THE CHARACTERISTICS OF GEOTECHNICAL DAMAGE BY THE 2011 VAN-ERCİŞ EARTHQUAKE

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ABSTRACT: An earthquake with a moment magnitude of 7.1 occurred at 13:41 on local time on October 23, 2011 in the Van province of the Eastern Turkey. Brief outlines of geology, hydrogeology and geotechnical conditions in Erciş town and Van City and along the shore of Van Lake are first given. Then, observed ground liquefactions, associated ground deformations, sand boils and their characteristics are presented. In addition, slope and embankment failures are also presented and their characteristics are compared with available approaches. Finally the effects of geotechnical events on structural damages are given and discussed.

Key Words: Van-Erçiş earthquake, ground liquefaction, lateral spreading, slope failure, embankment failure, geotechnical damage

INTRODUCTION

An earthquake, named as Van- Erciş, occurred at 13:41 on local time on October 23, 2011 in the Van province of the Eastern Turkey. The moment magnitude (M_w) of this earthquake was 7.1. Kandilli Observatory and Earthquake Research Institute (KOERI) estimated that the earthquake was centered near Tabanlı village. The estimated depth of this earthquake ranges between 5-19 kilometers depending upon the institutes and the movement of a 50 km long and 20 km wide thrust fault trending about E-W direction caused the earthquake.

The earthquake was felt over a large area in the eastern and southeastern parts of Turkey. The earthquake resulted in heavy damage to buildings and significant casualties in this province, particularly in Erciş town, which is located over a soft ground prone to ground liquefaction.

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. In addition to poor quality construction and inappropriate construction materials, the damage was caused partly by the permanent displacement of liquefied ground l in the vicinity of Erciş city at the northern part of the earthquake-affected region.

The authors have gathered some samples from sand boils observed during the reconnaissance. In addition, based on the available information on the geotechnical conditions in Erciş town and Van City the ground liquefaction conditions were re-evaluated. Moreover, there were a number of slope and embankment failures, and some of them reached to the Van-Ağrı Highway.

This paper outlines the characteristics of geotechnical damage induced by the 2011 Van-Erciş earthquake of October 23, 2011. In the first part of this paper, a brief outline of geological conditions of the Van province and geotechnical conditions of Erciş and Van settlements are given. In the second part, the sites of ground liquefaction, embankment failures, slope failures and rock falls are given and the characteristics of geotechnical damage by the Van-Erciş earthquake are compared with the observations of the past earthquakes in Turkey. In the final part, structural damage caused by ground liquefaction and associated lateral spreading, embankment and slope failures are described and the implications of the geotechnical damage by this earthquake in the regional context are also discussed.

GEOLOGICAL, HYDROGEOLOGICAL AND GEOTECHNICAL CONDITIONS

The Van Lake Basin is located at the East Anatolian Plateau and formed in Late Pliocene (Şaroğlu and Yılmaz, 1986). Its basement consists of Bitlis Metamorphics, Upper Cretaceous ophiolites and Tertiary aged marine sediments. In the Van Lake region, different rock units and alluvial deposits formed between Paleozoic and Holocene are observed. As seen from the simplified geological map shown in Fig. 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 fluvial and lacustrine deposits.

