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Dedicated to Dr. Atsushi Miyazaki and the people lost their lives in this earthquake

THE CHARACTERISTICS OF THE TRIGGERED 2011 VAN-EDREMİT EARTHQUAKE AND INDUCED DAMAGE

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ABSTRACT: The M_w=5.6 magnitude Van-Edremit earthquake occurred at 21:23 local time on November 9, 2011(USGS (2011)), was caused by a fault having a strike-slip mechanism. The earthquake was triggered by the effect of the stress state of the M_w 7.1 Van-Erciş earthquake on October 23, 2011 and it caused heavy damage and collapse of additional 30 buildings and 38 additional fatalities particularly in the city of Van, which was severely shaken by the earlier earthquake. . This paper outlines various aspects of the triggered earthquake.. Following a brief outline of geology, seismo-tectonics and geotechnical conditions in Van City, an evaluation of strong ground motion characteristics and structural and geotechnical damage are described and the findings and lessons learned from this earthquake are presented.

Key Words: Van-Edremit earthquake, geology, strike-slip faulting, high ground motions, structural damage, liquefaction

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, it caused heavy damage in the city of Van and added to the distress caused by the earlier M_w 7.1 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. This earthquake is considered to have been triggered by the effect of the crustal stress state of the October 23, 2011 event.

Van-Edremit earthquake caused very high ground accelerations in the City of Van, and resulted in collapse of 30 additional reinforced concrete buildings, most of which had suffered substantial damage during the 23 October 2011 earthquake. Fortunately, 23 of the collapsed buildings had been evacuated due to the damage caused by the 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 casualties and injured people caused by this earthquake are 38 and 30, respectively.

This earthquake also caused some ground liquefaction along the Van lakeshore and the ground liquefaction again occurred at the Van port, where the ground liquefaction was also observed following the 23 October 2011 earthquake.

This paper outlines various aspects of the Van-Edremit earthquake of November 9, 2011. In the first part of the paper, brief outlines of geology, seismo-tectonics and geotechnical conditions in Van City and its close vicinity are given. The second part involves seismic characteristics of the earthquake and evaluation of strong ground motion characteristics. The third part describes both structural and geotechnical damages, and the effect of non-appropriate repair of the buildings is also discussed. In the final part, the findings and lessons learned from this earthquake are summarized.

GEOLOGY AND GEOTECHNICAL CONDITIONS

Fig. 1 shows the geological conditions of the City of Van and its close proximity. Van is mainly located over a mainly alluvial fan (Qey), and the area along the lakeshore and in the vicinity of Karasu River is mainly composed of recent alluvial deposits (Qa). The shear wave velocity of alluvial deposits of recent alluvial deposits (Qa) is estimated to be ranging between 250-300 m/s while the shear wave velocity of alluvial deposits (Qey) is about 350 m/s. The town of Edremit, close to the epicenter, is located over travertine deposits (Qpltr).

There are several types of faults in the epicentral area. Besides main thrust faults trending E-W, there are conjugate strike-slip faults with some normal components. Özkaymak et al. (2004) recognized NW-SE and NE-SW trending strike-slip faults. Alabayır fault is one of such faults.

