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THE CHARACTERISTICS OF SEISMIC, STRONG MOTION AND STRUCTURAL DAMAGE OF THE 2011 VAN-ERCİŞ EARTHQUAKE

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ABSTRACT: An earthquake with a moment magnitude (M_w) of 7.1 and a local magnitude of 6.7 occurred at 13:41 local time on October 23, 2011 in the Van province of eastern Turkey, which is known to experience large earthquakes in the past. As previous earthquakes did, this earthquake also caused heavy damages to buildings and other structures particularly in the town of Erciş. Collapse of numerous residential and commercial buildings resulted in 604 fatalities and 2608 injuries during the main shock. Following a brief outline of geology, seismo-tectonics and geotechnical conditions in the town of Erciş, an evaluation of strong ground motion characteristics and structural damage are described and the findings and lessons learned from this earthquake are presented.

Key Words: Van-Erciş earthquake, geology, thrust faulting, high ground motions, directivity effect, structural damage

INTRODUCTION

An earthquake with a moment magnitude (M_w) of 7.1 occurred at 13:41 local time on October 23,2011 in the Van province of Turkey (USGS (2011).). The major energy release occurred within 20 seconds although the total duration of the rupture was about 50 seconds. Kandilli Observatory and Earthquake Research Institute (KOERI) estimated that the epicenter of the earthquake was near Tabanlı village (38.628N, 43.486E). The earthquake originated at a depth of 20 km and it was 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 earthquake was felt over a large area in the eastern and southeastern parts of Turkey, particularly in the province of Van, which had a total population of 1,035,418 as of 2010 (The City of Van and the town of Erciş had populations of 539,619 and 145,229, respectively). The earthquake resulted in heavy damage to buildings and significant casualties in this province, particularly in the town of Erciş, the City of Van and a number of villages in the province. The number of fatalities is 604 and the number of injured people is 2608, both caused by collapsed or damaged residential and commercial buildings.

In the first part of the paper, a brief outline of geology, seismo-tectonics and geotechnical conditions of the town of Erciş and its close vicinity is given. The second part involves seismic characteristics of the earthquake and evaluation of strong ground motion characteristics. The third part describes structural damages. In the final part, the findings and lessons learned from this earthquake are presented.

GEOLOGICAL AND GEOTECHNICAL CONDITIONS

The Van Lake Basin is located in the East Anatolian Plateau, which has resulted from the collision between the Eurasian an Arabian Plates in Late Miocene (Şengör and Kidd, 1979; Şengör and Yılmaz, 1983). The basin, formed in Late Pliocene (Şaroğlu and Yılmaz, 1986), is underlined by a basement consisting of Bitlis Metamorphics, Upper Cretaceous ophiolites and Tertiary aged marine sediments. In the 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 Fig. 1, the Van Lake region includes metamorphic rocks belonging to the Bitlis Massive at the south, volcanic and volcano-clastic rocks at the west and north originated from the old volcanoes called Nemrut Süphan and Tendürek.