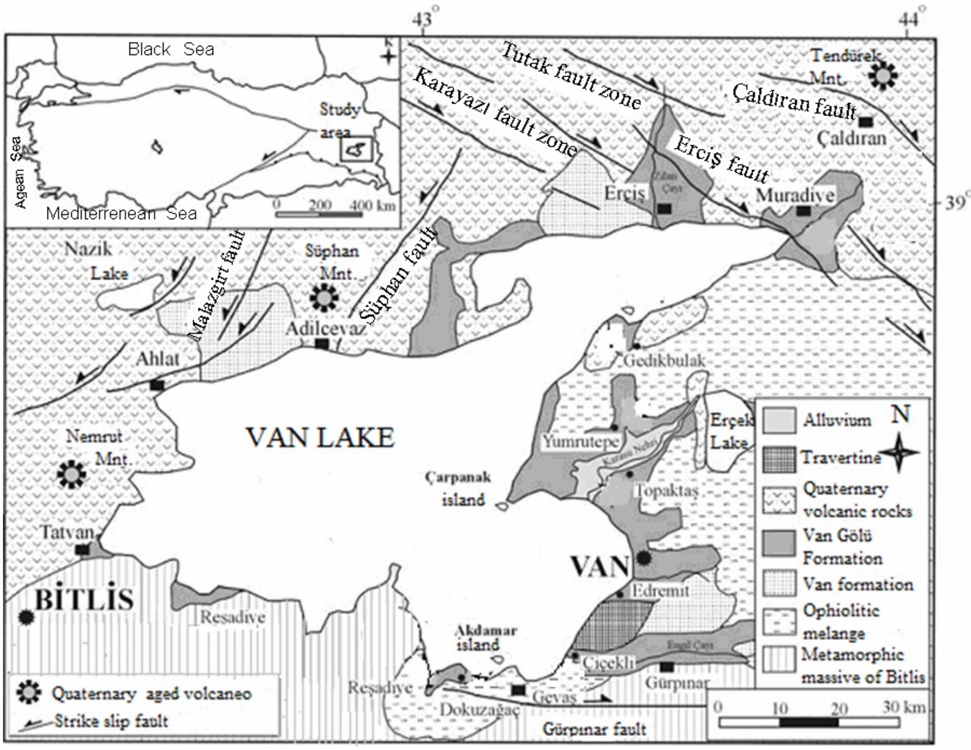

Fig. 1 Simplified geological map of the close vicinity of Lake Van (modified from Üner et al., 2010)

The Van formation 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 (Özkaymak, 2004). The Holocene deposits in the region 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).

Van Lake is situated at 1,648 m above sea level in the eastern Taurus Mountains, southeast Turkey. Fig. 2 shows the long-term fluctuation of water level of Van Lake. The water level of the lake was about 50 m higher than the present water level about 3 kyr B.P.. 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). In this area, there are ten big rivers flowing to the lake following different courses. 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, Zilan Stream created another plain in the vicinity of Erciş at the northern part of Van Lake. As the damage was quite heavy and extensive in Erciş due to the October 23, 2011 earthquake, a brief outline of hydrogeological and geotechnical conditions discussed herein.

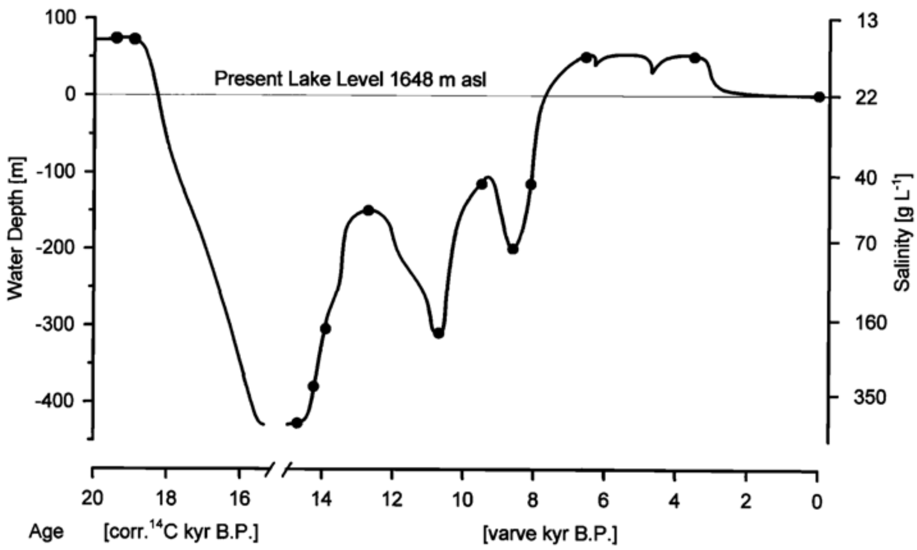

Fig.2 Long-term period fluctuation of water level in Van Lake (from Landmann et al. 1996)