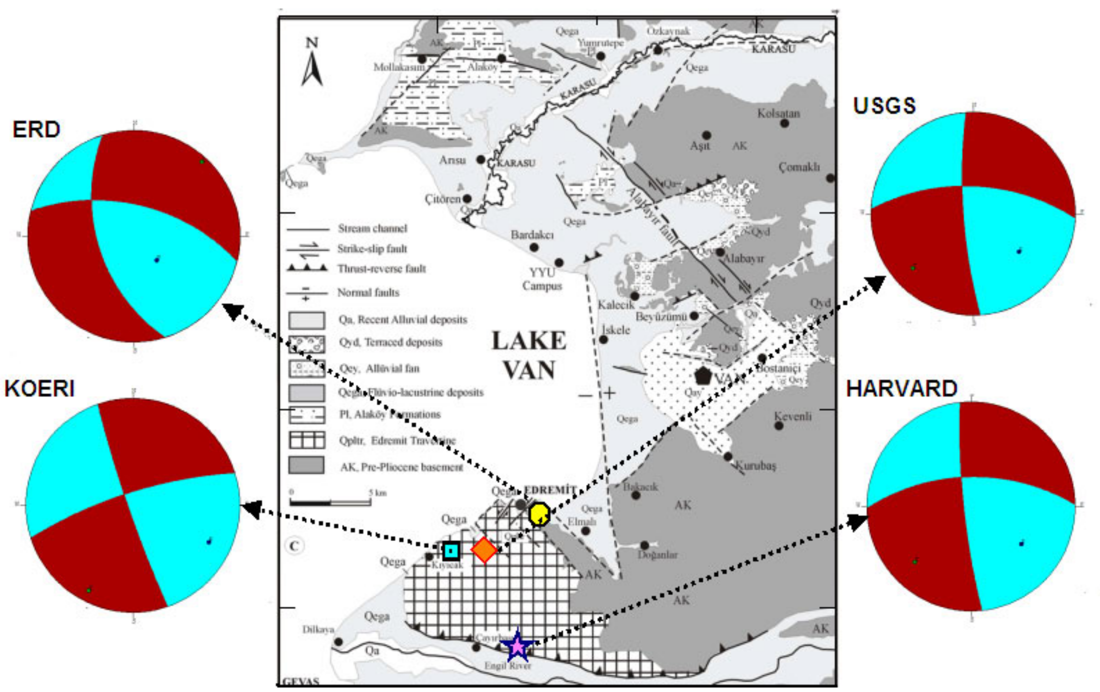


Fig. 1 Geology of Van and its close vicinity and faulting mechanisms for the Van-Edremit earthquake estimated by different institutes (base map from Özkaymak et al., 2004)

FOCAL MECHANISM AND SEISMICITY

Fig. 1 also shows the focal mechanisms obtained by 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 Fig. 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.