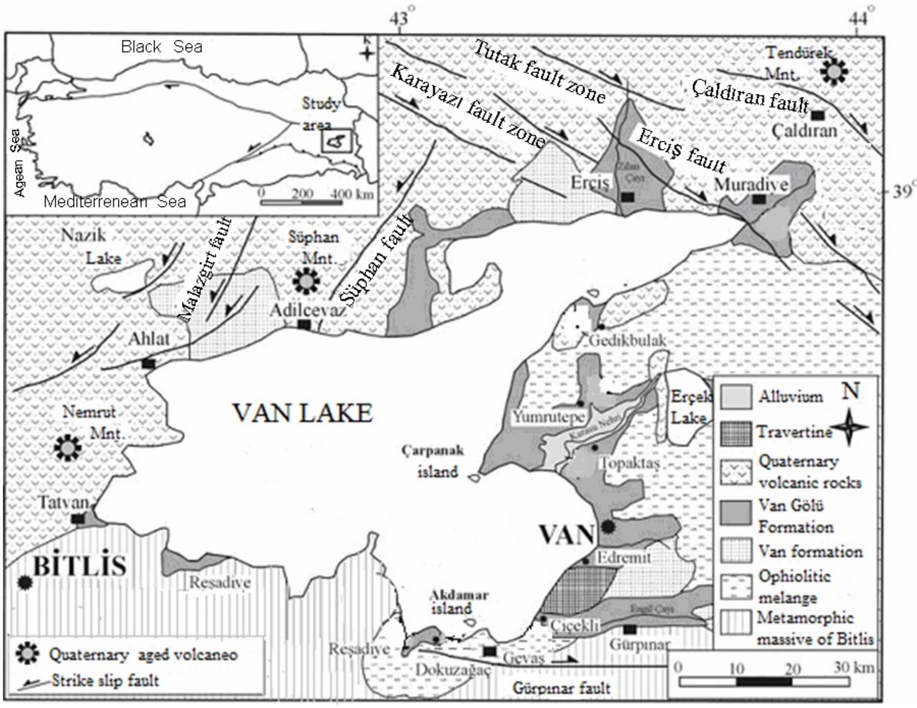

Fig. 1 Simplified geological map of the close vicinity of Van Lake (modified from Üner et al., 2010)

The Van formation, outcropping at the south of Van, west of Erciş and Adilcevaz towns at the north, mainly consists of alternations of loosely packaged sandstone, mudstone and turbitides including pebble layers. This formation has thinly-to-moderately spaced beddings. The majority of these deposits have formed depending on the variations in the water level of Van Lake occurred after the latest ice period and they unconformably overlie the old units (Altunkaynak et al., 2003).

The Holocene deposits in the region consist mainly 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

Van Lake, situated at 1,648 m above sea level in the eastern Taurus Mountains of southeast Turkey is the fourth largest terminal lake in the World (a body of water with streams discharging into without any out-flow). Its surface area is about 3,600 km^2 and mean depth is between 200 and 300 m with maximum water depth measured as 451 m near Adilcevaz at north. The lake water elevation 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 (Landmann and Reimer, 1998). In this area, there are ten big rivers flowing into the lake following different paths. Among them, the Karasu River, flowing in NE-SW direction, is the longest river in the earthquake affected area and forms a large plain at the north of Van.

Similarly, Zilan Stream creates another plain in the vicinity of Erciş at the northern part of Van Lake (Fig. 2). As the damage was quite heavy and extensive in Erciş due to the October 23, 2011 earthquake, a brief outline of hydro-geological and geotechnical conditions of Erciş region is discussed herein.

Zilan and İrşat streams form the main drainage system of the Erciş Plain. The aquifer in this area consists of Plio-Quaternary deposits with a thickness reaching up to 188 m (DSİ, 1977). The measurements from 11 water wells indicated that depth of the static water level was between 0 and 12 m, and in some boreholes artesian pressures were also noted. Özvan et al. (2008) indicated shallow depths of groundwater table ranging between 1 and 8 m in their geotechnical investigations in Erciş town. The direction of groundwater flow is towards SE and SW and the depth of groundwater table becomes considerably shallower near to the lake (Fig. 2).