The groundwater table is generally close to the ground surface in the cities and towns situated on low lands where damage was quite heavy. Based on long-period measurements in 33 borings drilled in Van Plain, the groundwater table in Van and its close vicinity has an inclination from east to west and SW depending on topography, and depth of static water level in these boreholes ranges between 1 and 29 m (Özler, 2008). Özvan et al. (2005) also indicate that the groundwater table is very close to the ground surface next to Van Lake (1646 m) and it is 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, was carried out (Selçuk and Çiftçi, 2007). This study based on the data from 31 boreholes suggested that depth of the groundwater level in YYU campus area was between 1.5 to 10 m flowing towards S and SW indicating the presence of a shallow seated groundwater table. The Van aquifer is an 11 km wide and 14 km long, and Özler (2008) mentioned that the Van Gölü formation forms this aquifer in the vicinity of Van and has shore plain aquifer characteristics (Fig. 3). Inclination of the layers in this formation, which is mainly composed of sands and gravels with clay interlayers, ranges between 15 and 30^0 towards Van Lake. This investigator also reported an artesian (+2 m) in the boreholes drilled at the vicinity of the port of Van due to the existence of 2-8 m thick clay layer above a sandy-gravelly layer with a thickness of 5-10 m. The groundwater table reaches up to its maximum level in March and April, and to the lowest level in July and August, and it does not fall below the water level in Van Lake.