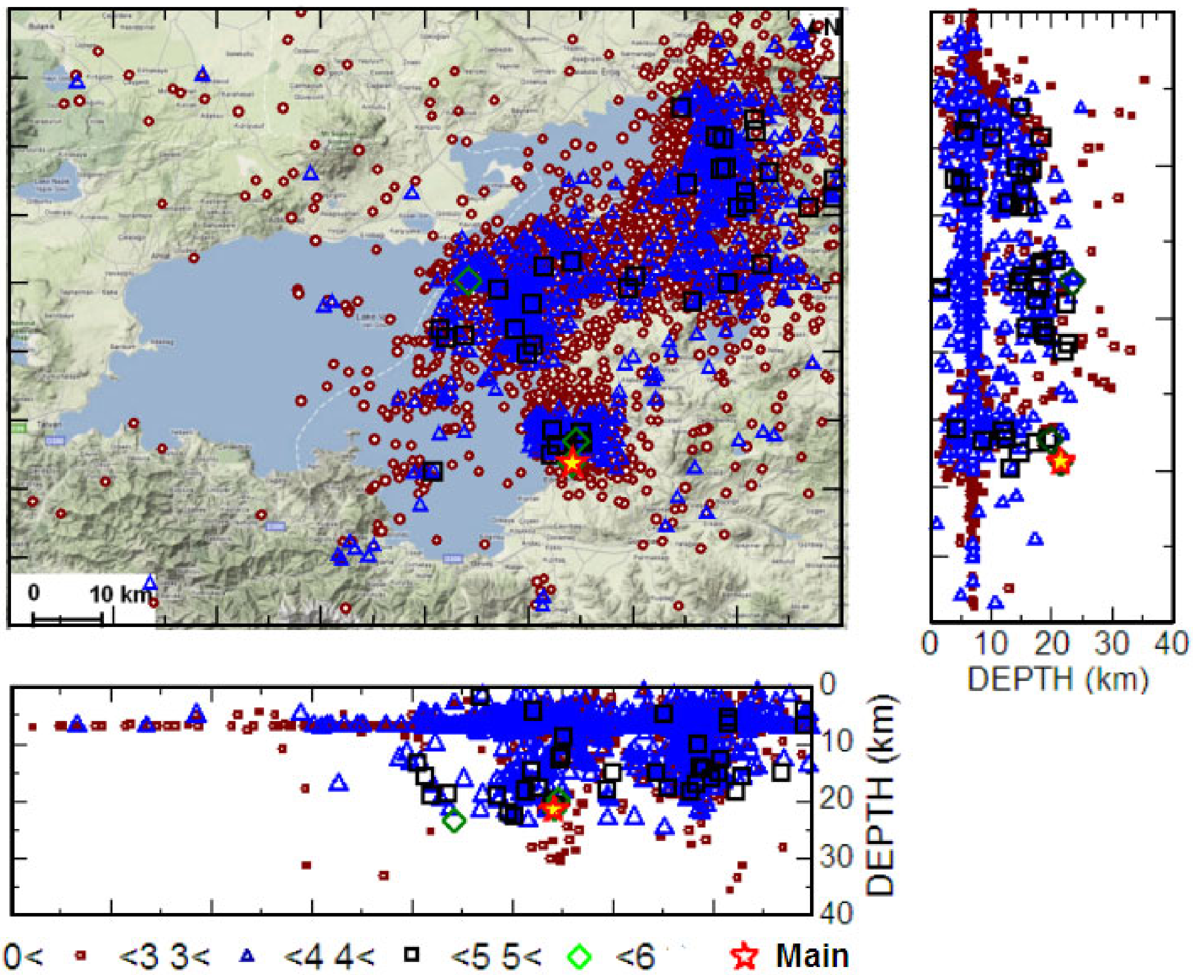


Fig. 2 Seismicity of epicentral areas of Nov. 09, 2011 and Oct. 23, 2011 since Nov. 09, 2011

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 (Fig. 3). Fig. 4 compares the acceleration records and acceleration response spectra of motions recorded at soil stations while