October 23rd, 2011 Van Earthquake: Preliminary Reconnaissance Report: Structural and Geotechnical Aspects of the Damage

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SUMMARY:
October 23rd, 2011 M7.2 Tabanli - Van and November 9th, 2011 M5.2 Edremit – Van earthquakes caused damage in a widespread area across the Van province in Turkey. In this study, the ground motions and the damaged caused by these powerful earthquakes are presented. First, the key properties of the recorded strong ground motions are evaluated. The geotechnical aspects of the damage are presented. The damage to reinforced concrete and masonry structures are discussed. Common structural damage patterns observed on the field were identified. The relationship between the key structural properties and the sustained damage grade is investigated. The primary loss drivers across the region were identified to be the poor quality of workmanship and improper use of building materials. The results from the investigation suggest that a large portion of the loss could have been prevented if sufficient attention and care was given to the design and construction regulations.

Keywords: Reconnaissance, observed damage, Van earthquake, October 23rd, November 9th, damage progression

1. INTRODUCTION

A destructive earthquake of M_L=6.9 (M_w=7.1 USGS) hit Van Province of Turkey on October 23, 2011 at 13:41 local time. The epicenter of the earthquake was announced to be Tabanli village; however severe damage was observed in Ercis district having 18424 residential buildings with 60 of them totally collapsed and many heavily damaged during the shake (Governorate of Van). The earthquake was felt in a widespread area including the neighbouring provinces Bitlis, Agri, Mus, Siirt and Bingol. 17 days after the event, another earthquake of ML5.6 shook the region again on the 9th of November having the epicentral location on Edremit district. With 40 casualties, 30 saved people and 25 totally collapsed buildings, the second earthquake mostly affected Van city centre.

This paper gives information about the characteristics of the strong motions recorded during both earthquakes as well as the site and soil conditions based on experimental data. Furthermore, damages to reinforced-concrete and masonry structures after each earthquake are comparatively exhibited herein, including the discussions concerned with the reasons of the observed structural and non-structural damages.

2. SEISMIC BACKGROUND AND STRONG MOTION CHARACTERISTICS

The province of Van settles in the East Anatolian Region of Turkey, which is continuously in compression due to the northward collision of the Arabian plate towards Eurasia (Sengör et.al, 2008). Researches on active tectonics of the region indicate a complex source structure. The October 23, 2011 earthquake took place on “Van Fault”, which is recently discovered and is not available in the Active Fault Map of Turkey, (Emre et.al, 2011). The M_w7.2 event specifically affected Ercis district of Van, which settles 38.81 km away from the epicenter. However, the November 9, 2011 earthquake with magnitude M_w 5.7 was closer to central Van with an epicentral distance of 13.56 km causing severe damages to structures in Van City. Within the next 30 days from the first earthquake, a number of 5205 aftershock events are recorded.

2.1. Evaluation of the Recorded Motions

Performing a baseline correction and employing a 4th order Butterworth type band-pass filter, for which the corner frequencies are decided from Fourier Amplitude Spectrum (FAS) of each raw motion, strong motion records are processed. Fig 2.1 show the acceleration, velocity and displacement traces for the closest Muradiye station.

