The Effects of Site and Soil Conditions To the Earthquake Damage: Oct, 23 2011 Van-Tabanlı Earthquake (M_w=7.2)

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SUMMARY:
A strong earthquake of magnitude M_w=7.2 occurred on October 23, 2011 close to the city of Van in Eastern Turkey. The earthquake took place at a depth about 18km on the shore of Lake Van causing significant damage to Van and neighboring countries. According to the preliminary evaluation damage reports, 3713 heavily damaged buildings (not safe to occupy) and 2209 damaged buildings (possibly safe to occupy) are determined. Most of the damage has been localized in Ercis district. In this study, first findings following the earthquake were realized focusing on structural and geotechnical damages on site, analyzing the strong and weak motions recorded different stations located in the region. The response of deep soft alluvial layers, which is located at Ercis district, was also analyzed. Possible site and soil effects on huge structural damage were investigated.

Keywords: Earthquake damage, local site conditions, strong motion data

1. INTRODUCTION

A strong earthquake of magnitude M_w=7.2 occurred on October 23, 2011 at 10:41:22.0 UTC close to the city of Van in Eastern Turkey near Lake Van. The earthquake took place at a depth of ~18km on the shore of lake Van causing significant damage to Van and neighboring towns. It has also been largely felt in Turkey and in the neighboring countries. No surface rupture has been observed. The rupture duration was about 50 seconds. According to the preliminary evaluation damage reports ; 3,713 and 2,209 buildings are determined as heavily damaged (not safe to occupy) and damaged (possibly safe to occupy), respectively. Most of the damage has been localized in Erciş district. The seismotectonics of the region are dominated by the collision of the Arabian and Eurasian plates. The Arabian plate converges with Eurasia in N-S direction at a rate of ~24 mm/yr. The October 23, 2011 earthquake occurred near the East and North Anatolian strike-slip fault zones. Two fault systems extend across central and western Turkey and accommodate the western motion of the Anatolian block. In the area of Lake Van, tectonics is dominated by the Bitlis Suture Zone.

In this study, first findings following the earthquake were discussed focusing on geotechnical damages on site, analyzing the strong ground and weak motions recorded at different stations located in the region and possible reasons for structural damage. The response of deep soft alluvial layers during the earthquake, which is located in Ercis district, was also analyzed.

2. VAN- TABANLI EARTHQUAKE (M_W=7.2) OCT, 23 2011

The epicenter of the Van-Tabanlı earthquake is reported to be about 30km to the north of the Van city center by Bogazici University, Kandilli Observatory and Earthquake Research Inst. (BU-KOERI). The earthquake parameters reported by different institutions are given in Table 1. In this part of the paper, geology of the region, historical earthquakes in Van region and local geology are briefly discussed (Cetin *et al*.,2012).

2.1. Geology of the Region

The collision of the Arabian block with the Eurasian plate resulted in neotectonic provinces in Turkey including the East Anatolian Contractional Province, North Anatolian Province, Central Anatolian Province and West Anatolian Extensional Province (Figure 1). The East Anatolian Contractional Province is bounded by the Bitlis-Zagros Suture Zone in south and Caucasus in North. The region is characterized by a N-S compressional tectonic regime which resulted in mainly NW-SE trending dextral and NE-SW trending sinistral conjugate strike-slip faults (Figure 2). Nearly E-W trending thrust faults and N-S extending normal faults or extensional fissures also exist in the region.

A thrust fault in north of Van was reactivated by a 7.2 earthquake on October 23, 2011. This fault is called Van Fault by Akyuz *et al*. (2011) and Emre *et al*. (2011) extending between Lake Van in west and Lake Ercek in east and it was not mapped in previous studies (Figure 2). The total length of the fault is about 27km in land, but it probably continues both further west and east beneath Lake Van and Lake Ercek, respectively. The northern side is uplifting along the nearly E-W-trending fault line (Figure 3). The October 23rd, 2011 Van earthquake involved surface faulting between Lake Van in west and Lake Ercek in east. Surface rupture was mapped by different teams in the field. According to Akyuz *et al*. (2011), the rupture extends for a distance of about 4km in north of Bardakcı Village. However, Emre *et al*. (2011) mapped about 10km long surface rupture for the October 23, 2011 Van earthquake (Figure 2.3). The northern block uplifted up to 10cm along the surface rupture. Compressional deformation structures observed in the field (Figure 3) along the rupture zone indicates thrust faulting. Akyuz *et al*. (2011) states that the surface rupture occurred during the October 23, 2011 earthquake follows a pre-existing morphological scarp which was probably produced by historical earthquakes.