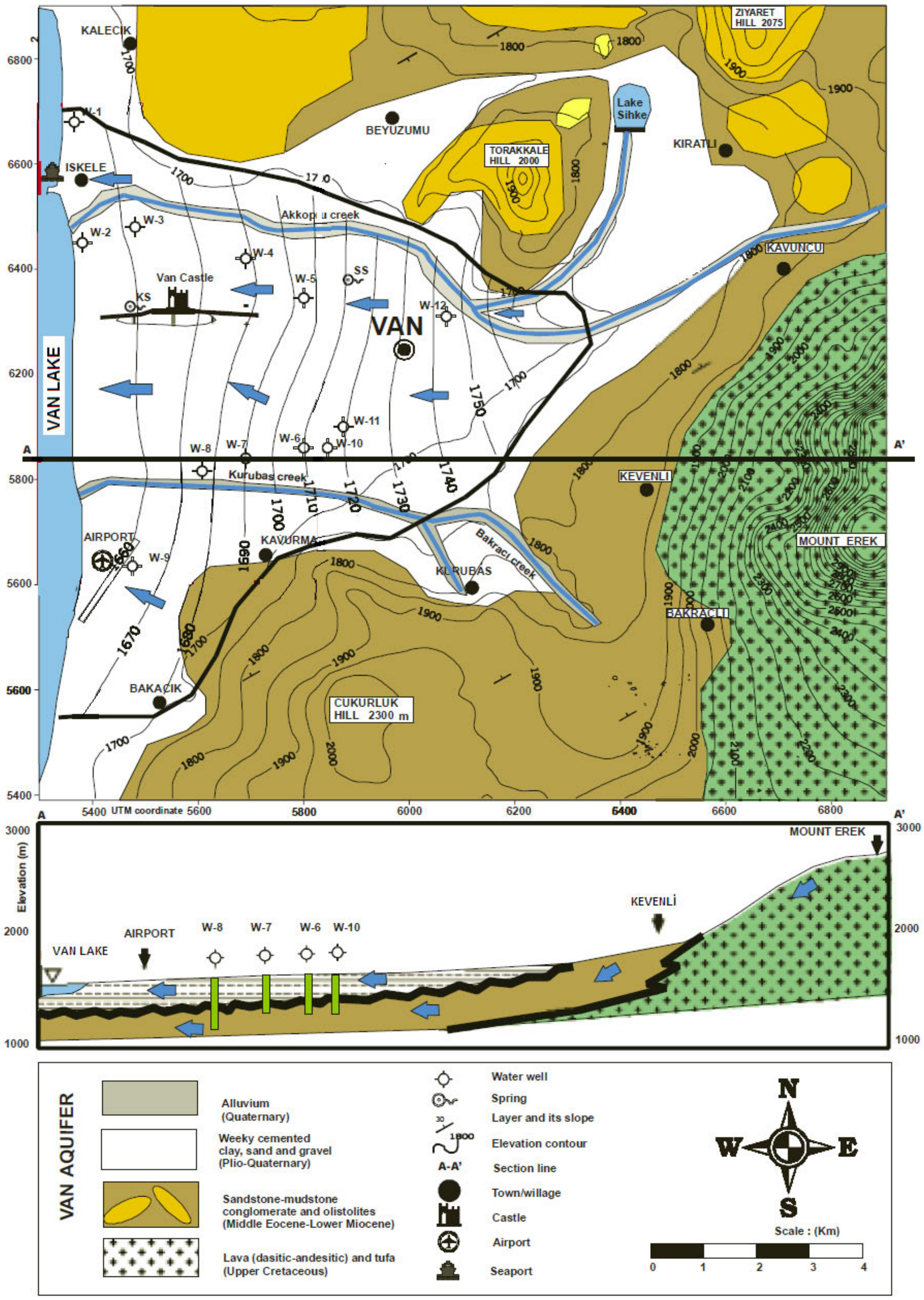

Fig. 3 Geology and hydrogeology of Van plain (modified from Özler, 2001)

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. For Erciş town, Özvan et al. (2008) reported shallow depths of groundwater table ranging between 1 and 8 m. The direction of groundwater flow is towards SE and SW and the depth of groundwater table becomes considerably shallower near to the lake (Fig. 4).

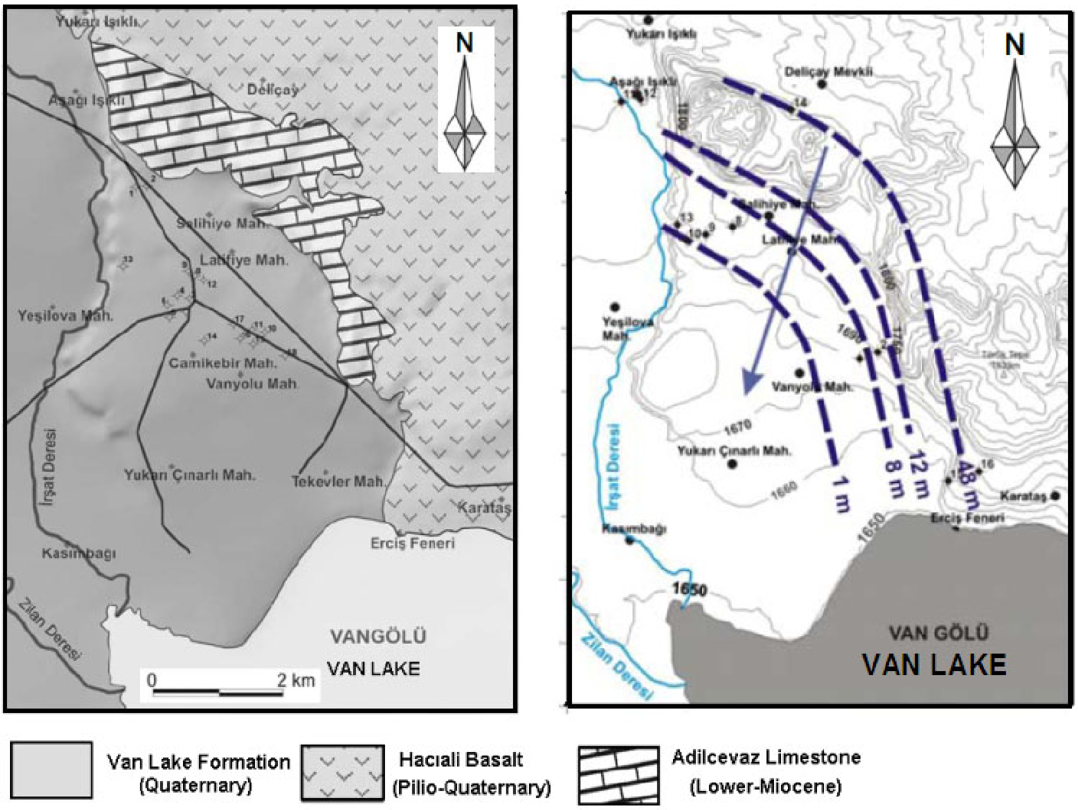

Fig. 4 Geology and hydrogeology of Erciş plain (Özvan et al., 2008)