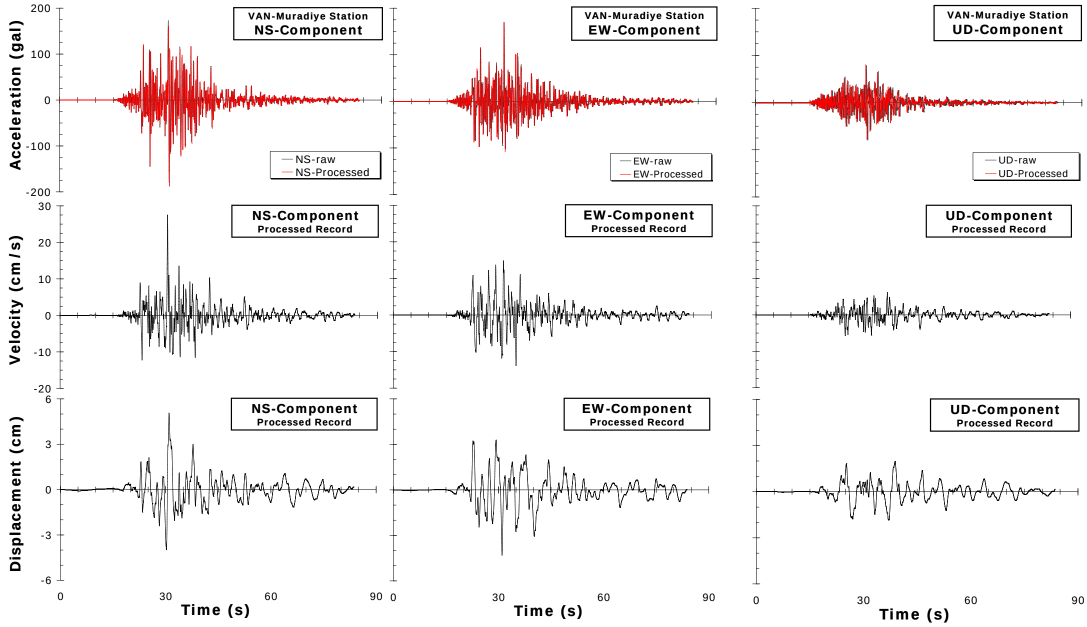


Figure 2.1. Acceleration, velocity and displacement histories of Muradiye NS (left column); EW (middle column) and UD (right column) components.

The highest PGA of the M_w7.2 earthquake was recorded as the NS component from Muradiye station with a processed value of 181.17 cm/s^2. Fig 2.2 shows the acceleration, velocity and displacement spectra for the horizontal components of the processed motions recorded at Muradiye station employing different damping ratios. November 9, 2011 earthquake of M_L5.6 occurred on a strike-slip fault located in Van Lake close to the shores of Edremit district of Van province. This second event was recorded by Van station with PGAs of 148.1 gal in the NS direction; 245.9 gal in the EW direction and 150.5 gal in the UD direction. Similar procedures are carried out to process the raw motions. It is concluded that the peak ground velocity and the displacement are recorded in the EW direction with maximum values of 31.6 cm/s and 7.5 cm, respectively.

The 5% damped normalized acceleration response spectra of the nearest three stations' NS and EW components of M_w7.2 earthquake and Van station records for the M_L5.6 earthquake are computed and compared to the design spectra defined in the Turkish Earthquake Resistant Design Code (TERDC, 2007) for soil classes Z1, Z2, Z3 and Z4, where Z1 represents the firmest and Z4 represents the softest soil. It can be observed from Fig 2.3 that, the site amplification for moderate periods of T=0.25~0.75 s exceeds the design code limit of 2.5 up to 60% for Bitlis records and 40% for Muradiye records. For periods longer than 1.5 s, Malazgirt records indicate soft soil conditions with significantly higher amplification values compared to the code. When the second earthquake is considered high amplification values are only encountered for a period range between 0.30~0.45 seconds with a maximum value of 3.5.