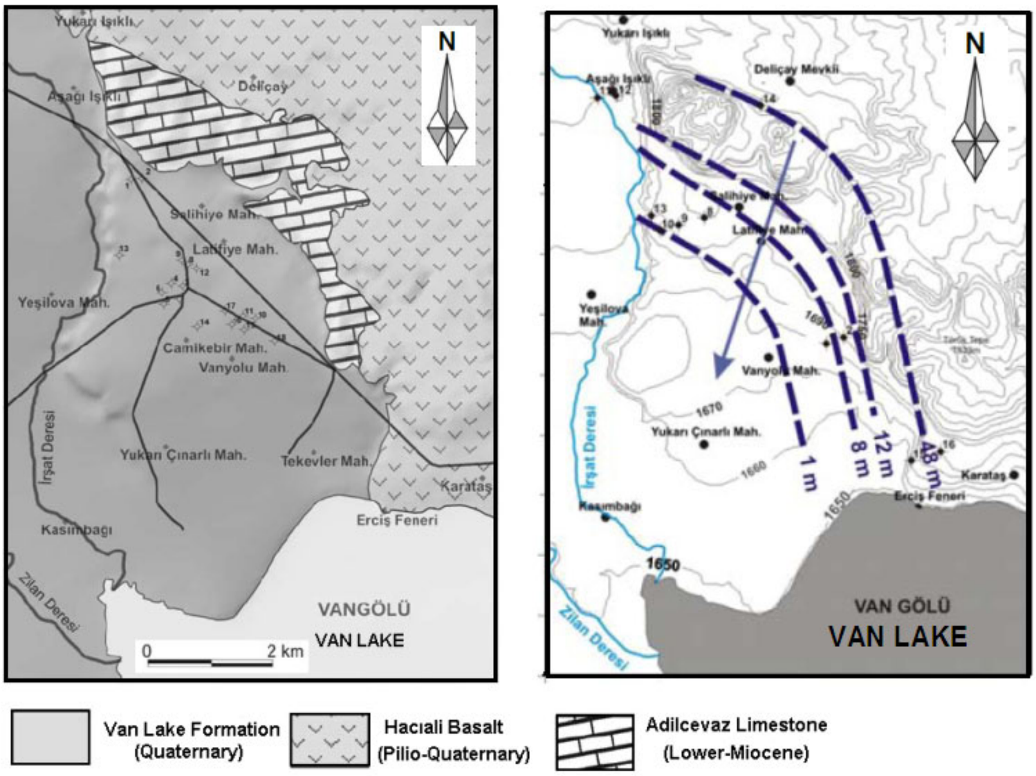

Fig. 2. Geology and hydrogeology of Erciş Plain (re-arranged from Özvan et al., 2008)

TECTONICS, FAULTING MECHANISM AND AFTERSHOCK ACTIVITY

Keskin (2003) proposed a general tectonic model for Eastern Anatolia to explain the uplift of the crust and main driving forces of crustal deformation and associated earthquakes. The tectonics of the region is influenced by the northward moving and subducting Arabian plate beneath the Anadolu plate. The Anadolu plate squeezed between the Arabian plate in the south and 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. Şaroğlu and Yılmaz (1986) studied the neotectonics of the Eastern Anadolu in a broad sense and recognized some major folding axes in the epicentral area and some faults in the north and north-east of Van Lake.

The major active faults of the region are shown in Fig. 1. Regarding the active fault map of Turkey prepared by Maden Tetkik Arama (MTA, 1992), it is interesting to note that no active fault is recognized in the epicentral area. Ketin (1977) was first person studying the tectonics of the epicentral region following the 1976 Çaldıran earthquake. He pointed out the possible traces of faults, which are activated during this earthquake and indicated the necessity for further investigations. Besides the main thrust faults trending E-W, there are conjugate strike-slip faults with some normal components. Özkaymak et al. (2004) recognized thrust and NW-SE and NE-SW trending strike-slip faults. One of them is a thrust fault observed near the campus area of Yüzüncü Yıl University (YYU) located at the NW of the Van city center. This fault is a reverse 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 just below the soil horizon, suggesting that the fault surface was reactivated several times. A more detailed tectonic map of the epicentral area has been released by Koçyiğit et al. (2011) following the earthquake as shown in Fig. 3. He also attempted to relate the faults drawn in his map with the focal mechanism solutions of main and major aftershocks. However, his attempt is quite disputable in many aspects.

The major earthquakes in the close vicinity of Van Lake are 1941 Erciş (M_s 5.9), 1966 Varto (M_s 6.8), 1975 Lice (M_s 6.6) and 1976 Çaldıran (M_s 7.3) earthquakes. While Varto and Lice earthquakes are of thrust type, Çaldıran (M_s 7.3) earthquake has a strike-slip character. The 1976 Çaldıran (M_s 7.3) earthquake also induced some discussion on the continuity of North Anadolu Fault Zone (NAFZ) to the east of Van Lake extending towards Iran. Two intermediate earthquakes having moment magnitudes of 5.4 on 1988 June 14 and 5.7 on 2000 Nov. 15 recently occurred in the eastern part of Van Lake. The faulting mechanism of these earthquakes were of thrust type.

Kandilli Observatory and Earthquake Research Institute (KOERI) estimated that the earthquake was centered about 30 km north of the Van city center near Tabanlı village. 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 together with an inference from fault striation in Topraktaş village as shown in Fig. 3. If the seismicity shown in Figure 4 is considered, the NW dipping faults may be assumed to be the causative fault with a slight sinistral component. The average inclination of the NW dipping fault may be about 40 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 (Photo 1). The earthquake originated at a depth of ranging between 5-19 kilometers depending upon the institutes and it was 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 major energy release occurred within 20 seconds although the total duration of the rupture was about 50 seconds.

