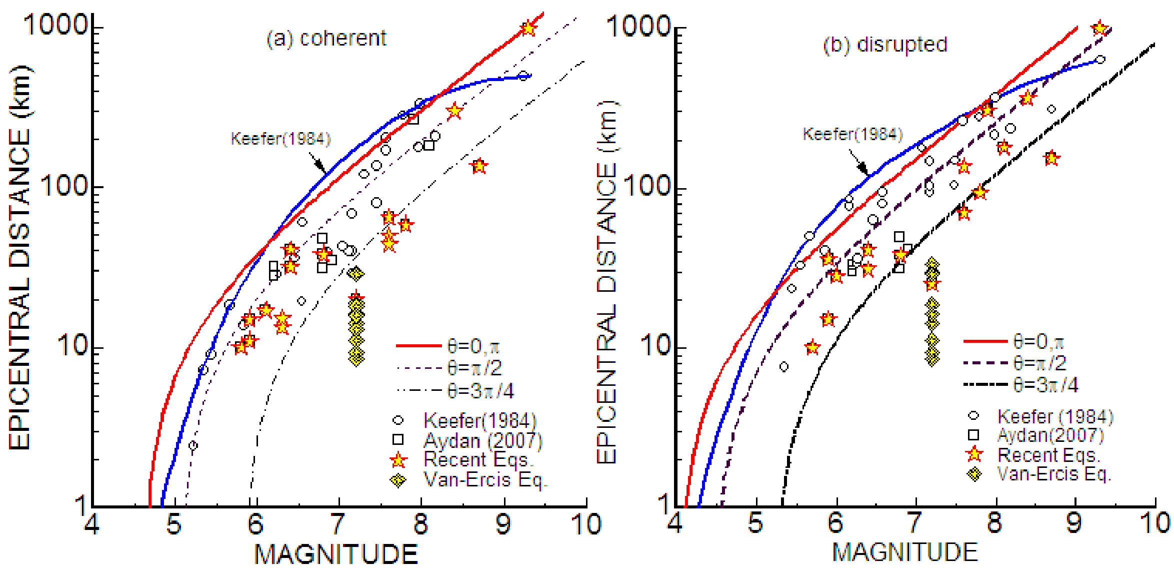


Figure 10.31. Comparison of observational results with empirical relations between earthqauke magnitude and epicentral limit distance for slope failures.

Embankment failures were observed at several localities. Major embankment failures were observed on the Van-Ağrı Highway. Figure 8.2 shows one example of embankment failure. The embankment seen in this figure moved towards the lake and settled.

11. TRIGGERED VAN-EDREMIT EARTHQUAKE

11.1. Introduction

Van- Edremit earthquake occurred at 21:23 local time on November 9, 2011. Although the moment magnitude (M_w) of this earthquake was only 5.6 (M_L=5.6-5.7), it caused heavy damage in the city of Van and added to the distress caused by the earlier M_w 7.0-7.2 Van-Erciş earthquake on October 23, 2011. The epicenter of this earthquake (38.4288N, 43.229E) is located near Edremit, a town on the eastern shore of Van Lake about 16 km to the south of Van city center (Figure 1.2). This earthquake is considered to be triggered by the effect of the crustal stress state following the October 23, 2011 event. This chapter outlines various aspects of the Van-Edremit earthquake of November 9, 2011. Because the earthquake occurred in the same region; geology, seismo-tectonics and local site conditions are not repeated herein. This chapter mainly involves seismic characteristics of the earthquake and evaluation of strong ground motion characteristics, description of both structural and geotechnical damages, and the effect of non-appropriate repair of the buildings is also briefly discussed.

11.2. Focal Mechanism and Seismicity

Figure 11.1 shows the focal mechanisms obtained by various institutes such as USGS (2011), ERD(2011), KOERI (2011) and HARVARD(2011). All focal mechanisms solutions indicated that the faulting mechanism of this earthquake was due to strike-slip faulting. Although the solutions yield two fault planes, NW-SE trending fault may be the causative fault. In view of the seismicity since November 09, 2011 shown in Figure 11.2 and recognized fault traces in the field, a sinistral NW-SE tending steeply dipping fault should be the causative fault. This fault probably is located to the east of Edremit.

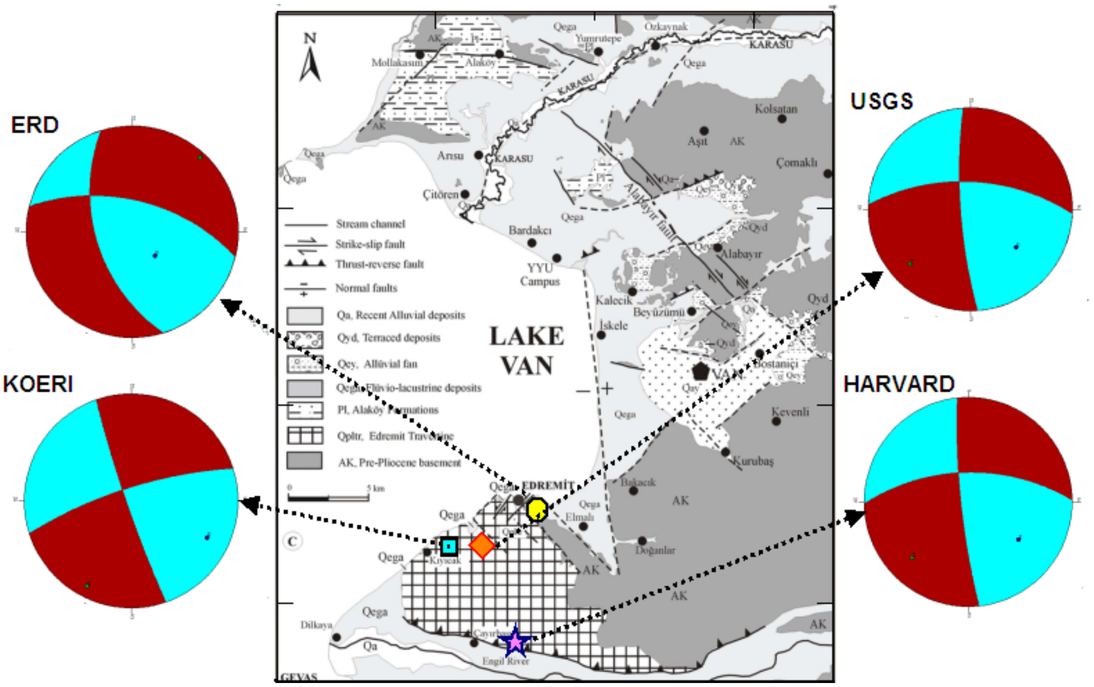


Figure 11.1. Geology of Van and its close vicinity and faulting mechanisms for the Van-Edremit earthquake estimated by different institutes (base map from Özkaymak et al., 2004).