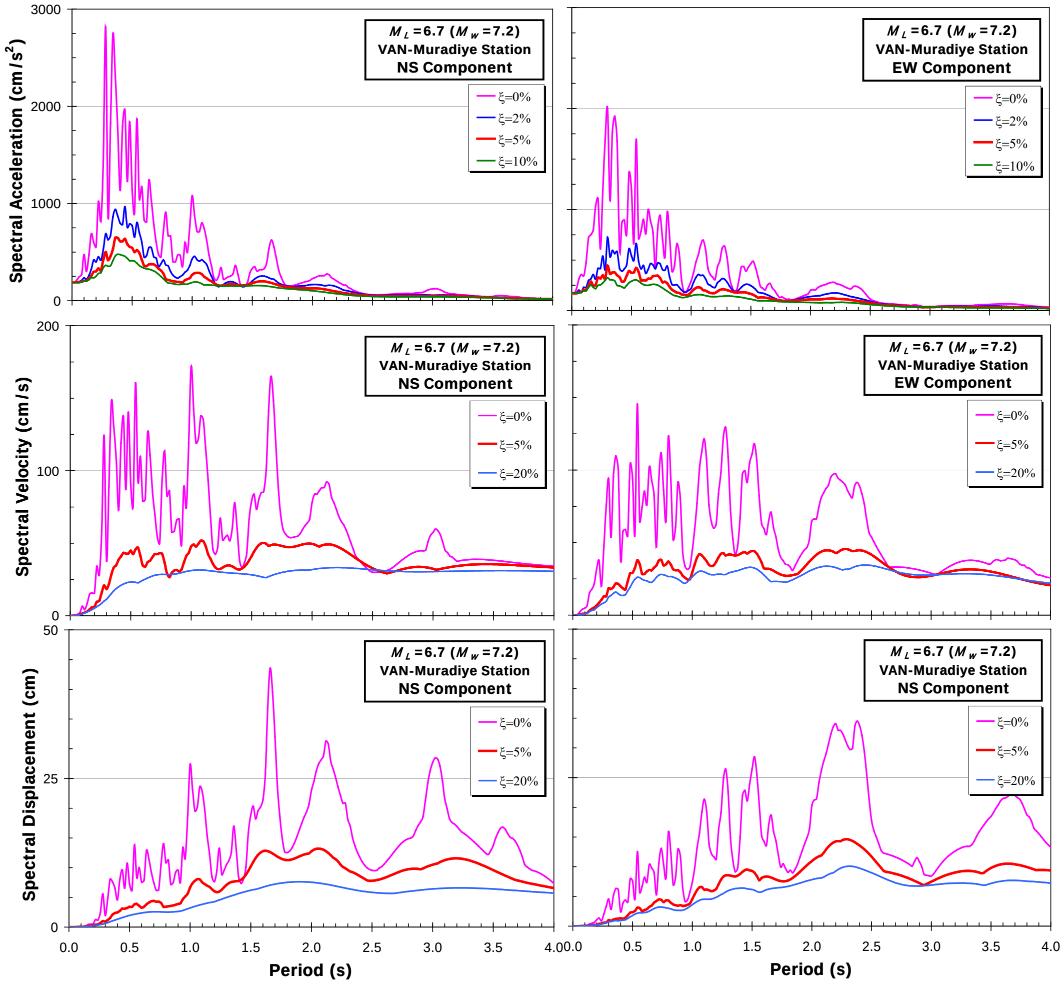


Figure 2.2. Acceleration (top row), velocity (middle row) and displacement (bottom row) spectra of Muradiye NS and EW components