The October 23, 2011 Van earthquake occurred in a broad region of convergence beyond the eastern extent of strike-slip tectonics. In the area of Lake Van, tectonics is dominated by the Bitlis Suture Zone and Zagros fold and thrust belt. The East Anatolian Plateau with an average elevation of ~1500m experienced large earthquakes in the past. The region is located between two very different tectonic regimes. To the east, a great deal of convergence is observed as the Arabian plate to the south moves northwards into the Eurasian plate, as part of a mountain belt which runs from the Alps to the Himalayas. To the west, the strike-slip faulting is concentrated on the North and East Anatolian Faults.

Table 1. Van-Tabanlı Earthquake Parameters

	BU-KOERI	DEMP	USGS	EMSC	INGV
Date/ Time	2011/10/23 13:41:21 (local)	2011/10/23 13:41:20	2011/10/23 10:41:21 UTC	2011/10/23 10:41:22.7 UTC	2011/10/23 10:41:00 UTC
Latitude	38.7578N	38.6890N	38.628N	38.86N	38.86N
Longitude	43.3602E	43.4657E	43.486E	43.48E	43.48E
Depth	5km	19.02km	20km	10km	10km
Magnitude	6.6(ML),7.2 (Mw)	6.7(ML), 7.0(MW)	7.2 (Mw)	7.3 (Mw)	7.3 (Mw)
Location	Tabanlı-Van	Van-Merkez	Eastern Turkey	Eastern Turkey	Eastern Turkey

BU-KOERI: Bogazici University, Kandilli Observatory and Earthquake Research Inst.
DEMP: Disaster and Emergency Management Presidency; USGS: United State Geological Survey
EMSC: European-Mediterranean Seismological Centre; INGV: Instituto Nazionale di Geofisica e Vulcanologia

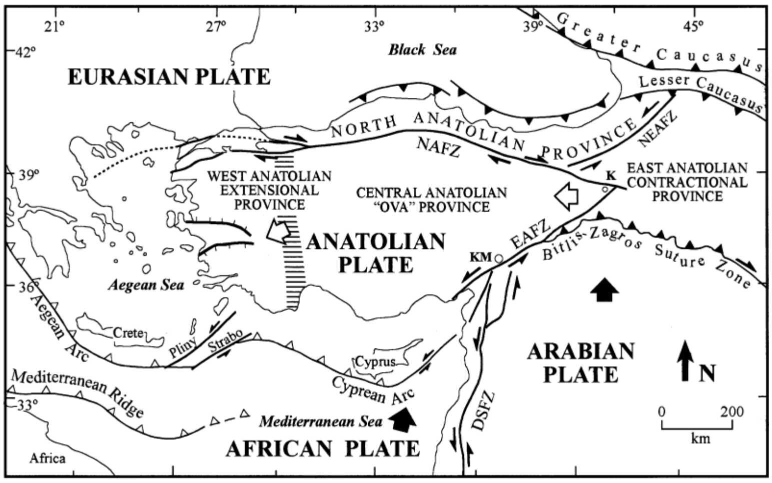


Figure 1. Neotectonic provinces of Turkey and major active fault zones (Bozkurt, 2001)