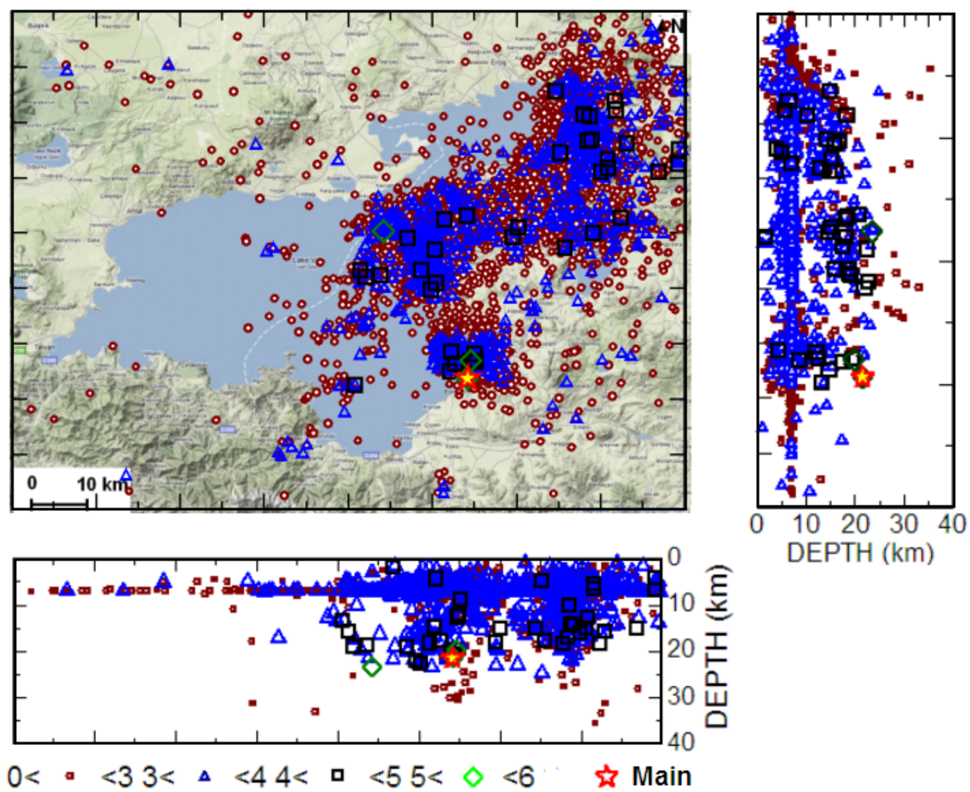


Figure 12.2. 2 Seismicity of epicentral areas of November 09, 2011 and October 23, 2011 since November 09, 2011.

11.3. Characteristics of Strong Motions

During this earthquake, strong ground motions were recorded by National Strong Motion Network of Turkey operated by the Earthquake Research Department (ERD) and temporarily installed network by Kandilli Observatory and Earthquake Research Institute (KOERI) following the October 23, 2011 Van-Erciş earthquake. KOERI also installed strong motion stations on both soil (VNKEA) and rock (VNS). The maximum ground acceleration recorded by the ERD (VBIM) and KOERI (VNKEA) at two soil ground sites in the City of Van are 0.27 g and 0.29 g, respectively (Figure 11.2). Figure 11.3 compares the acceleration records and acceleration response spectra of motions recorded at soil stations while Figure 11.4 compares recorded motions and corresponding spectra at soil (VNKEA) and rock stations (VNS). Although the amplitudes of waves are slightly different, the records are quite similar to each other. Furthermore, the accelerations are amplifed for periods of 0.1-0.15s and 0.35-0.4s.

Figure 11.3. Locations of strong motion stations (base map from Google earth)

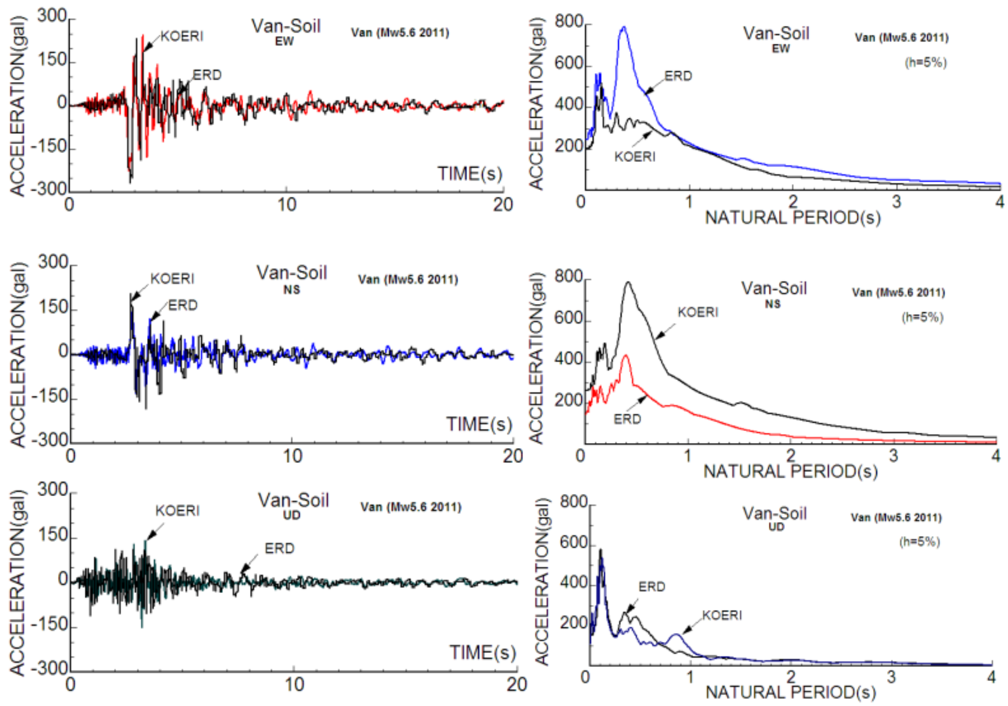


Figure 11.4. Comparison of the acceleration records and their acceleration response spectra of ERD and KOERI stations in Van.

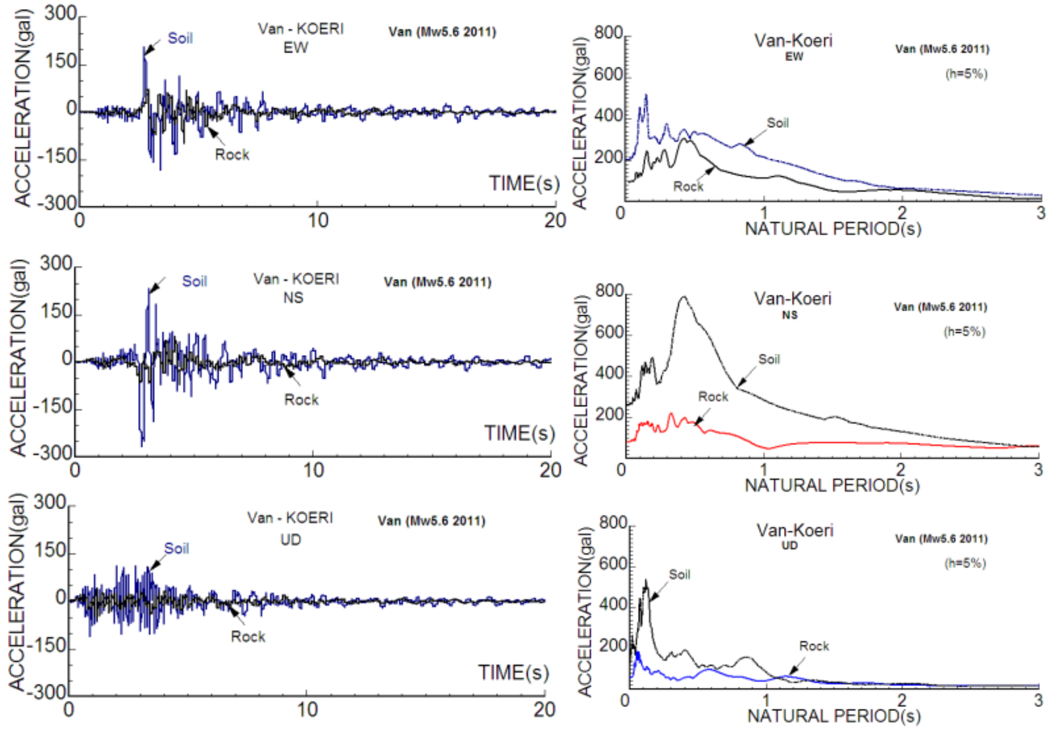


Figure 11.5. Comparison of the acceleration records and their acceleration response spectra on soil and rock stations in Van.