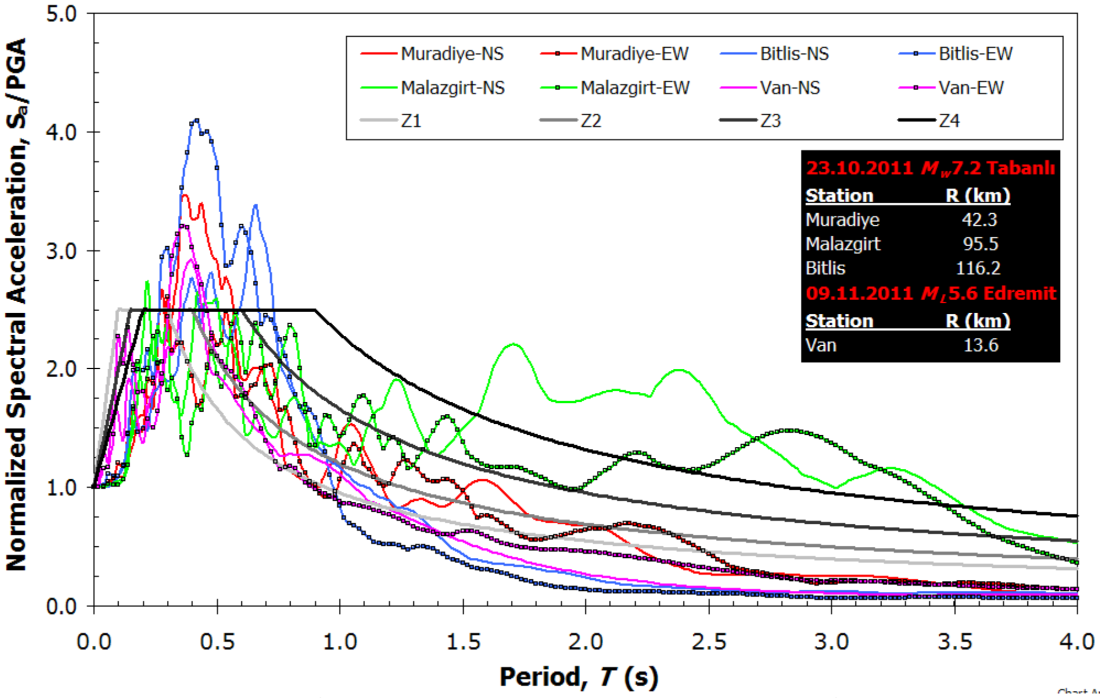


Figure 2.3. Comparison of the normalized spectra with the design spectra for Z1, Z2, Z3 and Z4

3. GEOTECHNICAL ASPECTS

The major geological units encountered in the earthquake-affected areas are Pliocene-Quaternary deposits (Lake Van Formation), young Quaternary deposits and ophiolitic melange series (Fig. 3.1). Van City and Ercis where a heavy damage occurred are located mostly on soil deposits of Lake Van Formation which consists of lacustrine, fluvial and alluvial sediments differing in density and thickness depending on the formation process, age and locality. The thickness of these sedimentary units is around 50 m in the center of Van city and 150 m in its near vicinity (Selçuk and Çiftçi, 2007) while it reaches almost 240 m in Ercis (Özvan et al., 2008).

The city of Van sits on Lake Van Formation having a heterogeneous stratification of medium/dense and hard/very hard soil layers. Ground water table is located at 2 m~12 m depth. A few buildings experienced settlements of around 0.5 cm to 2.0 cm due to unfavorable soil conditions. No other significant damage due to soil conditions was observed in the city center.

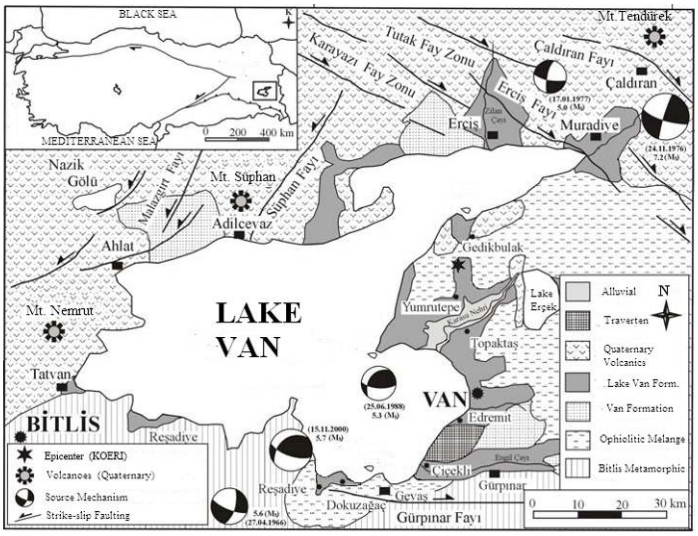


Figure. 3.1. Simplified geology of Van and its vicinity (Adapted from Üner et al., 2010; Utkucu, 2006; Bozkurt, 2001; Koçyiğit et al., 2001; Kurtman et al., 1978)

A widespread liquefaction and liquefaction-triggered lateral spreading cases, landslides and slope failures were observed. Specifically, in the near vicinity of the fault but especially on the hanging wall-side and at locations along Karasu River to the north of Van City and coastal sections of Van Lake where young alluvial deposits prevail, an extensive liquefaction phenomena manifested by sand boils, ground water eruption, lateral spreadings and settlements were encountered. Several liquefaction cases were observed that triggered landslides at steep slopes especially throughout Karasu Delta. It was observed that the backfill material at Van Port liquefied resulting in lateral displacement and settlements of 4 cm to 6 cm and a few centimeters, respectively. A severe liquefaction and lateral spreading case was observed in Ercis Plain, mainly at Çelebibağı and Kasımbağı. Previous studies showed that there is a high liquefaction potential for this area having a soil profile of loose silty sand layers with a high ground water table (Özvan et al., 2008). At İnönü district, the soil displacements reached almost one meter both laterally and vertically. Several adobe and brick houses, RC buildings of single to two stories and water ditches were heavily damaged while some houses were translated laterally 50 cm to 70 cm (Fig. 3.2).