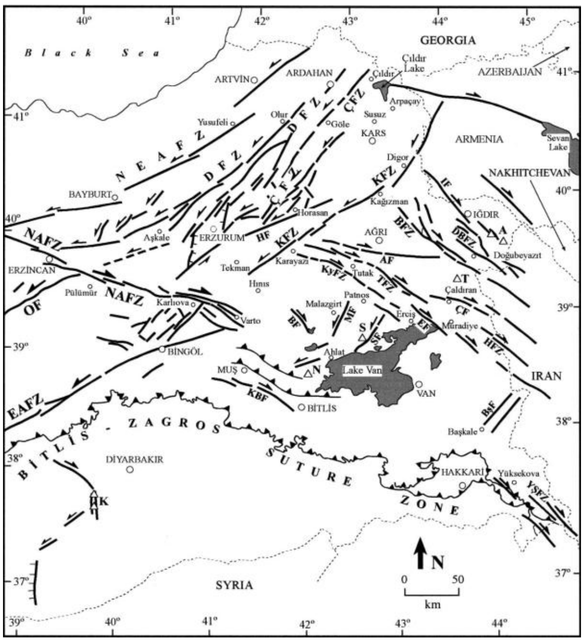


Figure 2. Main active faults in East Anatolia (NAFZ: North Anatolian Fault Zone, EAFZ: East Anatolian Fault Zone, EF: Ercis Fault, CF: Caldiran Fault (source of the M=7.5 earthquake in 1976)) (Bozkurt, 2001)

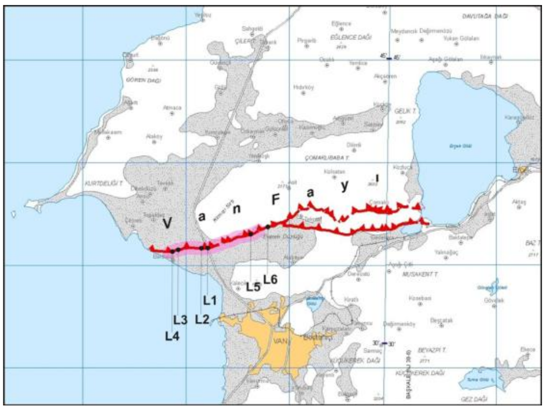


Figure 3. Surface rupture map of the October 23, 2011 Van earthquake (Emre *et al*. 2011) (pink line is the surface rupture

2.2. Historical Earthquakes in Van Region

An overview of earthquake records both in historical times and instrumental period shows that the faults are seismically active and some major earthquakes occurred in the region. According to Guidoboni and Comastri (2005), an earthquake occurred around Van in 1117 (or 1118) and a destructive earthquake destroyed Ahlat (located western coast of Lake Van) and Ercis in 1275. According to Ambraseys (2009), an earthquake occurred in April 1646 and caused heavy damage in Van, Edremit, Gurpınar and Ercek. Ambraseys (2009) reported that more than 2000 people died. As Table 2 shows, moderate to large earthquakes also occurred in the 20th century and caused damages in the region.

Table 2. Damaging earthquakes around Van in the 20th century (BU-KOERI)

Date	Time	Location	Intensity	Magnitude	Total death	Damaged building
28.04.1903	01:46	Malazgirt	IX	6.7	600	450
10.09.1941	23:53	Ercis	VIII	5.9	192	600
24.11.1976	14:22	Muradiye	IX	7.5	3840	9232

2.3. Local Geology

The Lake Van Basin is located on the Eastern Anatolia Plateau resulted by the collision of the Arabian block with the Eurasian plate in the Late Miocene (Sengor and Kidd, 1979; Sengor and Yilmaz, 1981). The Lake Van Basin formed in the Late Pliocene (Saroglu and Yilmaz, 1986) is situated on main structure formed by deep marine sediments with the Tertiary Age, and ophiolitics aged in the Upper Cretaceus and Bitlis metamorphics. The Quaternary aged volcanic from Nemrut in the west and Suphan in the north and in the same aged lacustrine sediments (Lake Van Formation) overlie unconformably above the main structure in the Lake Van Basin. The Basin sediments are ended by travertens aged in the Late Quaternary and unconsolidated fluvial sediments. According to Uner et al. (2010), the Basin is formed in the Late Pliocene and attained its final shape with Quaternary volcanic activities. They found some deformed structures in Quaternary aged sandy and silty lacustrine sediments in the Lake Van Basin.