GROUND LIQUEFACTION AND ITS CHARACTERISTICS

In this earthquake, liquefaction and associated ground deformations were evident and wide spread sand boils were observed particularly in Erciş Plain (Çelebibağı and Kasımbağı villages, and along Zilan stream) and the flood plain of Karasu River (Topraktaş, Arısu, Göllü, Tevekli, Çitören, Mollakasım and Alaköy villages), YYU port, Van Port, Esenkıyı (Fig. 5, Photo 1). Lateral spreading was quite extensive at Çelebibağı and Topraktaş villages.

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 is located would liquefy entirely. As there was no strong motion record for Erciş, it is very difficult to verify the estimations by Özvan et al. (2008). As the maximum ground acceleration recorded in Muradiye was 0.2g, it is expected that some partial liquefaction might occur. The reported and observed settlement of buildings in Erciş town may imply partial liquefaction did occur. Furthermore, ground liquefaction observed in Çelebibağı, Kasımbağı, the bridge on Van-Ağrı Highway over Zilan stream may be a conformation of their estimation. Similarly, Özvan et al. (2008) pointed out that there is a high potential liquefaction risk for areas in Van City near lakeshore. The authors observed ground liquefaction at Van Port and YYU Port and they may be a confirmation of their estimation.

The authors have gathered some samples from sand boils observed during the reconnaissance. Fig. 6 shows the grain size distribution of boiled sand samples. Although some samples have high fine content, they are still within the easily liquefiable bounds.

Fig.7 shows empirical relations for the magnitude and hypocenter limit distance for liquefaction with observations. 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.