Sieve analyses were conducted on samples taken from the sand boils at Alaköy, Topraktaş and Çelebibağı. The samples tested were determined to be as sand with 8% to 27% fines ratio. On The grain size distribution curve depicted in Fig. 3.3, Port and Harbour Research Institute of Japan (1997) recommendation for upper and lower boundaries for liquefaction potential is given as a reference to capture the liquefaction potential of the soil samples.

Figure. 3.2. Extensive lateral spreading due to liquefaction and resulting damages at Çelebibağı, Erciş

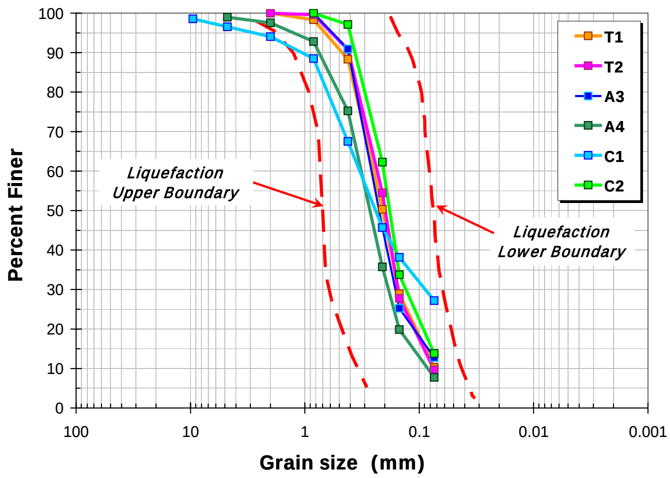


Figure. 3.3. Grain size distribution of soil samples taken from sand boils at Alaköy, Topraktaş and Çelebibağı

Widespread landslide and slope failure cases were reported especially in the near vicinity of the epicenter and at sections located on the hanging wall-side of the fault line. One particular case is the extensive slope failure near Gedikbulak village located 10 km north-east of the epicenter that caused damage along Van-Ağrı highway that was repaired immediately. Several head scarfs and cracks due to landslides and slope failures can be identified along the highway. Specifically, slope failures occurred along Karasu River in the near vicinity of Tirleşin Bridge which caused settlement of bridge abutments. Lanslides triggered by liquefaction and rockfalls are also observed (Fig. 3.4)

Figure. 3.4. Liquefaction-triggered landslide at Topraktaş and damage caused by rockfall at Karaağaç.

4. STRUCTURAL ASPECTS OF THE OBSERVED DAMAGE

The large majority of the buildings damaged due to the earthquakes of 2011 are located in the cities of Ercis and Van. Since the Van and Ercis were distant from the strong motion station located in Muradiye, the actual levels of ground motion intensity at these cities can only be estimated with substantial uncertainty. The peak ground acceleration (PGA) estimated to have occurred in Van during October 23rd earthquake is in the range from 0.15g to 0.44g while peak ground velocity (PGV) estimates are in the range from 16 to 43 cm/s (Table 4.1).

Table 4.1. Estimated peak ground acceleration (PGA) and peak ground velocity (PGV) for Ercis and Van during October 23rd, 2011 Earthquake

	Erciş		Van	
Source	PGA [g]	PGV [cm/s]	PGA [g]	PGV [cm/s]
AFAD (2011a)	0.08 - 0.1	-	0.15 - 0.2	-
Aydan et al. (2012)	0.28 – 0.36	35 - 45	0.28 – 0.36	0.35 – 0.45
EMSC (2011)	0.18 - 0.15	20	0.15	15
IIEES (2011)	0.35-0.3	35 - 40	0.15 - 0.2	20 - 25
KOERI (2011a)	0.2 - 0.25	16 - 20	0.25 - 0.3	20 - 25
USGS (2011)	0.44	43	0.5	49