Figure 5 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.

Fig. 3 Locations of strong motion stations (base map from Google earth)

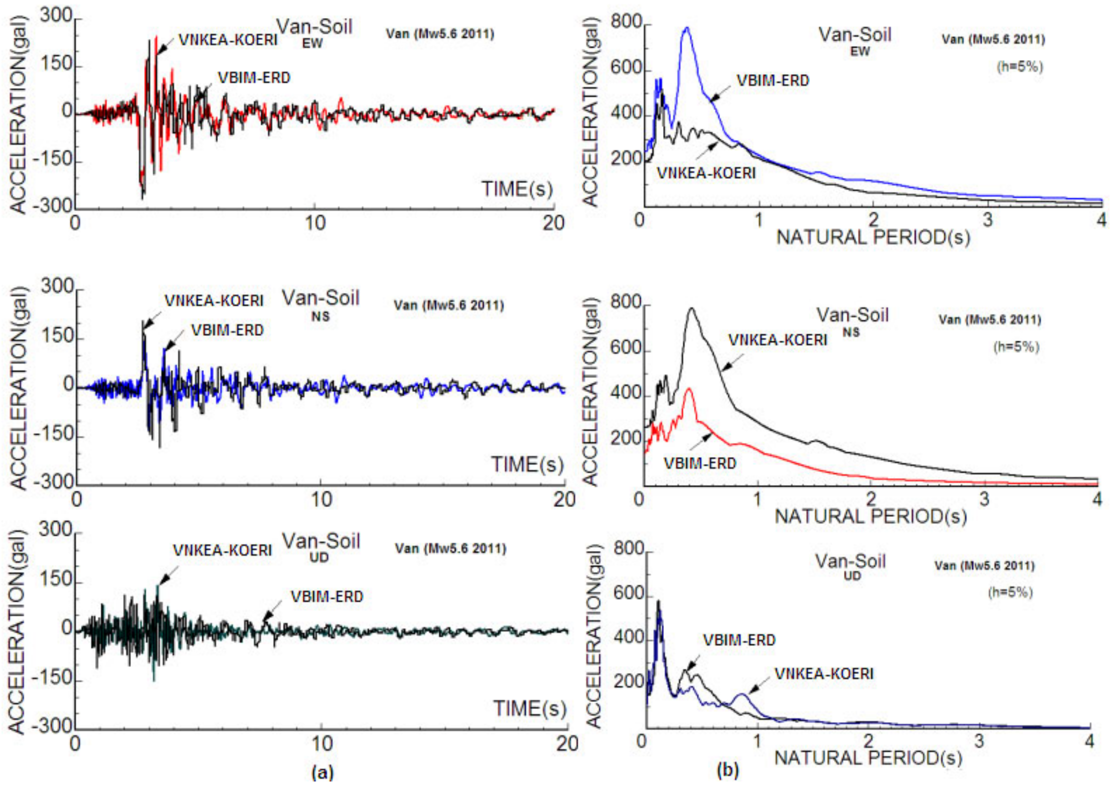


Fig. 4 Comparison of (a) acceleration records and (b) their acceleration response spectra of VBIM-ERD and VNKEA-KOERI stations in Van