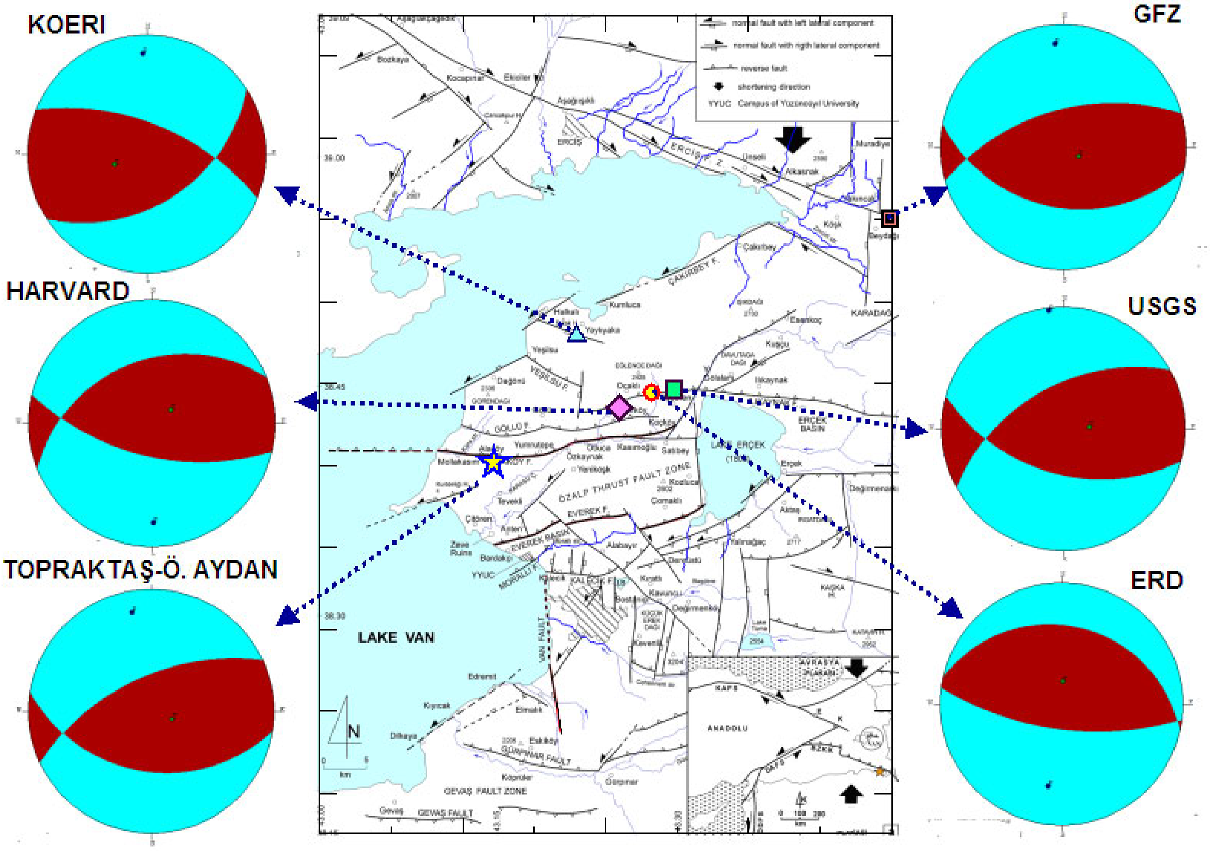

Fig. 3 Faults mapped by Koçyiğit et al. (2011) and focal mechanism solutions by various institutes