The strong ground motions in Van during November 9th earthquake were measured to be 0.27g and 0.29g by the strong motion stations operated by KOERI (2011b) and Earthquake Department of AFAD (2011b). For the city of Ercis, the PGAs that had taken place during November 9th earthquake are estimated to be in the range from 0.02g to 0.05g by AFAD (2011a). The Turkish seismic design code states a design spectrum with $S_a(T=0)=0.3g$ and 0.4g for the top two seismic active zones which include the Van province. When these values are interpreted as the PGA for the expected seismic event, it can be seen that the recorded PGA are relatively low.

4.1. Reinforced concrete buildings

The most of the RC buildings affected by the earthquakes were located at the central districts of Van and Ercis. Reinforced concrete buildings in the region are typically 4 to 8 stories high. Medium rise buildings are mostly for residential use, while the low rise ones are for mixed commercial and residential use.

Collapse of the ground story was the most common failure mechanism in the collapsed buildings (Fig 4.1a) in the region. The soft/weak ground stories were conceived to be one of the major causes of these collapses. The buildings which are not only residential often accommodate shops in the ground floor (Fig 4.1b,c). This arrangement is often preferred by the building owners in order to profit from the higher rents. Higher story heights and wider open spaces (i.e. fewer infill walls) are typically preferred by the commercial users. This preference results in softer and weaker soft stories when the structure is not designed and constructed by properly accounting for the irregularity at the ground story.

The structural members were observed to be laid out improperly in some of the buildings. Improper layout of the structural members was conceived to be one of the major causes of collapse of school building in Gedikbulak village (Fig 4.2). The three story school building had a reinforced concrete wall-frame structural system. The building had collapsed due to the earthquake even though it had a considerable percentage of structural walls. Two major factors that were perceived to have caused this collapse: (1) improper structural layout, and (2) poor material quality. The collapse has taken place in a torsional mode as seen in Fig 4.2a. The sketch of the plan layout the building (Fig 4.2c) reveals that stiffer RC members were densely located at the southern end of the building. Furthermore, concrete quality is estimated to be low and, bond between reinforcement and concrete was not established as Fig 4.2 clearly shows. In Van province, the Turkish government built a large number of schools. Especially performance of schools built recently has been found to be quite satisfactory.