3. GEOTECHNICAL EFFECTS

Post-earthquake damage investigations show that not only structures but also natural structure of soil and lifelines are damaged during a severe earthquake ground motion. Local soil conditions have played a major role on structural damage concentrating in some regions in past earthquakes. Soil failures due to Van earthquakes are presented below under three main components: landslides and slope instability; lateral spreading and settlements due to liquefaction; soil amplification Cetin *et al*. (2012).

3.1. Landslides and Slope Instabilities

Significant landslides and settlements were mostly observed around Celebibag Village (Ercis) which is located on the upper-west of Lake Van. Soil cracks shown in Figure 4 can be characteristically assessed as the main scarps due to land sliding. Permanent ground deformations extended up to 50cm in the horizontal and vertical directions. Some numerous landslides were also observed along the Shore of Karasu River. During Van-Tabanlı earthquake, some slope instabilities have also been observed at highway embankments and artificial infills. A slope failure extending all the way through the Van-Ercis highway embankment was mapped as shown in Figure 5a. A maximum of ~40 cm vertical offset was also mapped along with lateral deformations exceeding 15 cm (Figure 5b). Rockfalls which can be defined as a massive rock of any size detached from a steep slope or cliff along a surface were observed along the highway. Approximate diameters of the rocks varied in the range of 1.0-1.3m (Figure 6a). The path of rollling can be seen in Figure 6b.

3.2. Liquefaction and Lateral Spreading

Some evidences of liquefaction and sand boils were observed at different locations near the shoreline of Lake Van and along the Karasu and Zilan Rivers during Van-Tabanlı earthquake. Extensive geotechnical hazard such as liquefaction, liquefaction-induced lateral spreading and settlements occurred in Celebibag located in western Ercis near the Ercis-Patnos highway and in the rural areas of North-western Van. Liquefaction induced lateral spreading and settlement and rockfalls happened nearby Topaktas village (15 km away from the Van city center), next to the river in Northern Van, 6 km to the north of the Van 100. Yil University (Figure 7). By the natural beach of Lake Van, significant seismically-induced lateral spreading and settlements were observed. Surface manifestation of soil liquefaction in the form of sand boils was widespread. The extent of lateral deformations was mapped as 22 cm along with 15-25 cm relative settlement (Figure 8a). Sieve analysis results performed on sampled sand boils are summarized in Figure 8b, indicating high-potential for liquefaction.

3.3. Soil Amplification

Site amplification plays a major role on damage distribution during earthquakes. Some typical soil layers (unconsolidated soils) can amplify earthquake ground motions resulting in damage to structures far from the epicenter of the earthquake. A site response analysis was performed with a typical site profile near Ercis to recognize if soil amplification took place during the earthquake. An idealized soil profile based on 21 borehole results in Ercis was taken out (Figure 9). Duzce (M_w=7.1) earthquake ground motion records (recorded at site class B) have been used as bedrock motion at engineering bedrock level (z=70m for this site). The motions at the surface (z=0) for Duzce, 1999 is determined after site response analyses by using SHAKE2000, and the motions corresponding to Duzce Earthquake, 1999 are given in Figure 10. The peak ground accelerations at the surface increased between 59-96% with respect to the bedrock motion.