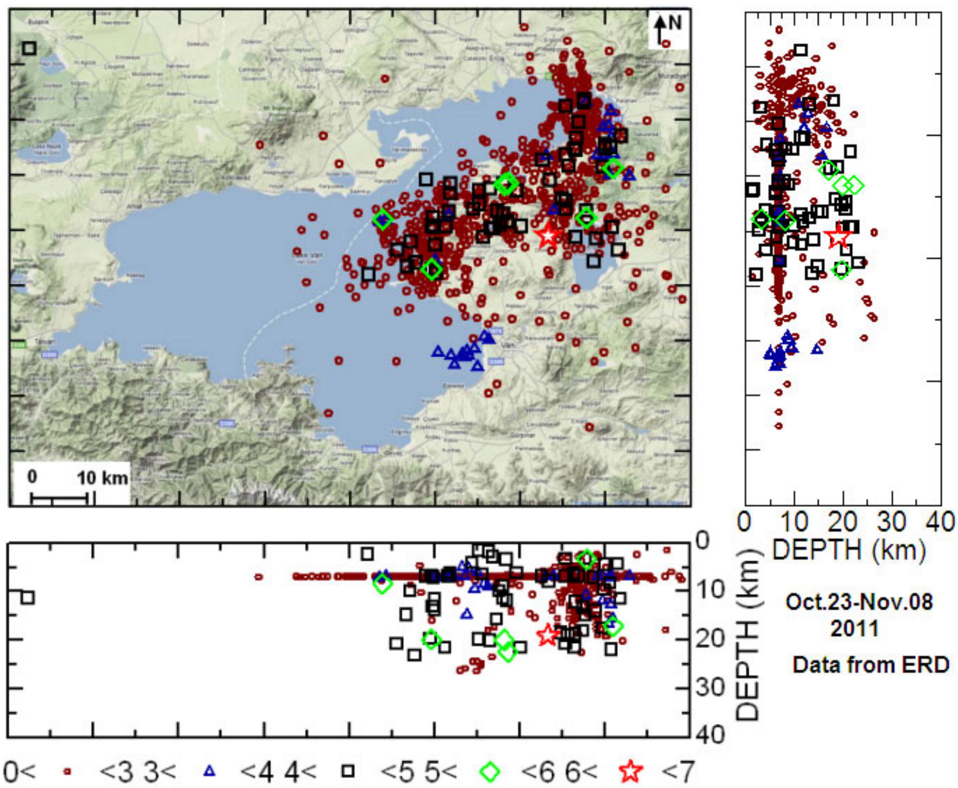

Fig. 4 Aftershock activity following the main shock (aftershock data from ERD)

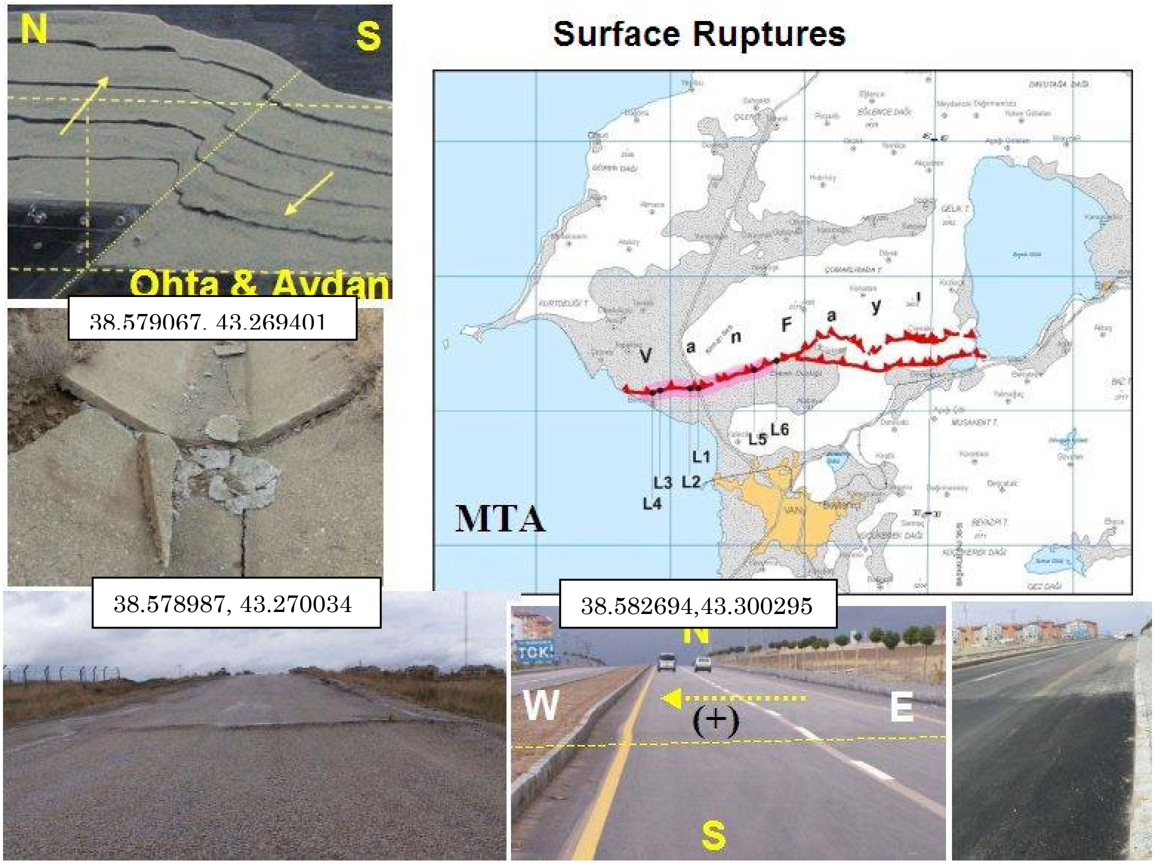

Photo 1 Views of surface rupture along the fault trace (base map from Emre et al., 2011)