Figure 4.1. Soft story reinforced concrete buildings in: (a) Ercis and (b,c) Van

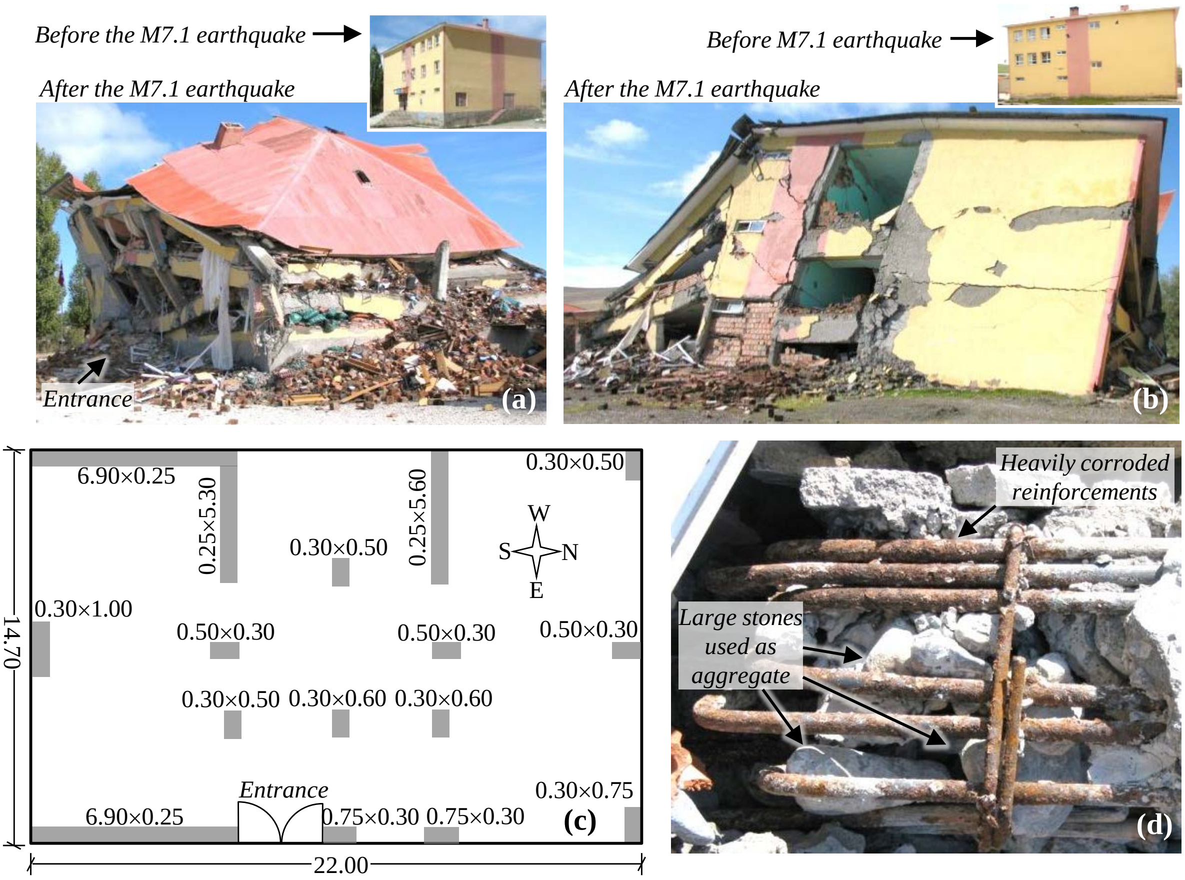
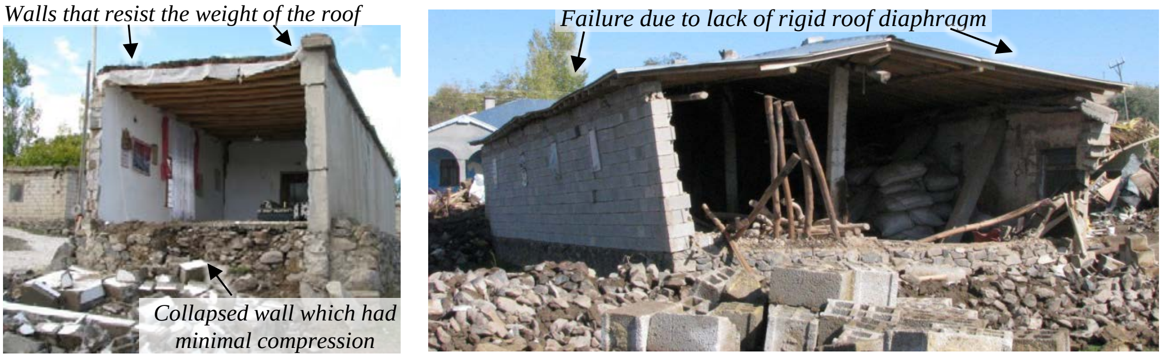


Figure 4.2. Collapsed school building in Gedikbulak: (a) North-East view, (b) South-West View, (c) beam column joint detail and (d) structural layout (units are in m) (Photos of the building before the earthquake are from MEB (2010))

4.2. Masonry buildings

The masonry is the predominant type of structural system in the rural settlements throughout the region. In the current Turkish seismic design code, masonry buildings are allowed to have a maximum of two and three stories in the seismic zones of 1st and 2nd grade, respectively. However, as a result of inadequate enforcement of the regulation several four-story masonry buildings were built in the region.