The comparison of raw acceleration records and their acceleration response spectra indicated that the amplifications were 2.4 and 3.6 times, respectively. Furthermore, the maximum spectral accelerations roughly correspond to those of periods of 0.36-0.4 s, which generally corresponds to the natural periods of 6-8 story reinforced concrete buildings.

Figure 11.6 shows the attenuation of strong motions recorded by the ERD and KOERI with the empirical relations of Aydan (2001), Aydan and Ohta (2011a) and Ulusay et al. (2004). The maximum ground acceleration on soil is well predicted by the attenuation relation proposed by Aydan (2001) while the relations by Aydan and Ohta (2011a) using the shear velocity of Van strong motion station and Ulusay et al. (2004) underestimated the maximum ground accelerations by 30-40% less.

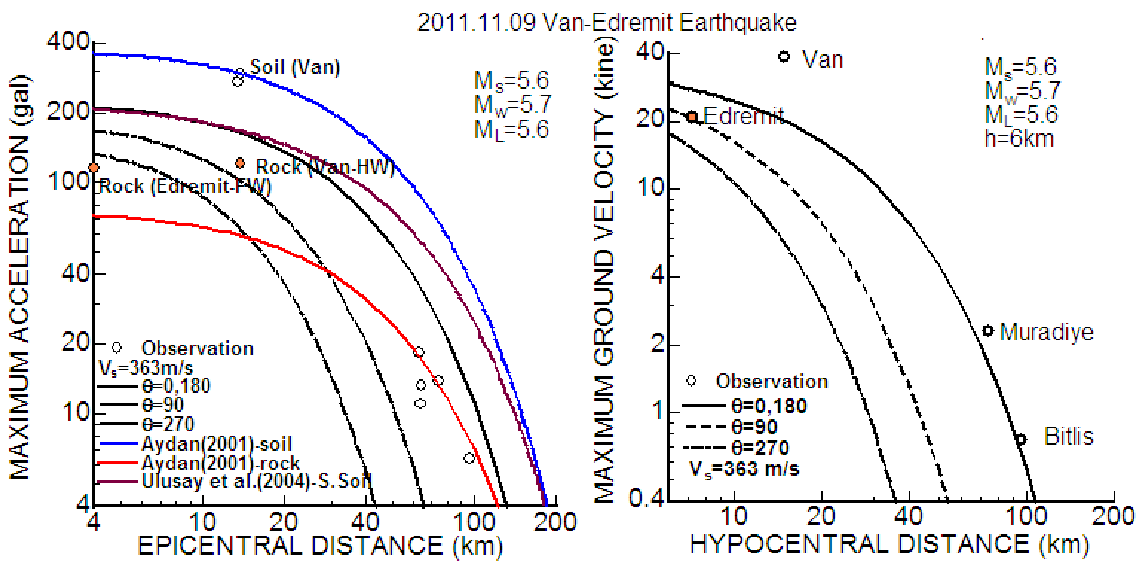


Figure 11.6. Comparison of some empirical attenuation relations for maximum ground acceleration and velocıty with observations

Aydan and Ohta (2011b) modified slightly their original method called EPS method (Ohta and Aydan, 2007) to estimate the behavious of ground during earthquake and to compute the permanent ground deformation from strong motion records. This method wass applied to near field stations, specifically VBIM-ERD, EDR-ERD, VNS-KOERI and VNKEA-KOERI, around the epicentral area Figure 11.6(a) compares the responses for three different directions in the City of Van, which is located on the mobile side of the fault. It is interesting to note that the top soil may even move opposite direction compared to that of rock base. This further implies that ground shaking may cause the plastic deformation of top soil layer.

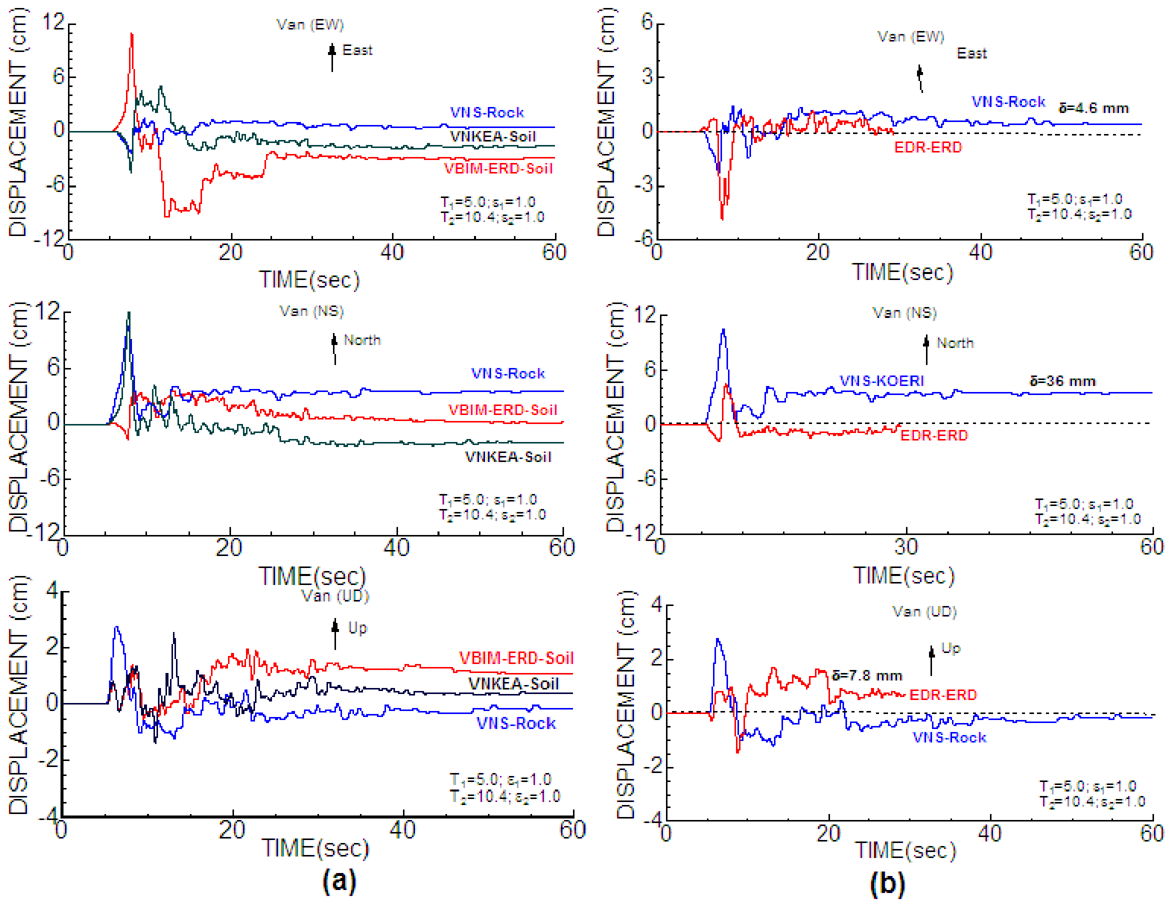


Figure 11.7. Displacement responses of strong motion stations computed from EPS method (a) The City of Van), (b) Rock ground at Edremit and Van

11.4. Casualties and Structural Damage

This earthquake resulted in the loss of 40 lives as it happened at 21:23 in the evening. On the other hand, the 23 October 2011 Van-Erciş earthquake resulted in the loss of 604 people and occurred at 13:41 on Sunday. Figure 11.8 shows the relations between local magnitude and casualties. The estimations for upper (UL), mean (ML) and lower (LL) limits are computed from the following function proposed in this article using the data from various catalogues for Turkey (i.e. Ergin et al. 1967; Soysal et al. 1981; Eyidoğan et al. 1991).

$$N = A(M_L - B)^c \tag{12.1}$$

The values of constants A and c are 2 and 7, while the values of constant B are 3.5, 4.5 and 5.5 for UL, ML and LL, respectively. The main reason for such large ranges may be related to the time of earthquake, quality of buildings and ground conditions.