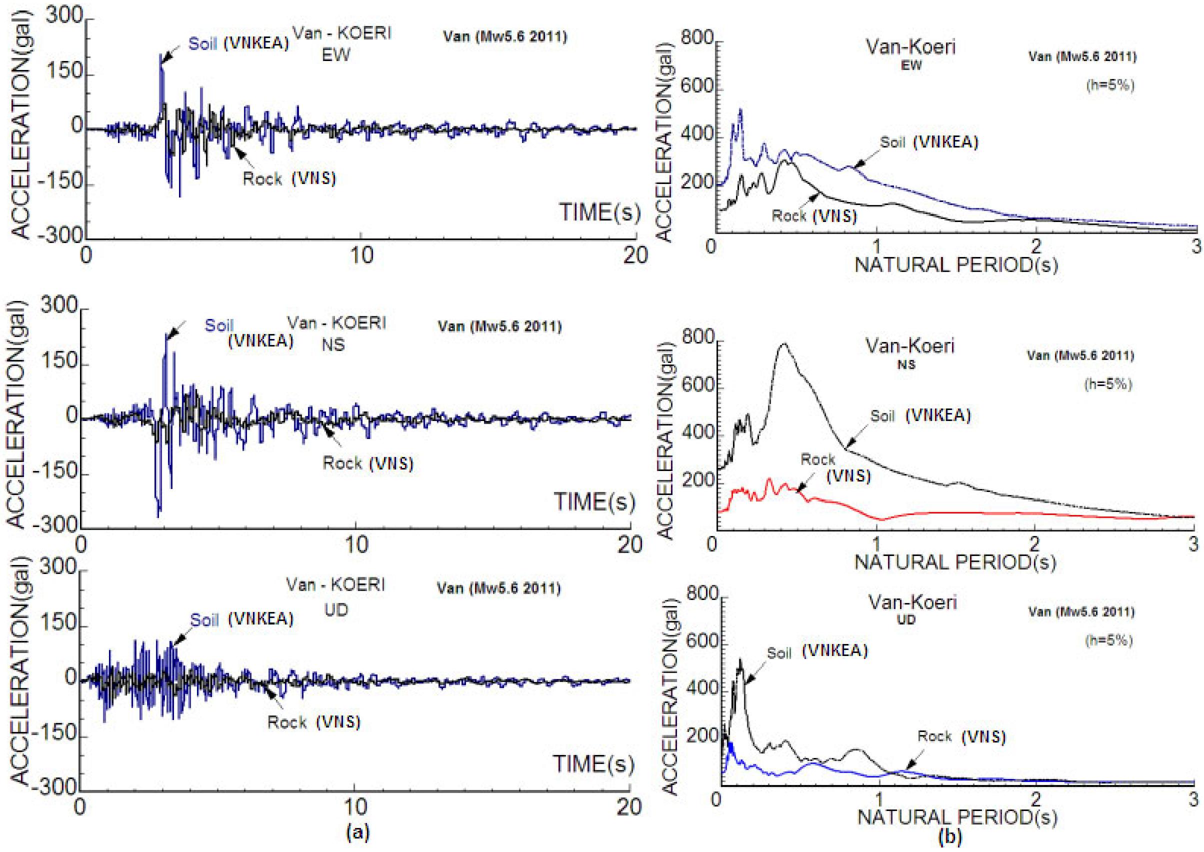


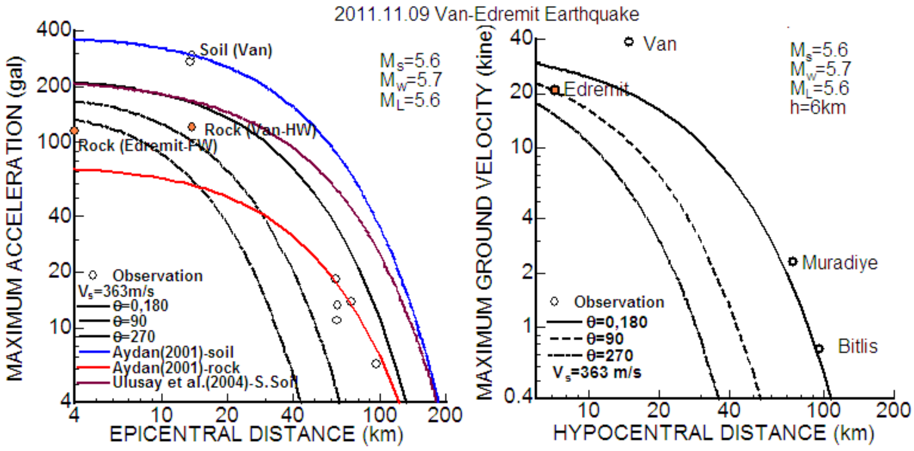
Fig. 5 Comparison of the acceleration records and their acceleration response spectra on soil (VNKEA) and rock (VNS) stations in Van

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.

Fig. 5 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.

One of important observations in Fig. 5 is the effect of the fault orientation. While Edremit station is on the stationary or footwall, Van station is on the mobile or hanging wall side. The maximum ground accelerations are almost same, the distances of the Edremit and Van strong motion stations to the fault are 4 and 12 km, respectively. This fact also illustrates the fundamental reason for seemingly scattering of observed data when spherical and cylindrical attenuation relations are employed.

Aydan and Ohta (2011a) improved the attenuation relations of Aydan (2007) by considering the dip angle and fault length also. The attenuation relations of Aydan and Ohta (2011a) for maximum ground velocity are compared in Fig. 5. The computed maximum ground velocity values at Edremit, Muradiye and Bitlis are well estimated by the attenuation relations of Aydan and Ohta (2011a). However, the observed value of Van strong motion station is somewhat higher than the estimations when the shear wave velocity (V_{s30}) of 363 m/s is used. Therefore, the concept of using the shear wave velocity for top 30 m ground as the representative value of site conditions is very questionable. Similar conclusion is valid for the records taken in Japan.



(a) (b)

Fig. 5 Comparison of some empirical attenuation relations for maximum ground acceleration and maximum ground velocity 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 Fig. 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.