Most of the single story masonry houses have no ring beams. In these houses, the roof is supported by poplar tree trunks with diameters in the range from 20 to 30 cm. These wooden logs are simply seated on the masonry walls at the two ends. As a result, the walls that support the logs are subjected to axial compression while perpendicular ones have very minimal compressive load. When there is no ring beam to provide a diaphragm constraint, the walls without axial load deform separately when the system is excited by a strong ground motion. When the building deforms under inertial forces, these walls fail much earlier than the others (Fig 4.3a). In the dwellings with inclined roofs, failure progresses further as the roof pushes the adjacent walls apart (Fig 4.3b). These types of buildings are constructed for storage rooms. They have a rectangular planar shape and surrounding walls. The shorter walls have large door openings and the longer walls have small window openings. Often, they do not have any lateral wall to use the interior space effectively. The longitudinal walls are prone to out-of-the plane deformation, which can result in total collapse, as seen in Fig 4.3b.



(a) (b)

Figure 4.3. Typical damage mechanisms observed in the regional unconfined brick masonry buildings

4.3. Progression of damage due to November 9th earthquake

Structures in the city of Van were damaged by the two earthquakes that affected the region. The progression of the damage to a set of structures in the city of Van was investigated by the authors. For this purpose, a second reconnaissance visit was made after the November 9th earthquake (i.e. second earthquake). In this second reconnaissance visit, the progress of damage to structures in Van was investigated.

(a) (b) (c)

Figure 4.4. Progression of damage in a ground story column hinge: (a) location of hinge, (b) damage after the October 29th earthquake, and (c) damage after the November 9th earthquake.

The damages that were sustained after October 23th earthquake and that after November 9th earthquake are presented in Fig 4.4. In these figures, a column hinge from the ground story of a seven story reinforced concrete building is considered. In Fig 4.5b, it is seen that parts of cover concrete has been detached due to October 23rd earthquake. The damage is seen to have progressed further during the subsequent November 9th earthquake (Fig 4.4c). Buckled reinforcement bars are observed and larger pieces of cover concrete has fallen off. Thus, it may be concluded that November 9th earthquake seems to have deformed this component further than the deformation exhibited during October 23rd earthquake.

5. CONCLUSIONS

The damages observed after October 23rd, 2011 M7.1 and after November 9th, 2011 Van earthquakes are discussed in this study. First, the key properties of the recorded strong ground motions are evaluated. After that, the damages to reinforced concrete and masonry structures due to these earthquakes are presented. The common structural damage patterns observed in the affected region are discussed. The progress of damage to structures with each earthquake is qualitatively evaluated. Based on the field observations, the relationship between the key structural properties and the sustained damage grade is investigated. Based on the results from this investigation, the following conclusions can be drawn:

- The recorded peak ground accelerations are relatively lower than the peak accelerations expected in the region according to the current design codes.
- Extensive liquefaction, landslide and slope failure cases were observed but fortunately such ground failures did not lead to casualties. But a severe liquefaction phenomenon resulted in heavy damages to several structures in Ercis Plain.
- Extensive damages and collapses observed for the buildings in Ercis with fundamental periods of vibration in the range from 0.4s to 0.6 can be interpreted as result of the amplification of ground motion for that period range. This opinion necessitates an extensive research.
- The primary drivers of loss across the region were identified to be the poor quality of workmanship and improper use of building materials. A large variety of design and construction defects were observed in the inspected buildings.
- In reinforced concrete buildings, the quality of concrete was very poor. In the damaged buildings excessively large pieces of concrete aggregates were observed. Concrete clear cover was seen to be insufficient or totally not presented in several of the buildings in the region.
- Improper reinforcement detailing and lack of sufficient anchorage length was noticed in many of the damaged buildings.
- One of the major causes of collapse of buildings in the region was the severe irregularities of the structural system across the plan and across the height. Weak/soft story irregularity can be considered one of them. These were identified as the primary drivers of loss in the region.
- Based on the results from the two reconnaissance visits it was observed that the damages sustained by the structures in Van during October 23rd earthquake had progressed further due to occurrence of the November 9th earthquake.
- Although the observations are presented for Van region, they can be generalized very easily for the other regions of Turkey as well.
- The authors believe that the Turkish seismic code has very advanced concepts and requirements which can be found in the modern codes. A successful seismic performance of the building can be achieved by following the requirements of the code.
- For the masonry buildings, the lack of proper pasting material and insufficient floor or roof diaphragm stiffness were observed as the key structural defects.

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