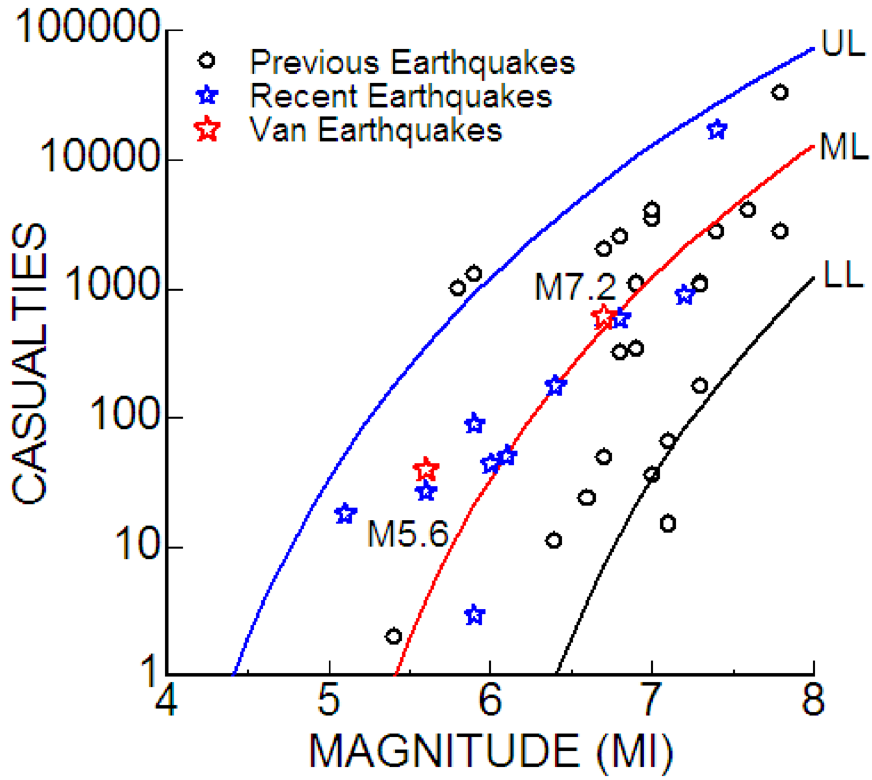


Figure 11.8. Relation between local magnitude of earthquakes and casualties.

This earthquake caused the collapse of the 30 reinforced concrete buildings, most of which had already suffered substantial damage during the 23 October 2011 earthquake (Figures 11. 9- 11.11). Fortunately, 23 of the collapsed buildings had been evacuated due to the damage caused by the earlier earthquake. However, two hotel buildings were open during this second earthquake and some of the people staying there lost their lives (Figure 11.9). This earthquake also caused additional damage to some buildings. The collapsed hotels had cracks following the October 23, 2011 earthquake and they were cosmetically repaired. The authors noticed such non-structural repairs in the city of Van during their reconnaissance for the October 23, 2011 earthquake (Figure 11.12).

(a) (b)

Figure 11.9. Views of Bayram Otel (a) before and (b) after the Van-Edremit earthquake (Anadolu Ajansı, 2011).

Şekil 11.9. Bayram Oteli'nin Van-Edremit depremi öncesi (a) ve sonrası (b) görüntüleri (Anadolu Ajansı, 2011).

The major causes of the heavy damage to reinforced concrete buildings were basically similar to the previous observations during previous earthquakes in Turkey:

(a) Quality of construction materials,

(b) Lack of implementation of design codes (bars, stir-ups, proper column-beam connections, tie-beams, good foundation etc.),

(c) Existence of soft-floor (weak-floor),

(d) Pounding,

(e) Lack of ductility,

(f) Poor integrity of RC frame with in-fill walls,

(g) Quality of workmanship,

(h) Poor ground conditions.

Furthermore, cosmetic non-structural by re-plastering of cracked beams, columns, infill-walls and beam column connections had disastrous effects. Similar problem was observed in buildings damaged by the 1999 Kocaeli earthquake in Düzce during the 1999 Düzce earthquake (Aydan et al., 2000a and 2000b).

Figure 11.10. Views of a collapsed reinforced concrete building in Van (Van-Edremit earthquake) (Anadolu Ajansı, 2011).

Figure 11.11. Views of heavily damaged reinforced concrete buildings of DSI in Van (Van-Edremit earthquake) (Photos: Ayhan Koçbay).

Figure 11.12. Cosmetic repairs applied to a damaged RC building in Van on November 5, 2011 after the Van-Erciş earthquake.

11.5. Geotechnical Aspects and Associated Damages

This earthquake also caused some ground liquefaction along the Van lakeshore (Figure 11.13a) and the ground liquefaction again occurred at the Van Port, where the ground liquefaction was also observed following the 23 October 2011 earthquake. Figure 11.13b shows the grain size distribution of the boiled sand, which was sampled from the Port of Van by Dr. Onur Köse of Yüzüncü Yıl University to be used in this study. The grain size distributions in Figure 11.13b are within the most liquefiable bounds with high percentage of fine content and very similar to those observed in the Van-Erciş earthquake at the port area.

(a)

(b)

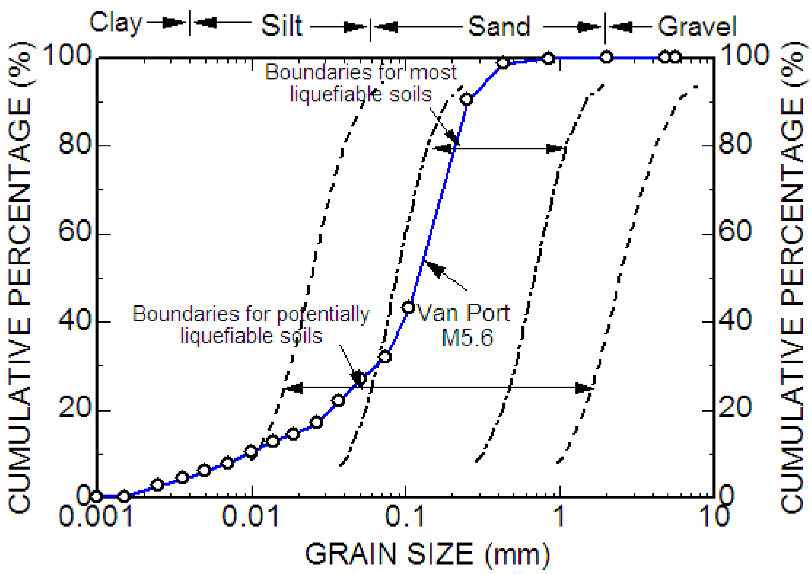


Figure 11.13. (a) Views of boiled sand in Van Port due to the M5.6 Van-Edremit earthquake and (b) its grain size distribution.

Figure 11.14 shows the empirical relations between earthquake magnitude (M_w) and hypocentral distance of liquefaction location proposed by Aydan et al. (1998) and Aydan (2007) with the observation in this earthquake. The observation is within the proposed empirical limits. However, it is also noted that despite the smaller magnitude (M5.6) of this earthquake, it caused ground liquefaction at a location where previously liquefaction has also occurred and this is the first time for liquefaction occurred during an earthquake with a magnitude smaller than 6 experienced in Turkey.