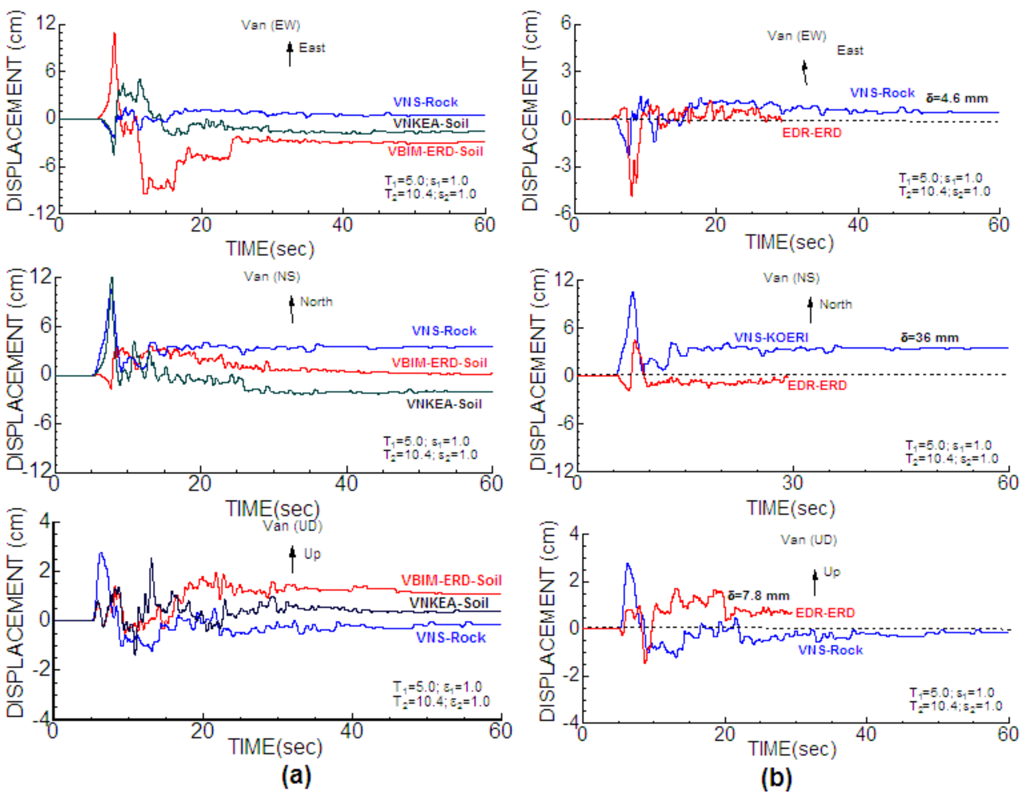


Fig. 6 Displacement responses of strong motion stations computed from EPS method (a) The City of Van), (b) Rock ground at Edremit and Van

Next the deformation responses of stations (EDR-ERD and VNS-KOERI) located over rock are compared as shown in Fig. 6(b). If the mobile side of the N-S trending fault is the east block, the strike slip faulting implies that there should be considerable permanent ground displacement at VNS-KOERI station as compared with that at EDR-ERD station. The net permanent displacement of the VNS-KOERI is about 37 mm northward while that of the EDR-ERD is almost nill. This conclusion may also be of great value to explain why there was huge damage in the City of Van as compared to the light damage in Edremit.

CASUALTIES AND STRUCTURAL DAMAGE

This earthquake resulted in the loss of 38 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. Fig. 7 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).

$$N = A(M_L - B)^c \tag{1}$$

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.

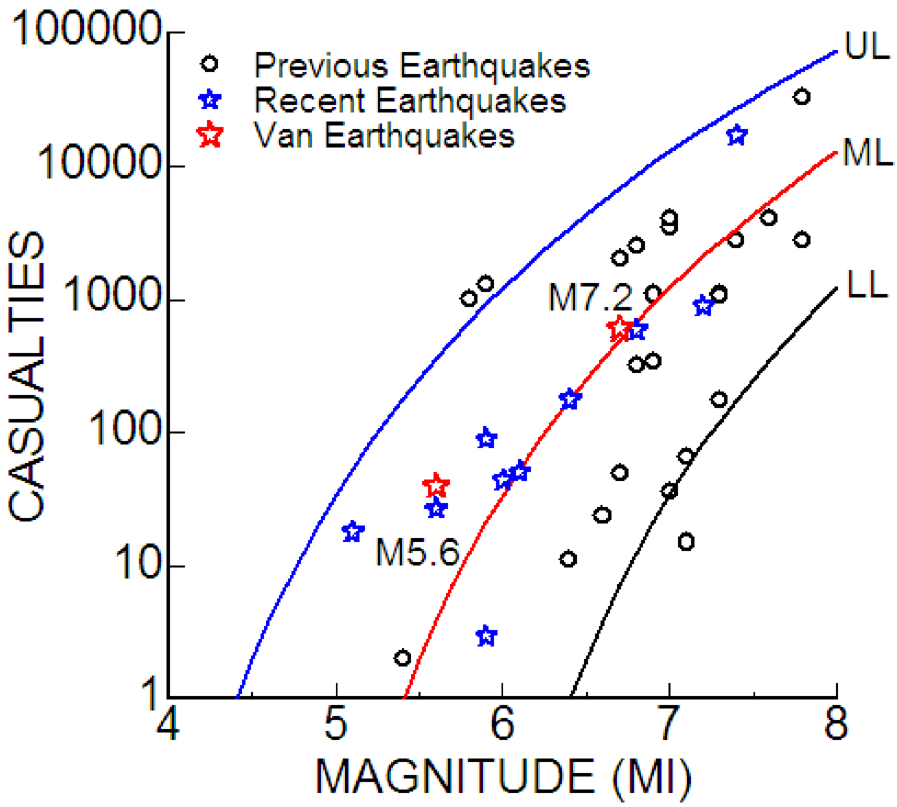


Fig. 7 Relation between local magnitude of earthquakes and casualties

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 (Photos 1, 2 and 3). 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. 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 (Photo 4).