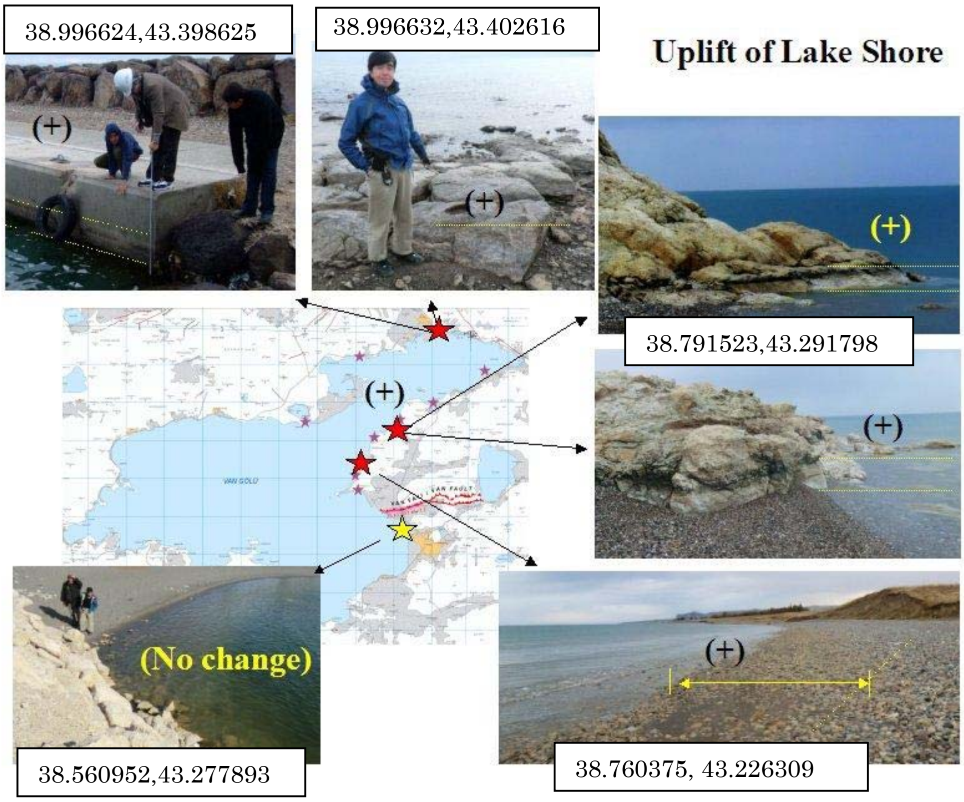

Photo 2 Views of uplift of shoreline at several localities along Van Lake

One of the typical effects of this earthquake is a change in the shoreline of Van Lake as seen in Photo 2. Similar observations were also reported for Erçek Lake (ERD, 2011). The measurements at certain locations on the lakeshore at the northern and eastern parts of the earthquake region by the authors during reconnaissance indicated that uplift of the recent shoreline ranging between 15 and 35 cm has occurred.

CHARACTERISTICS OF STRONG MOTIONS

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. Unfortunately, no strong motion was recorded in neither Van nor in 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.

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 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. Fig. 5 shows the acceleration records taken at Muradiye and Bitlis (38.46600N-42.15000E). The acceleration response of these strong motion stations together with those of Malazgirt and Muş strong motion stations are shown in Fig. 6. Maximum spectral acceleration are observed for a natural period of 0.4 seconds for Muradiye record. In view of natural periods common to reinforced concrete (RC) structures in Turkey, the acceleration response of 6 and 8 story RC buildings should have been very higher. This result can explain why 6–8 story RC buildings collapsed or heavily damaged during this earthquake. 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.