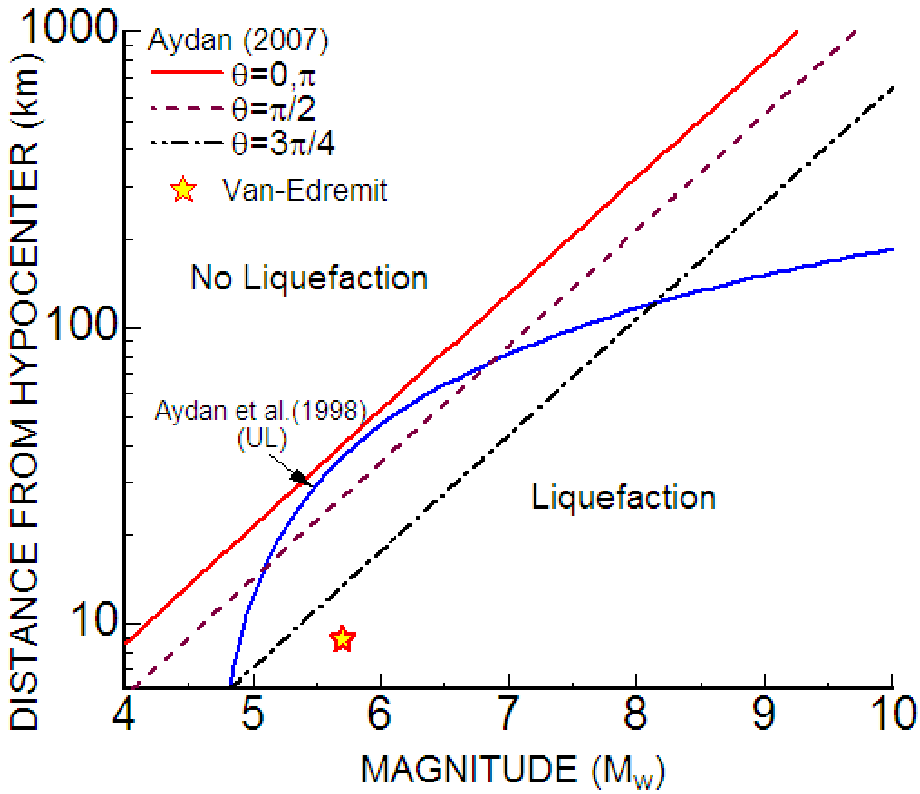


Figure 11.14. Comparison of empirical relations for magnitude and liquefaction limits with observations at liquefied site (Van Port) performed in the earthquake region.

12. CONCLUSIONS AND RECOMMENDATIONS

In this report, the authors have described the site observations and information they have gathered during their investigation, and made some assessments on different aspects of the October 23, 2011 and November 9, 2011 Van-Erciş and Van-Edremit earthquakes, respectively. This study is an inter-disciplinary work of various disciplines of science and engineering such as geology, seismology, tectonics, engineering geology, and geotechnical and earthquake engineering. This investigation was carried out to cover both engineering and scientific aspects of this earthquake. The following conclusions are drawn from this study.

This earthquake was caused by thrust type faulting, which is generally rare for Turkey, but it is typical of faulting mechanism for this tectonic province of Turkey. The thick soil and weathered rock above the rock base diluted the deformation of ground over a large zone so that a clear fault scarp is not observed. The likely deformation of soft soil and weathered rock should be similar to that seen in Figure 5.4e. The failures of slopes and embankments and rock falls and ground liquefaction may also be indications of diluted ground deformation caused by the earthquake fault.

From the seismicity, it seems that a wedge like body bounded by fault planes FP1 and FP2 shown in Figure 5.2 is uplifted. As a result of this movement, the uplift of the northern shoreline of Van Lake should have occurred.

The Van-Edremit earthquake is not an aftershock of the October 23, 2011 Van-Erciş earthquake. It has a different faulting mechanism. However, there is no doubt that it was triggered due to the variation of crustal stresses induced by the October 23, 2011 earthquake. This example also shows that the necessity of a clear definition of aftershocks.

The strong motions induced by this earthquake have a strong directivity effect and Erciş town with a population of 100,000 people suffered heavy damage and casualties as it was on the hanging wall side of the fault.

Although the magnitude of the triggered Van-Edremit earthquake was small, high ground motions with a strong directivity effect were recorded. The maximum ground accelerations on soil ground were amplified up to 3.6 times that on rocky ground.

The main causes of heavy damage or collapse of reinforced concrete buildings are similar to those observed in previous earthquakes occurred in Turkey. These are poor workmanship, construction mistakes, negligence and lack of moral, lack of implementation of seismic codes in structural design, resonance phenomenon due to ground conditions, soft (weak) floors, pounding of adjacent structures and liquefaction of ground. This earthquake also showed that the non-structural repairs of buildings are disastrous and must be avoided. Except buildings, the damage to common civil engineering structures such as roadways, bridges, tunnels and dams was almost none or slight.

From observations, it is strongly suggested that the construction practices in earthquake prone areas of Turkey should be changed from that of reinforced concrete moment framed system to reinforced concrete shear-wall system. Such a change would reduce drift ratios and prevent collapse of buildings, thus averting loss of lives and property. There are some golden rules how to construct masonry buildings in earthquake-prone areas, which are outcomes of experiences gained from the long-history of seismicity of Turkey. These rules can be summarized as follow:

(a) Built on a base-mat concrete or firm base (if ground condition is poor)
(b) Roof should be light (toprak dam (earthen roof)) is not desirable)
(c) Use hatıls (timber or concrete beam) at each 1 m interval at the top of the wall. Reinforcement is desirable if possible. They are effective at corners even they are short
(e) Use lime (cement)-based mortar with saman (straws) in kerpiç (adobe) bricks (original idea of fiber-reinforced concrete/shotcrete comes from this concept)
(h) Plaster walls in order to prevent water diffusion into kerpiç (adobe) bricks

The site investigations clearly showed that the epicentral area is vulnerable to damage from ground liquefaction and slope failures. The anticipated ground liquefaction did occur in Erciş town and the north of Van city and settlement along rivers. However, the intensity of ground liquefaction was not that high.

The Van-Edremit earthquake with a magnitude of 5.6 is probably the smallest magnitude earthquake to cause liquefaction in Turkey so far. Once again, this earthquake showed that ground liquefaction can occur in the same location repeatedly.

Very thick soft sedimentary deposits exist along the shores of Van Lake. Any new developments of housing and road construction must consider the effect of such soft ground conditions.

The earthquake area is mountainous and it may suffer from rock falls and huge slope failures.

ACKNOWLEDGEMENTS

The authors would like to sincerely express, their thanks and gratitude to the followings without their help this investigation could not be very fruitful within a very short period of time.

The most findings described here are the outcomes of the survey by the Turkish and Japanese experts dispatched by the Japan Society of Civil Engineers (JSCE). In organizing the team, the Disaster-Information Network among JSCE, AIJ and JAEE (Chairman, Prof. K. Kawashima of the Tokyo Institute of Technology) took the initiative.

Assist. Prof. Dr. Şehabettin Öztürk (Yüzüncü Yıl University and Chairman of Van Branch of the Chamber of Architectures of Turkey) for his kind information and guidance by during reconnaissance visit to the earthquake affected region, and Assist. Prof. Dr. Onur Köse (Geological Engineering Department of Yüzüncü Yıl University) for his kind enthusiasm for providing information and samples from some liquefied soils.

Assoc. Prof. Dr. Ergun Tuncay, Res. Assist. Elif Avşar, laboratory technicians Ozgür Erol and Ahmet Bay from Hacettepe University, and Assist. Prof. Dr. İbrahim Çobanoğlu and Res. Assist. Sefer B. Çelik from Pamukkale University for their kind helps in geomechanical laboratory tests. Dr. Ayhan Koçbay from the General Directorate of State Hydraulic Works (DSİ) for the information and photographs of the damaged buildings of the DSİ Van Branch he provided.