(a) before (b) after

Photo 1 Views of Bayram Otel before and after the Van-Edremit earthquake (Anadolu Ajansı, 2011)

Photo 2 Views of a collapsed reinforced concrete building in Van (Anadolu Ajansı, 2011)

Photo 3 Views of heavily damaged reinforced concrete buildings of DSI in Van

Photo 4. Cosmetic repairs applied to a damaged RC building in Van on November 5, 2011 after the Van-Erciş earthquake

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).

GEOTECHNICAL DAMAGE

This earthquake also caused some ground liquefaction along the Van lakeshore (Photo 5) and the ground liquefaction again occurred at the Port of Van, where the ground liquefaction was also observed following the 23 October 2011 earthquake. This is probably the smallest magnitude earthquake to cause liquefaction in Turkey so far. Fig. 7 shows the grain size distribution of the boiled sand, which is within the most liquefiable bounds with high percentage of fine content.

Fig. 8 shows the empirical relations proposed 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.

Photo 5 Views of boiled sand in Van port due to the M5.6 earthquake

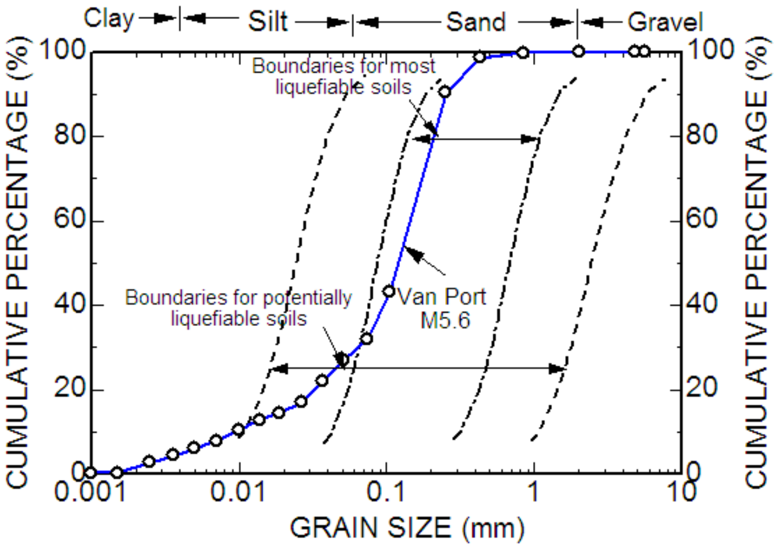


Fig. 8 Grain size distribution of boiled sand sample obtained from Port of Van immediately after the M5.6 earthquake

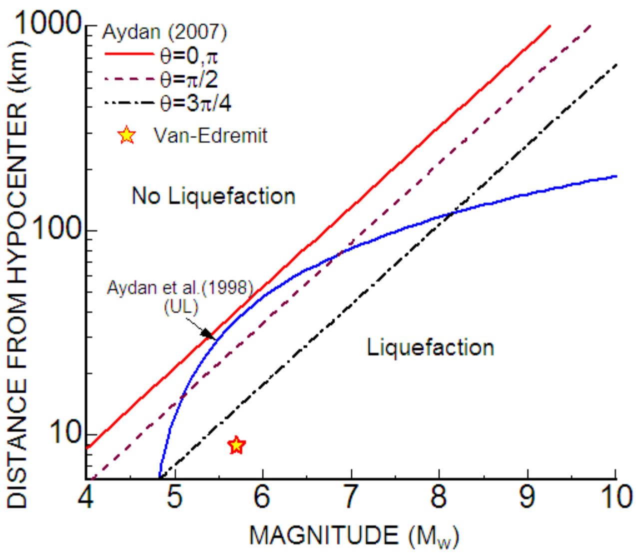


Fig. 9 Comparison of empirical relations with observation

CONCLUSIONS

The following conclusions may be drawn from the previous sections:

(a) This earthquake is not an aftershock of the October 23, 2011 Van-Erciş earthquake. It has 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.

(b) Although the magnitude of this 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.

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

(d) Van-Edremit is probably the smallest magnitude earthquake to cause liquefaction in Turkey so far. Furthermore, this earthquake caused ground liquefaction in the same location again.

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