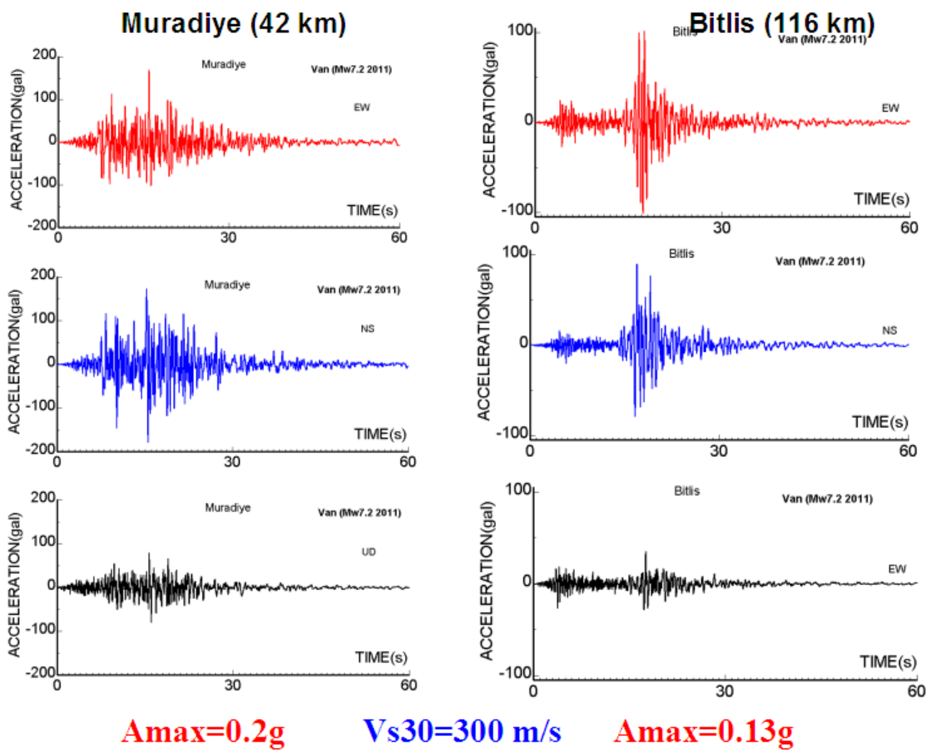

Fig. 5 Acceleration records taken at Muradiye and Bitlis strong motion stations

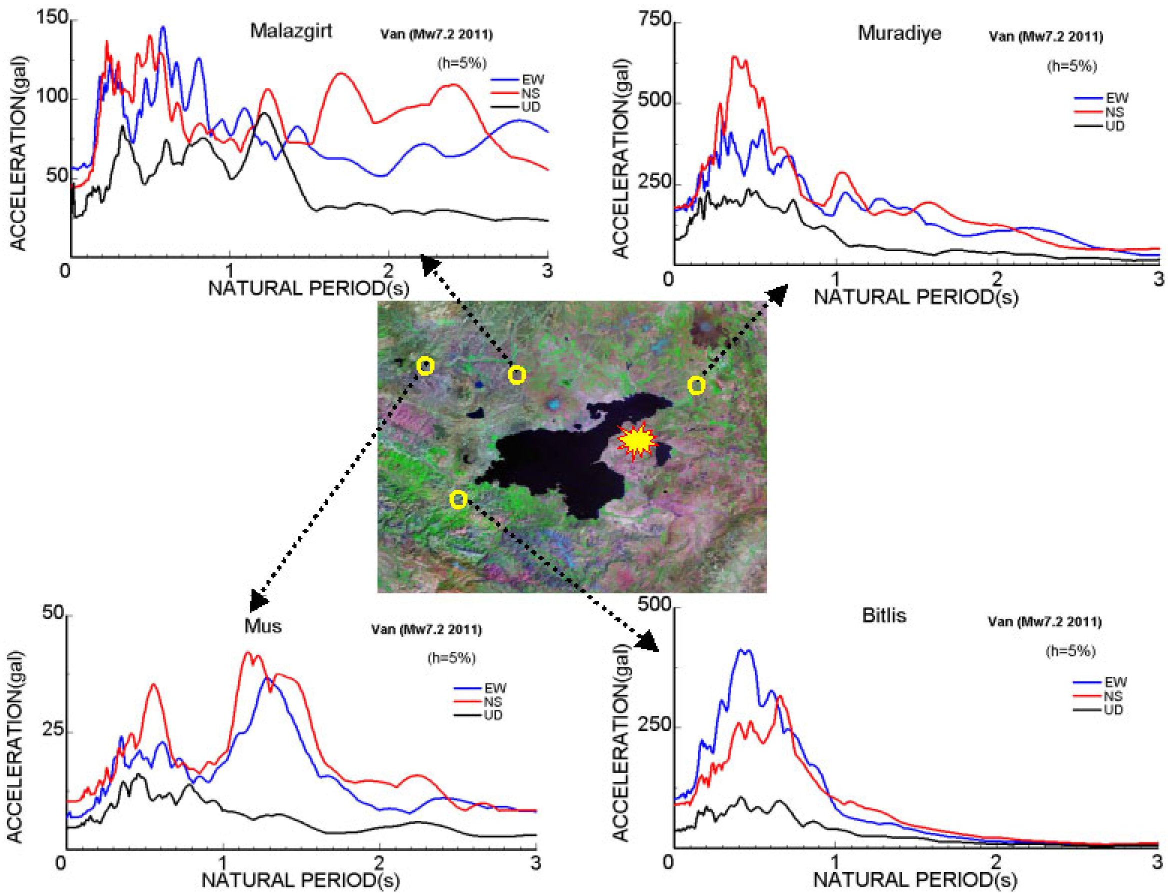

Fig. 6 Acceleration response spectra at selected strong motion stations

Fig. 7 compares estimations by several attenuation relations 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 (2011).