The last, but not the least, the people of the earthquake stricken area for their cooperation in gathering information on the extent of damage and guiding the authors to places of great significance, kindness and generosity even though they suffered the most by losing their properties as well as their beloved ones. The authors wish the quick recovery to their ordinary lives and want to end this report with a heartfelt condolence wishes. This report is dedicated to Dr. Atsushi Miyazaki, who was from Japan and working in Van for rescue studies and lost his life during the Van-Edremit

earthquake of November 9, 2011, and to the people lost their lives in Van-Erciş and Van-Edremit earthquakes.

REFERENCES

Acarlar, M., Bilgin, Z. A., Erkal, T., Güner, E., Şen, A.M., Umut, M., Elibol, E., Gedik, İ., Hakyemez, Y. ve Uğuz, M.F., 1991. Van Gölü doğu ve kuzeyinin jeoloji. MTA Rapor No: 9469 (in Turkish).

Adamia, S.H., Chkhotua, T., Kakelia, M., Lordkipanidze, M., and Shavishvili, I., 1981. Tectonics of the Caucasus and adjoining regions: implication for the evolution of the Tethys Ocean. J. Struc. Geol., 3, 437-447.

AFAD, 2011. www.afad.gov.tr

Aksoy, E., 1988. Van İli Doğu-Kuzeydoğu Yöresinin Stratigrafisi ve Tektoniği. Doktora Tezi, Fırat Üniversitesi Fen Bilimleri Enstitüsü (in Turkish).

Akyüz, S., Zabcı, C. ve Sançar, T., 2011. 23 Ekim 2011 Van depremi hakkında ön rapor. İTÜ Jeoloji Mühendisliği Bölümü, www.itu.edu.tr/DataFiles/Dosya/2011/van_rapor_ITU2.pdf (in Turkish).

Arpat, E., Şaroğlu, F. ve İz, H.B., 1977. 1976 Çaldıran depremi. Yeryuvarı ve İnsan, 2 (1), 29-41.

Aydan, Ö., 1997. Seismic characteristics of Turkish earthquakes. Turkish Earthquake Foundation, Türkiye Deprem Vakfı Raporu, TDV/TR 97-007, 41 p.

Aydan, Ö., 2000. Fay çiziklerinden yerkabuğunda etkiyen gerilimlerin saptanması için yeni bir yöntem ve uygulaması. Yerbilimleri, 22, 223-236.

Aydan, Ö., 2001. Comparison of suitability of submerged tunnel and shield tunnel for subsea passage of Bosphorus. Jeoloji Mühendisliği, 25 (1): 1-17 (in Turkish).

Aydan, Ö., 2002. The inference of the earthquake fault and strong motions for Kutch earthquake of January 26, 2001. A Symposium on the Records and Lessons from the Recent Large Domestic and Overseas Earthquakes, JSCE, Earthquake Engineering Committee, Tokyo, pp. 135-140.

Aydan, Ö., 2007. The inference of seismic and strong motion characteristics of earthquakes from faults with a particular emphasis on Turkish earthquakes. Proceedings of the 6th National Earthquake Engineering Conference of Turkey, İstanbul, 563-574.

Aydan, Ö., and Kumsar, H. 1996. A site investigation of Dinar earthquake of October 1, 1995. Turkish Earthquake Foundation, TDV/DR 97-003, İstanbul, 115p.

Aydan, Ö., and Ohta, Y., 2006. The characteristics of ground motions in the neighbourhood of earthquake faults and their evaluation. Symposium on the Records and Issues of Recent Great Earthquakes in Japan and Overseas, EEC-JSCE, Tokyo, pp. 114-120.

Aydan, Ö., and Ohta, Y., 2009. Shaking table experiments of breakwaters founded on liquefiable ground. Tokai University, Deptartmen of Marine Civil Engineering, 10 p (Unpublished interim report).

Aydan, Ö., and Ohta, Y., 2011a. A new proposal for strong ground motion estimations with the consideration of earthquake fault. 7th National Conference on Earthquake Engineering, Istanbul, Turkey, Paper No. 65 (on CD).

Aydan, Ö., and Ohta, Y., 2011b. The erratic pattern screening (EPS) method for estimation of co-seismic deformation of ground from acceleration records and its applications. Seventh National Conference on Earthquake Engineering, 30May- 3 June 2011, Istanbul, Turkey Paper No:66, 10 p.

Aydan, Ö., Sezaki, M., and Yarar, R., 1996. The seismic characteristics of Turkish earthquakes. 11th World Conference on Earthquake Engineering, Acapulco, Mexico, 1-8 (on CD).

Aydan, Ö., Shimizu, Y., and Kawamoto, T., 1991. The dynamic response and stability of rock slopes in discontinuous media. In: Bell, D.H. (Ed.), Proceedings of the Sixth Symposium on Landslides. Christchurch, pp. 1211–1217.

Aydan, Ö., Ulusay, R., Kumsar, H., Sönmez, H., and Tuncay, E., 1998. A site investigation of June 27, 1998 Adana-Ceyhan earthquake. Turkish Earthquake Foundation, İstanbul, Report No. TDV/DR 006-03.

Aydan, Ö., Ulusay, R., Hasgür, Z., and Taşkın, B., 2000a. A site investigation of Kocaeli Earthquake of August 17, 1999. Turkish Earthquake Foundation, TDV/DR 08-49, 180 p.

Aydan, Ö., Ulusay, R., Kumsar, H., and Tuncay, E., 2000b. Site investigation and engineering evaluation of the Düzce-Bolu earthquake of November 12, 1999. Turkish Earthquake Foundation, TDV/DR 09-51, 220 p.

Aydan, Ö., Ulusay, R., and Kumsar, H., 2000c. Liquefaction phenomena in the earthquakes of Turkey, including recent Erzincan, Dinar and Adana-Ceyhan earthquakes. Proceedings of the 12th World Conference on Earthquake Engineering, Auckland, New Zealand, 30 January – 4 February 2000, Paper No. 0709.

Aydan, Ö., Ulusay, R., and Miyajima, M., 2003. The Bingöl earthquake of May 1, 2003. Japan Society of Civil Engineers, 91 p (jsce.org.jp/report/19/frame.htm).

Aydan, Ö., Ulusay, R., and Kumsar, H., 2004. The inferences of maximum ground acceleration from the collapse of various structures during earthquakes and some examples from recent earthquakes in Turkey and India. 5th International Symposium on Eastern Mediterranean Geology (5th ISEMG), Thessaloniki, Greece, pp. 913-916.

Aydan, Ö., Hamada, H., and Konagai, K., 2006. An evaluation of strong ground motions and failures of natural and cut slopes induced by Kashmir Earthquake of October 8, 2005. 1st European Conference on Earthquake Engineering an Seismology, Paper No.1352 (on CD).

Aydan, Ö., Ulusay, R., and Atak, V.O., 2008. Evaluation of ground deformations induced by the 1999 Kocaeli earthquake (Turkey) at selected sites on shorelines. Environmental Geology 54: 165-182.

Aydar, E., Gourgaud, A., Ulusoy, İ., Digonnet, F., Labazuy, P., Şen, E., Bayhan, H., Kurttaş, Y., and Tolluoğlu, Ü., 2003. Morphological analysis of active Mount Nemrut stratovolcano, eastern Turkey: evidences and possible impact areas of future eruption. Journal of Volcanology and Geothermal Research, 123, 301–312.

Calvi,V.S., 1941. Erdbebenkatalog der Turkei und Einiger Benaehbarter Gebiete. MTA Enstitüsü Rapor No.276, Ankara.