Figure 4. Soil cracks due to landslides in Celebibag, Ercis

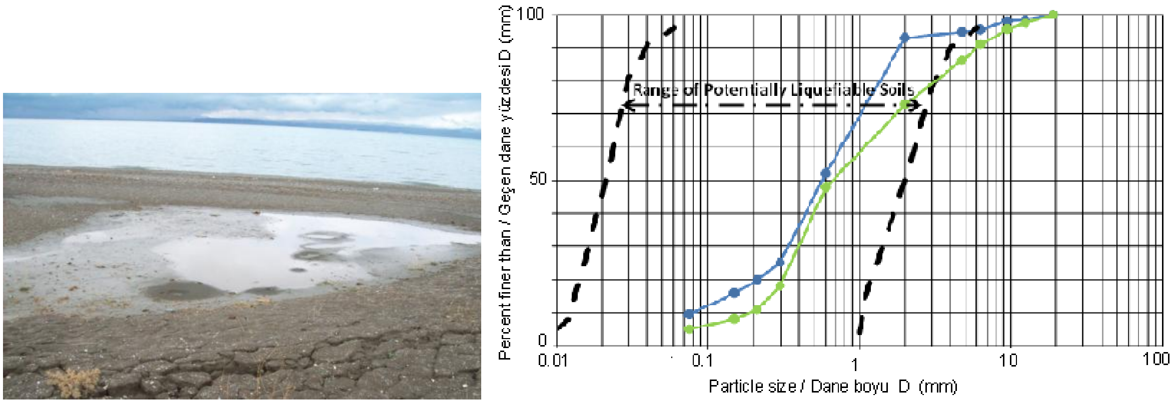
a. **b.**

Figure 5. Slope instabilities: a. slope failure; b. ~40cm offset along Van-Ercis highway

a. **b.**

Figure 6. Rockfalls: a. the rock on the highway; b. the trace of the rockfall path

Figure 7. Sand boils due to liquefaction in Topaktas village, Van



a. **b.**

Figure 8. Lateral deformations: a. seismic soil liquefaction-induced sand boils and lateral spreading by Lake Van; b. sieve analysis

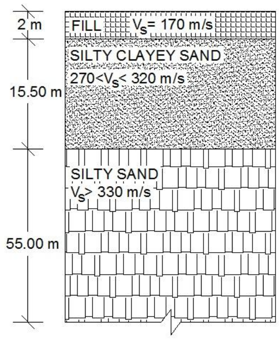


Figure 9. Idealized soil profile in Ercis

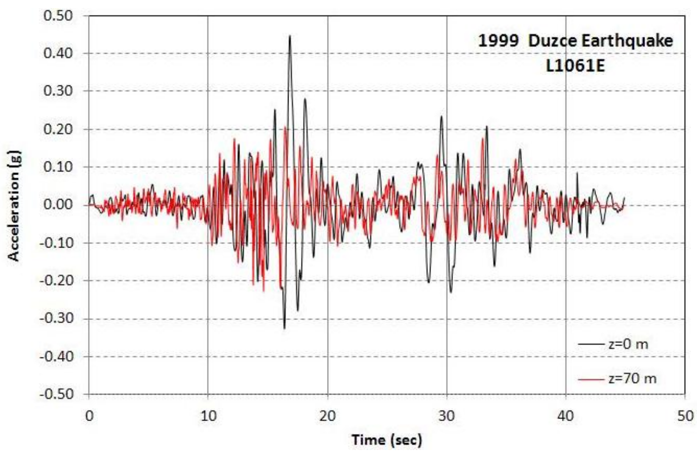


Figure 10. Time histories at surface (z=0) and z=70m depth obtained from site response analysis at idealized soil profile in Van region with using Duzce earthquake ground motion record in E-W direction

4. STRUCTURAL DAMAGES

A wide range of structural damage was observed along Vanyolu Street as shown in Figure 11 and 12. Many buildings collapsed due to the soft story mechanism and inadequate confinement in beam-to-column joints. The minarets' of some Mosques also collapsed (Figure 11b). One of the major problems after the earthquake that local authorities faced was the rapid assessment of the buildings damaged during the earthquake. Considering the amount of building stock, Ministry of Environment and Urbanization, Turkey assigned teams of experts from universities all over the country to label the level of damage in each building (medium, heavy, near collapse) using an evaluation form. Meanwhile, Housing Development Administration of Turkey started constructing buildings in the area for those whose buildings were damaged and lost their loved ones.

a. **b.**

Figure 11. Extent of structural damage along Vanyolu Street, Ercis: a. totally collapsed building due to soft story mechanism; b. collapsed minaret of Van Yolu Mosque (GIT-EQ, 2011)

a. **b.**

Figure 12. Beam-column joint failures in Ercis: a. failure in a beam-column joint due to inadequate confinement; b. brittle failure in a beam-column joint (GIT-EQ, 2011)