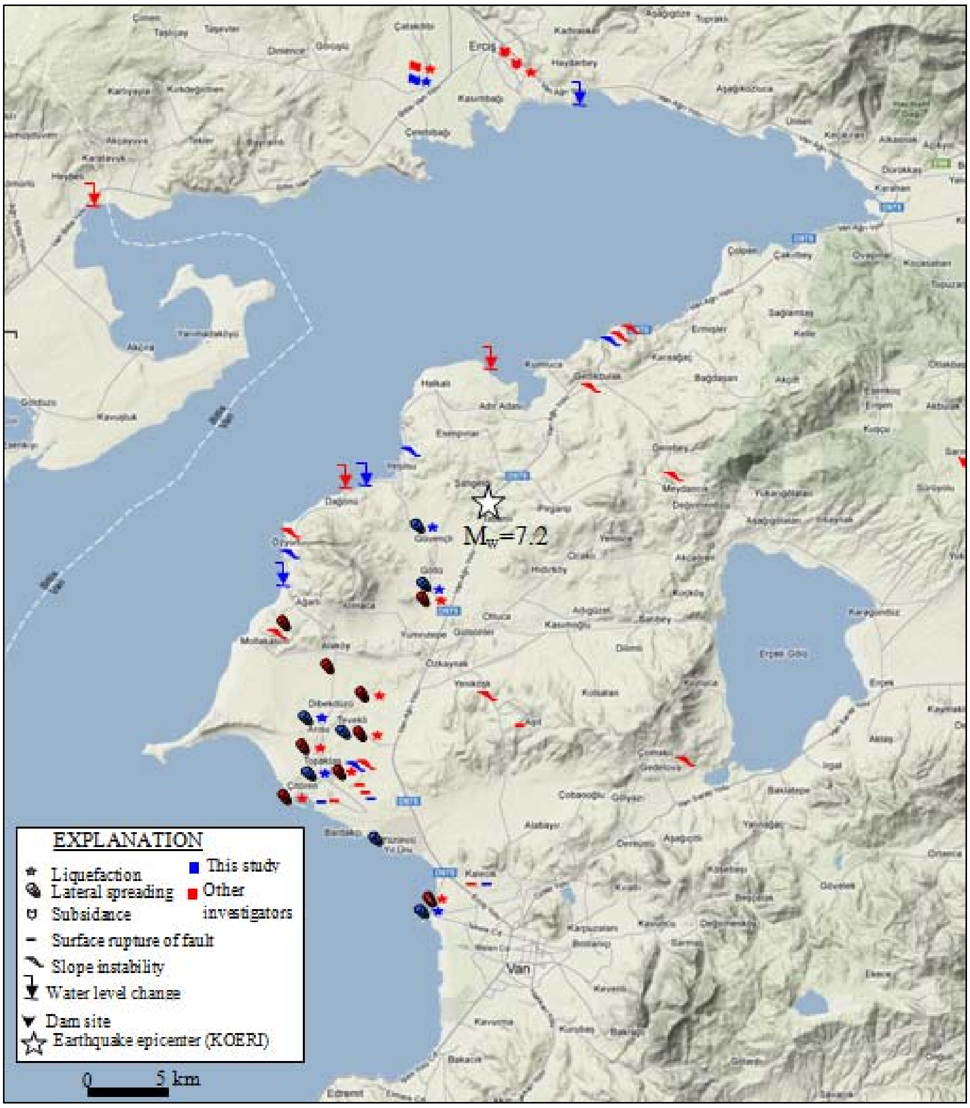

Fig. 5 Locations of observation on geotechnical damage

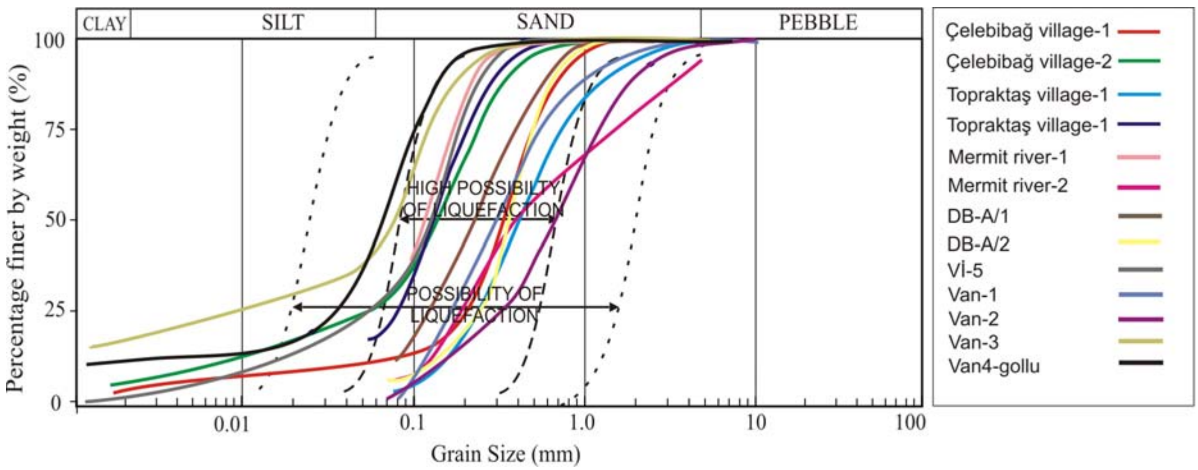

Fig. 6 Comparison of grain size distribution of boiled sand samples with empirical liquefaction bounds

(a) Liquefaction and lateral spreading at Çelebibağı (Erciş)

(b) Liquefaction and lateral spreading at Topraktaş village (Karasu plain)

(c) Liquefaction and lateral spreading at Van Port (Van lake shore)

Photo 1 Examples of ground liquefaction and lateral spreading at several localities