Çetin, K.Ö., Türkoğlu, M., Oral, S.Ü., and Nacar, U., 2011. Van-Tabanlı Earthquake (M_w=7.1) October 23, 2011 Preliminary Reconnaissance Report. Middle East Technical Univeristy, Civil Engineering Department (unpublished report).

Çiftçi, Y., Işık, M.A., Alkevli, T. ve Yeşilova, Ç., 2008. Van Gölü havzasının çevre jeolojisi. Jeoloji Mühendisliği, 32 (2), 45-77 (in Turkish).

Degens, E.T., and Kurtman, F., 1978. The geology of Lake Van. Maden Tetkik ve Arama Enstitüsü Yayını, No.169.

Degens, E.T., Wong, H.K., Kurtman, F., and Finkch, P., 1978. Geological development of Lake Van: A summary. In: The Geology of Van, E.T. Degens and F. Kurtman (eds.), Mineral Research and Exploration Institute of Turkey (MTA) Publication No. 169, pp.134-146.

Dewey, J.F., Hempton, M.R., Kidd, W.S.F., Şaroğlu, F., and Şengör, A.M.C., 1986. Shortening of continental lithosphere: The neotectonics of Eastern Anatolia -A young collision zone. Geol. Soc. Spec. Publ., 19, 3-37.

DSİ, 1977. Van-Erciş Ovası hidrojeolojik etüt raporu. DSİ Genel Müdürlüğü, Jeoteknik Hizmetler ve Yeraltısuları Dairesi Başkanlığı, Ankara (in Turkish).

DSİ, 2011. http://www.dsi.gov.tr/

Emre, Ö., Duman, T.Y., Özalp, S. ve Elmacı, H., 2011. 23 Ekim 2011 Van depremi saha gözlemleri ve kaynak faya ilişkin ön değerlendirmeler. MTA Genel Müdürlüğü (in Turkish). www.mta.gov.tr/.../deprem/2011_Van-Depremi_On-Degerlendirmeler

EMSC, 2011. http://www.emsc-csem.org/

ERD, 2011. http://www.deprem.gov.tr/

Erciş Municipality, 2011. http://www.ercis.bel.tr/

Ergin, K., Güçlü, U. ve Uz, Z., 1967. Türkiye ve civarının deprem kataloğu (MS. 11-1964). İTÜ Maden Fakültesi Arz Fiziği Enstitüsü Yayınları, No 28 (in Turkish).

Eyidoğan, H., Güçlü, U., Utku, Z. ve Değirmenci, E., 1991. Türkiye büyük depremleri makro-sismik rehberi. İTÜ Yayını (in Turkish).

GFZ, 2011. http://geofon.gfz-potsdam.de/eqinfo/

Gülen, L., Pınar, A., Kalafat, D., Özel, N., Horasan, G., Yılmazer, M., Isıkara, A.M., 2002. Surface fault breaks, aftershock distribution and rupture process of the 17 August 1999 ˙Izmit, Turkey earthquake. Bull. Seismolog. Soc. Am., 92 (1), 230–244.

HARVARD, 2011. http://www.seismology.harvard.edu/

Hempton, M.R., 1987. Constraints on Arabian plate motion and extensional history of the Red sea. Tectonics, 6, 687-705.

Iwasaki, T., Tokida, K., Tatsuoka, F., Watanabe, S., Yasuda, S., and Sato, H., 1982. Microzonation for soil liquefaction potential using simplified methods, Proceedings of the Third International Earthquake Microzonation Conference, USA, Volume 3, pp. 1319-1330.

İTÜ, 2011. October 23 2011 M7.2 Tabanlı-Van earthquake. İTÜ Report of Faculty of Civil engineering. www.eedmi.itu.edu.tr/Van_Depremi/index.html

JMO, 2011. Van depremleri (Tabanlı-Edremit) raporu. TMMOB Jeoloji Mühendisleri Odası Yayın No.110, 48 p (in Turkish).

Keefer, D.K., 1984. Landslides caused by earthquakes. Geol. Soc. Am. Bull., 95(2), 406-421.

Keskin, M., 2005. Domal uplift and volcanism in a collision zone without a mantle plume: Evidence from Eastern Anatolia. www.MantlePlumes.org

Keskin, M., Pearce, J.A., and Mitchell, J.G., 1998. Volcano-stratigraphy and geochemistry of collision-related volcanism on the Erzurum-Kars Plateau, North Eastern Turkey, J. Volc.Geotherm. Res., 85 (1-4), 355-404.

Ketin, İ., 1977. Van Gölü ile Iran sınırı arasındaki bölgede yapılan jeoloji gözlemlerinin sonuçları hakkında kısa bir açıklama. TJK Bülteni, 20, 79-85 (in Turksih).

Kıraner, F., 1959. Van Gölü doğu bölgesinin jeolojik etüdü. MTA Dergisi, s. 30-57 (in Turkish). (www.jmo.org.tr/resimler/ekler/4baaff0e2f11b53_ek.pdf?derg)

Koçyiğit, A., 1985. Karayazı fault. Geol. Soc. Turkey Bull., 28, 67-72.

Koçyiğit, A., 1991. An example of accretionary forearc basin from northern Central Anatolia and its implications for the history of subduction of Neo-Tethys in Turkey. Geol. Soc. America Bull., 103, 22-36.

Koçyiğit, A., 2002. Neotectonic characteristics and seismicity of East Anatolia. Workshop-2002 on the Geology of East Anatolia, Van, pp.1-3 (in Turksih).

Koçyiğit A., and Beyhan A., 1998. A new intracontinental transcurrent structure: The Central Anatolian Fault Zone, Turkey. Tectonophysics, 284, 317-336.

Koçyiğit, A., Yılmaz, A., Adamia, S., and Kuloshvili, S., 2001. Neotectonics of East Anotolian Plateau (Turkey) and Lesser Caucasus: Implication for transition from thrusting to strike-slip faulting. Geodinamica Acta, 14, 177-195.

Koçyiğit, A., Deveci, Ş. ve Kaplan, M., 2011. Van depremleri raporu (23 Ekim-30 Kasım, 2011). ODTÜ, Jeoloji Mühendisliği Bölümü, Aktif Tektonik ve Deprem Araştırma Laboratuvarı, 21 p (in Turkish).

KOERI, 2011. http://www.koeri.boun.edu.tr /

Köse, O., Gökdere F. ve Tolluoğlu D., 2005. Van Gölü havzasının genel tanıtımı. 12. Ulusal Kil Sempozyumu Bildiriler Kitabı, Van, s. 23-26.(in Turkish).

Kumsar, H., Aydan, Ö., Tano, H. ve Çelik, S.B., 2008. 23-26 Temmuz 2003 Buldan (Denizli) depremlerinin mühendislik incelemesi. Pamukkale Üniversitesi, Ekin Yayınevi, 118 s (in Turkish).

Ministry of Public Works and Settlement of Turkey, 1998. Turkish Seismic Codes. Ankara, 85 p (in Turkish).

METU/EERC, 2011. 23 Ekim 2011 M_w 7.2 Van depremi sismik ve yapısal hasara ilişkin saha gözlemleri. Ankara, Rapor No: METU-EERC 2011-4, 76 p.

MTA, 2002. 1:500 000 ölçekli Türkiye jeoloji haritaları, Van paftası. MTA Genel Müdürlüğü, Ankara (in Turkish).

Ohta, Y., and Aydan, Ö., 2004. An experimental study on ground motions and permanent deformation nearby earthquake faults. Journal of the School of Marine Science and Technology, Tokai University, 2 (3), 1-12 (in Japanese).

Ohta, Y., and Aydan, Ö., 2007. Integration of ground displacement from acceleration records. Proceedings of the JSCE Earthquake Engineering Symposium, pp. 1046-1051.