5. STRONG GROUND MOTION RECORDINGS OF THE MAINSHOCK

The strong motion recordings of the main shock are provided by the National Strong Ground Motion Network operated by the Earthquake Department of the Disaster and Emergency Management Presidency (http://www.deprem.gov.tr). Three of the stations are located within 150 km of the epicenter of the main shock; Muradiye, Bitlis and Agrı. Figure 12 shows the acceleration, velocity and displacement time histories of the ground motion recorded at Muradiye Station during the October 23, 2011 Van-Tabanlı earthquake. Figure 13 shows the acceleration spectra of the ground motion recorded at Muradiye, Bitlis and Agri Stations during the October 23, 2011 Van-Tabanlı earthquake. It can be seen that the ground shaking observed was low with peak accelerations not exceeding 0.2g in both horizontal directions, vertical accelerations below 0.1g, and the duration of strong ground motion in the order of 20 seconds. Peak ground accelerations of 0.18g, 0.101g and 0.018g are recorded at Muradiye Station (46 km away from the epicenter), Bitlis station (116 km away from the epicenter) and Agrı station, respectively. Response spectra of the earthquake ground motions recorded during the October 23, 2011 Van-Tabanlı earthquake are given in Figure 14. Design response spectra corresponding to 10% probability of exceedance in 50 years with respect to Turkish Earthquake Code (TEC, 2007) and Turkish Seismic Code for Shore Structures (DLH, 2007) are also included in Figure 15. As can be seen from Figure 15, the design response spectrum as given by DLH (2007) falls below the response spectrum of the earthquake ground motion recorded at Muradiye station, whereas TEC

(2007) spectrum fits quite well to this spectrum for the October 23, 2011 Van-Tabanlı earthquake.

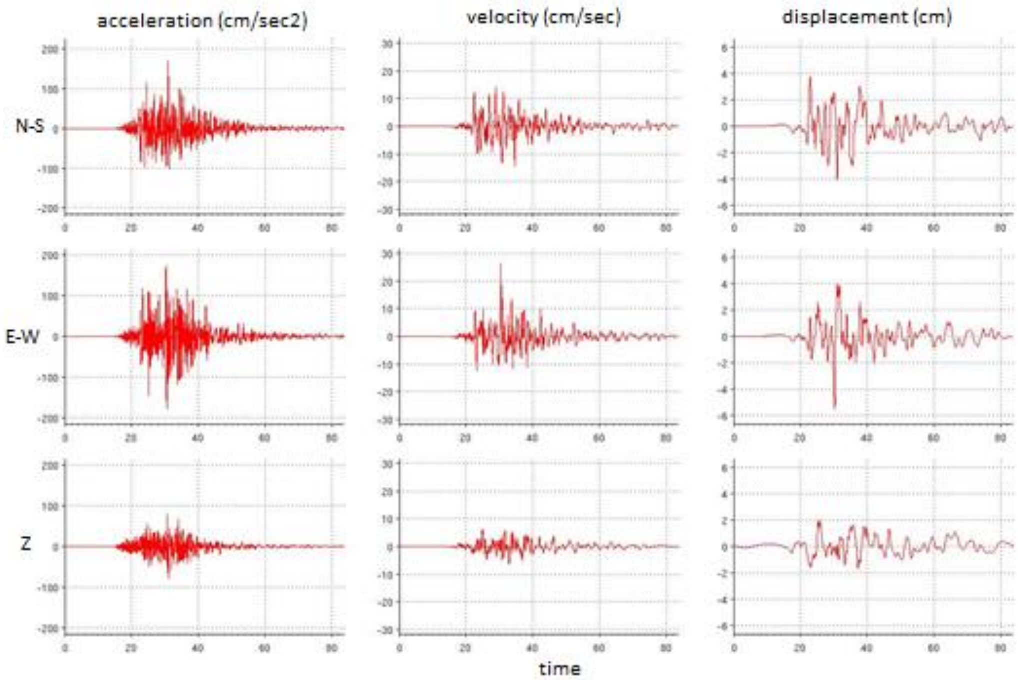


Figure 13. Acceleration, velocity and displacement time histories of the recordings of M_w=7.2 earthquake at the Van- Muradiye station