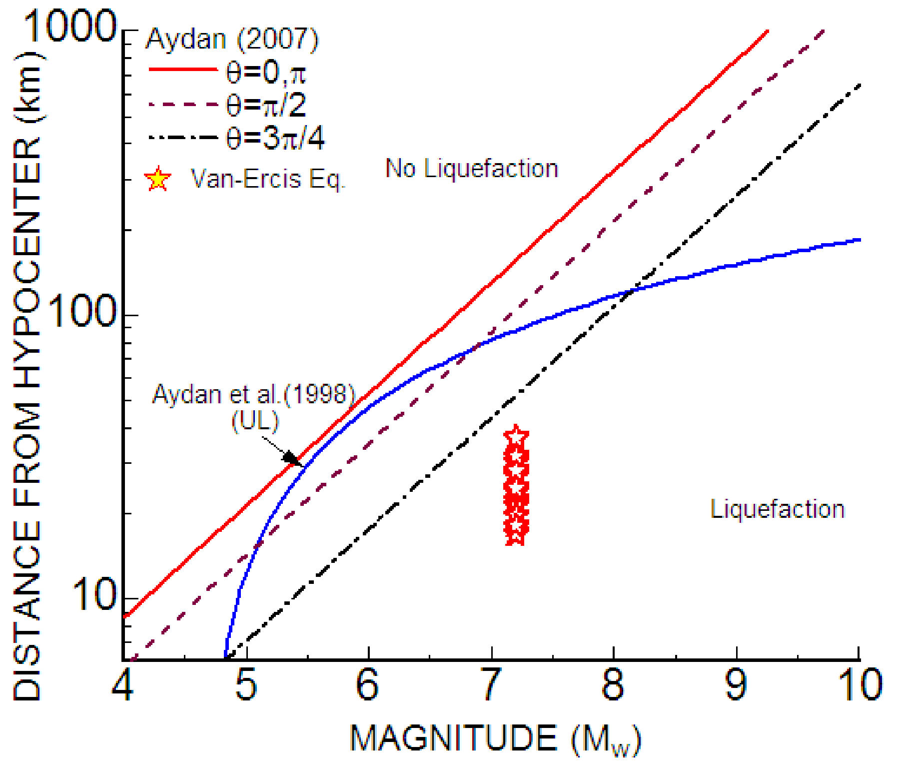

Fig. 7 Comparison of empirical relations for magnitude and liquefaction limits with observations

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 taken at Muradiye strong motion station and results are shown in Fig. 8. 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) as seen in Photo 1a, these computational results can explain the possible reason for large deformation at that locality.

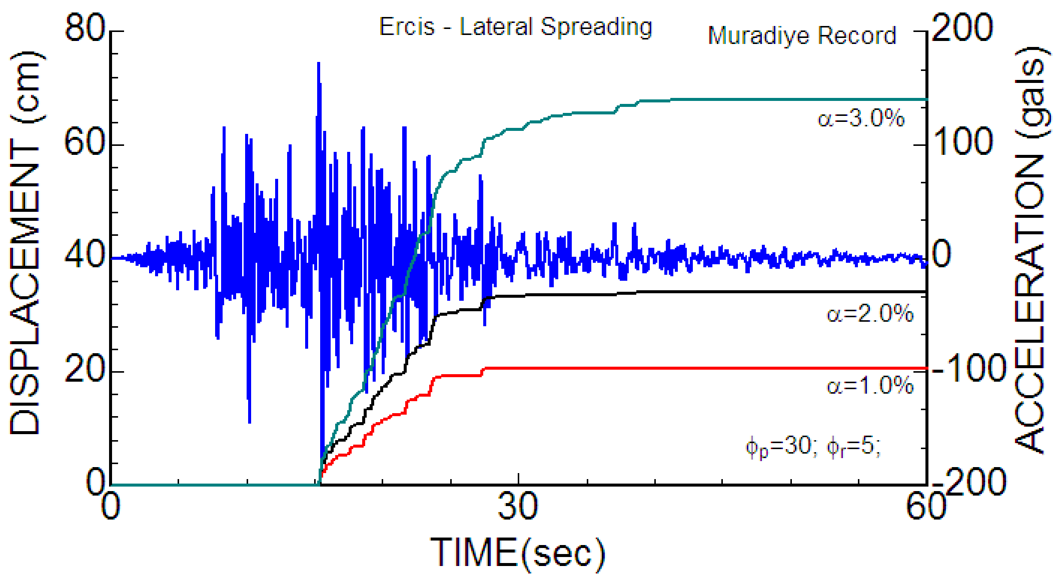

Fig. 8 Computed lateral spreading for three inclinations using the records taken at Muradiye

EMBANKMENT AND SLOPE FAILURES

Embankment failures were observed at several localities. Major embankment failures were observed on the Van-Ağrı Highway. Photo 2 shows one example of embankment failure. The embankment seen in Photo 2 moved towards the lake and settled.