Özden, Ş., Akpınar, E., and Atalay, H.M., 2011. Reconnaissance report – Van earthquake of October, 2011. Kocaeli University, 28 p.

Özkaymak, Ç., 2003. Van şehri ve yakın çevresinin aktif tektonik özellikleri. Yüksek Lisans Tezi, Yüzüncü Yıl Üniversitesi, Fen Bilimleri Enstitüsü, 76 s (in Turkish).

Özkaymak, Ç., Yürür, T., and Köse, O., 2004. An example of intercontinental active collisional tectonics in the Eastern Mediterranean region (Van, Eastern Turkey). 5th Int. Symp. on Eastern Mediterranean Geology, Thessaloniki, T1-44.

Özler, M., 2008. Van akiferinin hidrojeolojisi ve Van Gölü'nden sodalı su girişimi. 5. Dünya Su Forumu Hazırlık Süreci DSİ Yurtiçi Bölgesel Toplantıları: Van Gölü Hidrolojisi ve Kirliliği Konferansı Bildiri Kitabı, Van, s. 37- 54 (in Turkish).

Özvan, A., Akkaya, İ., Tapan, M. ve Şengül, M. A., 2005. Van yerleşkesinin deprem tehlikesi ve olasılı bir depremin sonuçları. Deprem Sempozyumu Kocaeli 2005 Özler Kitabı, Kocaeli Üniversitesi, s. 1386-1393 (in Turkish).

Özvan, A., Şengül, M.A. ve Tapan, M., 2008. Van Gölü havzası Neojen çökellerinin jeoteknik özelliklerine bir bakış: Erciş yerleşkesi. Geosound, 52, 297-310 (in Turkish).

Parlak, O., Delaloye, M., Kozlu, H., Höck, V., and Çelik, Ö.F., 2000. Geochemistry and tectonic setting of the Yüksekova ophiolite from the South-East Anatolian Orogenic Belt. International Earth Sciences Colloquium on the Aegean Region (IESCA-2000), 25-29 September 2000, p.240.

Pearce, J.A., Bender J.F., De Long S.E., Kidd W.S.F., Low P.J., Güner Y., Şaroğlu, F., Yılmaz, Y., Moorbath, S., and Mitchell, J.G., 1990. Genesis of collision volcanism in Eastern Anatolia, Turkey. J. Volcanol. Geotherm. Res., 44, 189-229.

Port and Harbour Research Institute of Japan, 1997. Handbook on Liquefaction Remediation of Reclaimed Land. Balkema, The Netherlands.

Sağlam, A., 2003. Van Gölü doğusu ve güneydogusunda yüzeyleyen Van formasyonunun stratigrafisi, paleontolojisi ve çökelme ortamları. Yüksek Lisans Tezi, Yüzüncü Yıl Üniversitesi, Fen Bilimleri Enstitüsü, 88 p (in Turkish).

Sayısal Grafik, 2011. www.sayisalgrafik.com.tr

Selçuk, L., and Çiftçi, Y., 2007. Microzonation of the Plio-Quaternary soils: A study on the liquefaction risk potential in the Van Lake Basin, Turkey. Bulletin of Engineering Geology and the. Environment, 66, 161-176.

Soysal, H., Sipahioğlu, S., Kolçak, D. ve Altınok, Y., 1981. Türkiye ve çevresinin tarihsel deprem kataloğu (2100 B.C.–1900 A.D.). TÜBİTAK Rapor No. TBAG-341 (in Turkish).

Şaroğlu, F. ve Yılmaz, Y., 1986. Doğu Anadolu'da neotektonik dönemdeki jeolojik evrim ve havza modelleri.. Maden Tetkik ve Arama Dergisi, 107, 73-94.

Şaroğlu, F., Emre, Ö. ve Kuşçu, İ., 1992. Türkiye diri fay haritası (1:1.000.000 öçekli) MTA Genel Müdürlüğü, Ankara.

Şengör, A.M.C., and Kidd, W.S.F., 1979. Post-collisional tectonics of the Turkish Iranian Plateau and a comparison with Tibet. Tectonophysics, 55, 361-376.

Şengör A.M.C., and Yılmaz Y., 1981. Tethyan evolution of Turkey: a plate tectonic approach, Tectonophysics, 75, 181–241.

Uluçam, A., 2000. Eski Erciş-Çelebibağı mezarlığı mezar taşları. Türk Tarih Kurumu, Ankara, 200 p (in Turkish).

Ulusay, R., 2000. Van Yüzüncü Yıl Üniversitesi yerleşkesindeki zemin koşulları hakkında ön değerlendirme. Unpublished report (in Turkish).

Ulusay, R., and Aydan, Ö., 2005. Characteristics and geo-engineering aspects of the 2003 Bingöl (Turkey) earthquake. Journal of Geodynamics, 40, 334-346.

Ulusay, R., Aydan, Ö., Kumsar, H., Sönmez, H. ve Tuncay, E., 2000. Türkiye'de son depremlerde gözlenen sıvılaşma olgusu ve Batı Anadolu'da sıvılaşma potansiyeline genel bir bakış. BADSEM 2000 - Batı Anadolu'nun Depremselliği Sempozyumu, 24-27 Mayıs 2000, İzmir, Bildiriler Kitabı, 323-336 (in Turkish).

Ulusay, R., Aydan, Ö., Erken, A., Kumsar, H., Tuncay, E. ve Kaya, Z., 2002. 3 Şubat 2002 Çay-Eber Depreminin Saha İncelemesi ve Mühendsilik Açısından Değerlendirilmesi. Türkiye Deprem Vakfı Araştırma Projesi No. 02-AP-119, TDV Yayın No. TDV/DR 012-79, İstanbul, 213 s.

Ulusay, R., Tuncay, E., Sönmez, H., and Gökçeoğlu, C., 2004. An attenuation relationship based on Turkish strong motion data and iso-acceleration map of Turkey. Engineering Geology, 74, 265-291.

USGS, 2011. http://earthquake.usgs.gov/earthquakes/

Üner, S., Yeşilova, Ç., Yakupoğlu, T. ve Üner, T., 2010. Pekişmemiş sedimanlarda oluşan deformasyon yapıları (sismitler): Van Gölü havzası, Doğu Anadolu. Yerbilimleri, 31 (1), 53-66 (in Turkish).

Van Province Governorship, 2011. http://www.van.gov.tr/

Van Municapility, 2011. http://www.van.bel.tr/tr/kat

Toksöz, M. N., Nabelek, J. and Arpat, E., 1978. Source properties of the 1976 earthquake east Turkey: A comparison of field data and teleseismic results. Tectonophysics, 49, 199-205.

Yılmaz, Y., 1990. Comparison of young volcanic associations of western and eastern Anatolia formed under a compressional regime: A review. Journal of Volcanology and Geothermal Research, 44, 69-87.

Yılmaz, Y., Dilek, Y. ve Işık, H., 1981. Gevaş (Van) ofiyolitinin jeolojisi ve sinkinematik bir makaslama zonu. Türkiye Jeoloji Kurumu Bülteni, 24, 37-44 (in Turkish).

Yılmaz, Y., Yiğitbaş, E., and Genç, Ş.C., 1993. Ophiolitic and metamorphic assemblages of southeast Anatolia and their significance in the geological evolution of the orogenic belt. Tectonics, 12 (5), 1280-1297.

Yılmaz,Y., Güner,Y., and Şaroğlu, F., 1998. Geology of the Quaternary volcanic centres of the East Anatolia. Journal of Volcanology and Geothermal Research, 85, 173-210.

YTÜ-DBAM, 2011. 23 Ekim 2011 Van depremi (M_w7.2) jeolojik ve jeomorfolojik ön değerlendirme raporu (in Turkish) (www.yildiz.edu.tr/~deguney/ytu-van-deprem-rapor.pdf).