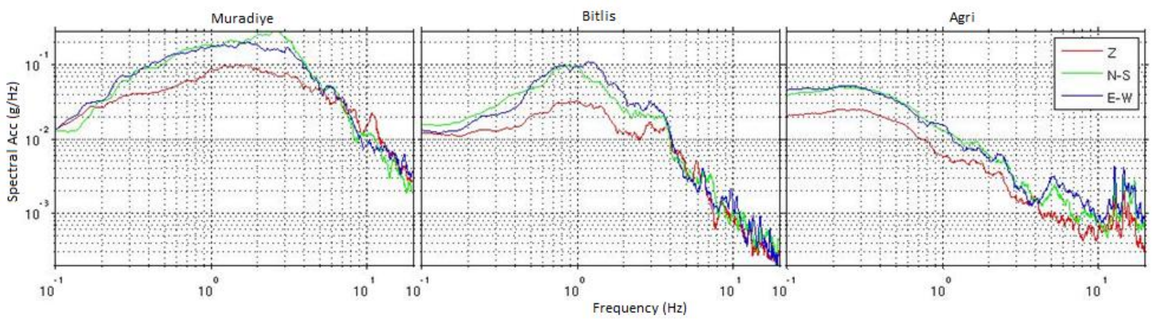


Figure 14. The acceleration amplitude spectra of the strong motion recordings at Muradiye, Bitlis and Agrı stations

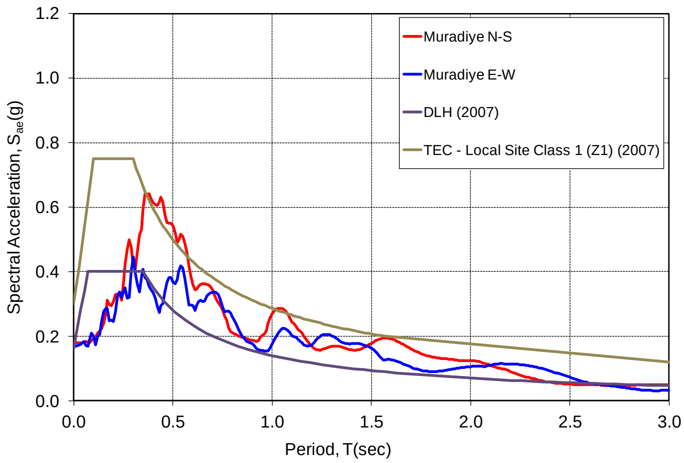


Figure 15. Response spectra of Van-Tabanlı earthquake of October 23, 2011

6. RESULTS AND CONCLUSIONS

October 23, 2011 Van-Tabanlı (M_w=7.2) earthquake caused many geological effects around the Van province. This study first put forward the general characteristics of the earthquake from various sources. Then, the geology of the region including local geology is evaluated in detail. Soil failures due to the earthquake are classified into three main components; landslides and slope instability; lateral spreading and settlements due to liquefaction; soil amplification. Some examples of structural damages in Ercis are briefly presented. Main and aftershocks are discussed in detail. In the last section, strong ground motions recordings including soil amplification and response spectra of the recorded earthquake ground motions for Van earthquakes are summarized. Results from the site response analyses on an idealized soil profile indicated a certain soil amplification which might be one of the reasons for extensive damage in Ercis. Van earthquake will have lasting consequences on engineering practices in Turkey. Many factors played key role leading to this catastrophe in the region including low engineering practice, rapid urbanization and economic growth in seismically risky areas. This region is prone to severe seismic events as many regions in Turkey. The severe impact of future earthquakes can be lessened by learning from the Van and past earthquakes.

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