Photo 2 Embankment failure on the Van-Ağrı Highway

Many slope failures were observed in the epicentral area. Most of slope failures occurred on the hanging wall-side of the fault. Photo 3 and 4 shows several examples of slope failures and Photo 5 shows numerous rock falls from a basaltic slopes near Keçikıran. Some of these rock falls reached to the Van-Ağrı Highway. Nevertheless, they did not result in any casualties.

Photo 3 Slope failure near Topraktaş

Photo 4 Rock slope failures at several localities

Photo 5 Rock falls near Keçikıran

Fig. 9 compares the empirical relations between the earthquake magnitude and limits of slope failures for coherent and disrupted states. The observations are within the bound of the empirical bounds proposed by Aydan (2007) and empirically darwn line by Keefer (1984). The relations proposed by Aydan (2007) considers the effect of fault orientation with respect to the observation point.

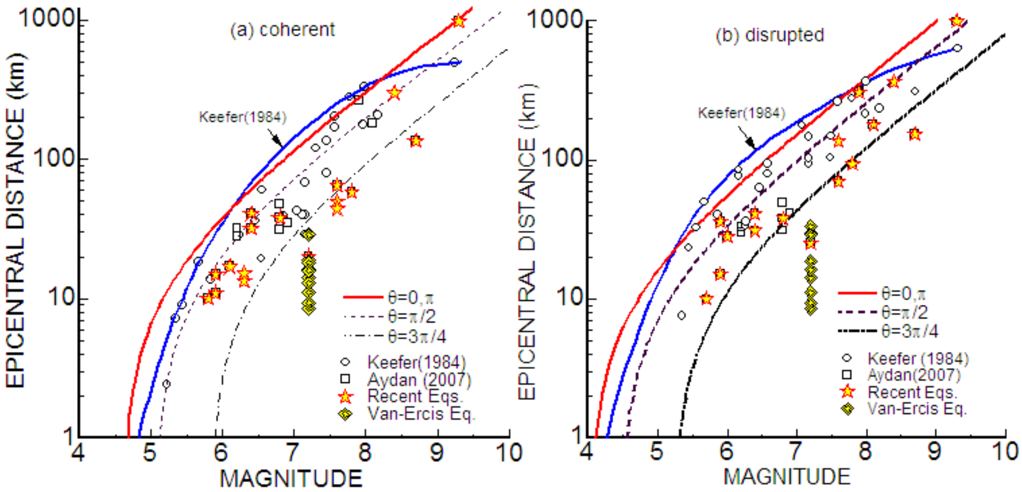

Fig. 9 Comparison of observational results with empirical relations between earthqauke magnitude and epicentral limit distance for slope failures

GEOTECHNICALLY INDUCED STRUCTURAL DAMAGES

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, bridges, railways and breakwaters. Photos 6 to 9 show some examples of geotechnically induced structural damages such as lateral spreading, settlement of liquefied ground or deformation of sloping ground and topographic amplification of slopes.

Photo 6 Lateral spreading induced damage to buildings in Çelebibağı (Erçiş)

Photo 7 Damage to bridge piers and abutments due to settlement and lateral spreading of ground

Photo 8 Settlement and spreading of breakwater of Van port and YYU port due to liquefaction of foundation ground

Photo 9 Damaged buildings due to permanent deformation of sloping ground

CONCLUSIONS

In this paper, geotechnical aspects of the 2011 October 23 Van-Erciş earthquake were presented. From the presented materials, one may draw the following conclusions:

(a) The site investigations clearly showed that the epicentral area is vulnerable to damage from ground liquefaction and slope failures.

(b) The anticipated ground liquefaction did occur in Erciş town and Van City and settlement along rivers. However, the intensity of ground liquefaction was not that high.

(c) 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.

(d) The earthquake area is mountainous and it may suffer from rockfalls and huge slope failures.

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