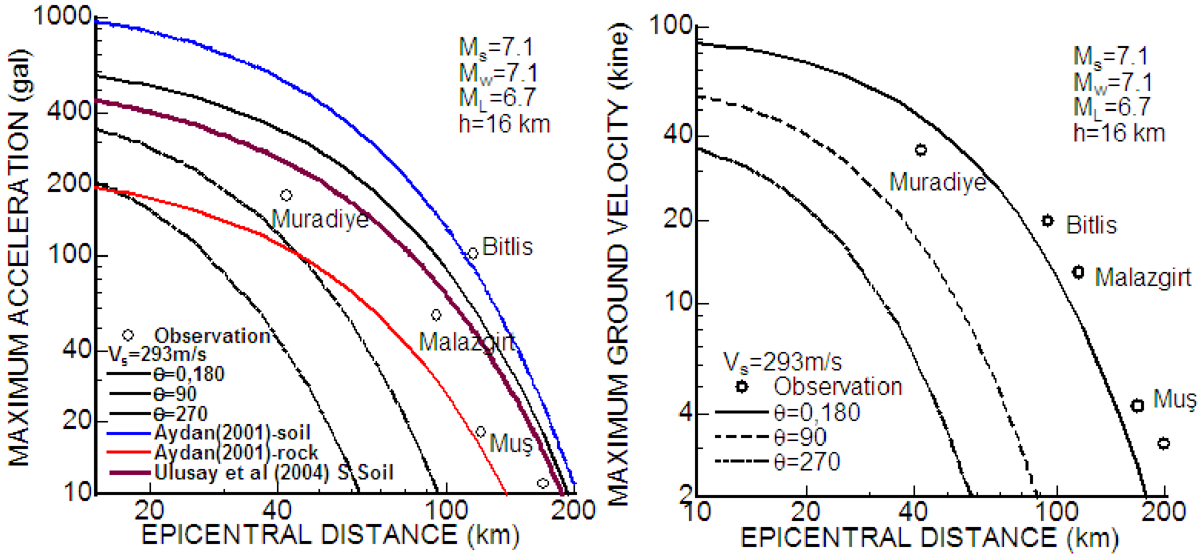

Fig. 7 Comparison of estimations by several attenuation relations with observations

STRUCTURAL DAMAGE

The earthquake resulted in heavy damage to buildings and significant casualties in this province, particularly in Erciş. A number of 6-8 stories RC buildings collapsed particularly in Erciş and Van (Photo 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. It should be added that site effects most likely contributed to alteration of frequency characteristics of the ground motions to adversely affect the buildings. There are available borehole logs but the depths of the logs are shallow and the depth to bedrock is not known.

Buildings in rural areas and villages are of brick masonry or stone masonry type (Photo 4). 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. The bridges are generally constructed using cast-in place technique. The earthquake caused very little damage to bridges. The damage was due to the settlement of piers and settlement and lateral deformation of approach embankments (Photo 5).

Some ground liquefaction occurred at Van port and there were some slight cracking to RC components and deformation of railways (Photo 6). Nevertheless, the port was functional.

There are several rock-fill dams up to 65 m high and earth-fill water reservoirs in the epicentral area. The earthquake did not cause any damage to the dams even some of them were very close to the earthquake epicenter.

Photo 3 Views of collapsed RC buildings and detailing of RC elements

Photo 4 Views of heavily damage brick masonry buildings

Photo 5 Views of slightly damaged Tirleşin bridge over Karasu on Van-Ağrı Highway

Photo 6 Views of slightly damaged Van port (all photos at around 38.516441, 43.308368)

CONCLUSIONS

The following conclusions may be drawn from the previous sections:

(a) 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.

(b) The strong motions induced by this earthquake has 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.

(c) The main causes of heavy damage or collapse of reinforced concrete buildings are similar to those observed in previous earthquakes occurred in Turkey. This earthquake also showed that the non-structural repairs of buildings are disastrous and must be avoided.

(d) Except buildings, the damage to common civil engineering structures such as roadways, bridges, tunnels and dams was almost none or slight.

As a result of the observations, it is strongly suggested that the construction practices in earthquake prone areas of Turkey 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.

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