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The evaluation of damage mechanism of unreinforced masonry buildings after Van (2011) and Elazig (2010) Earthquakes

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The evaluation of damage mechanism of unreinforced masonry buildings after Van (2011) and Elazig (2010) Earthquakes

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Abstract. On March 8th, 2010 Karakocan-Elazig earthquake of magnitude 6.0 occurred at a region where masonry and adobe construction is very common. Karakocan-Elazig is located in a high seismicity region on Eastern Anatolian Fault System (EAFS). Due to the earthquake, 42 people were killed and 14’113 buildings were damaged. Another city, Van located at South east of Turkey is hit by earthquakes with M = 7.2 occurred on October 23rd, 2011 at 13:41 (local time), whose epicenter was about 16 km north of Van (Tabanlı village) and M = 5.6 on November 9th, 2011 with an epicenter near the town of Edremit, south of Van and caused the loss of life and heavy damages. Both earthquakes killed 644 people and 2608 people were injured. Approximately 10’000 buildings were seriously damaged. There are many traditional types of structures existing in the region hit by earthquakes (both Van and Elazig). These buildings were built as adobe, unreinforced masonry or mixed type. These types of buildings are very common in rural areas (especially south and east) of Turkey because of easy workmanship and cheap construction cost. Many of those traditional type structures experienced serious damages. The use of masonry is very common in some of the world’s most hazard-prone regions, such as in Latin America, Africa, the Indian subcontinent and other parts of Asia, the Middle East, and southern Europe. Based on damage and failure mechanism of those buildings, the parameters affecting the seismic performance of those traditional buildings are analyzed in this paper. The foundation type, soil conditions, production method of the masonry blocks, construction method, the geometry of the masonry walls, workmanship quality, existence of wooden beams, type of roof, mortar between adobe blocks are studied in order to understand the reason of damage for these types of buildings.

1. Introduction

On October 23rd, 2011 Van city in eastern Turkey was hit by a large earthquake at 13:41 (10:41 GMT), on Sunday afternoon of magnitude 7.2. This earthquake had a shallow hypocenter depth of about 10 km. Effective duration of the earthquake according to Muradiye station records, was 20 sec, while it was 18 sec. according to Bitlis station records. The Van earthquake, where epicenter was about 16 km north of Van province, between Ercis county with a population of about 77 000 and Van

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city with population of about 370 000, has devastated the area, demolished many buildings with hundreds of people dead and thousands injured under the ruins. The location of epicenter can be seen in Fig. 1. The earthquake mainly affected Ercis County that is 90 km away from Van city. Hundreds of buildings totally collapsed; thousands of them were heavily damaged and 644 people died (Table 1). The 604 deaths during the first earthquake are 61 in the center, 66 in villages in the vicinity and 477 in Ercis; 40 people died because of second earthquake. The total economic loss is about 1 billion Turkish Lira (TL) to 4 billion TL (approx. 555 million–2.2 billion USD). This would represent around 17 to 66% of the provincial GDP (Gross Domestic Product) of Van [1].

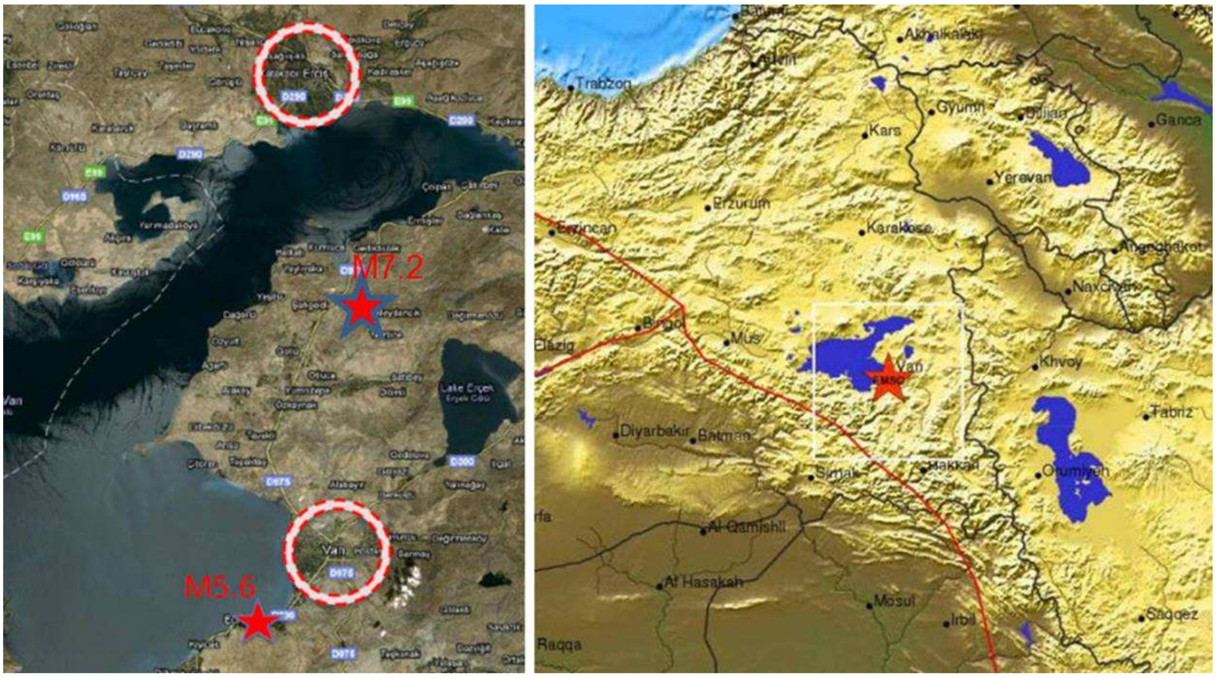

Figure 1. Location of earthquake epicenter

Table 1. Human losses and collapsed buildings.

Location	Life Losses	Injured	Total Collapsed Buildings
Center, Van	101	1150	10
Erciş, Van	477	1058	100
Villages	66	400	2197
Total	644	2608	2307

According to the information given by AFAD (The Disaster and Emergency Management Presidency), 644 people lost their lives and 252 people were saved alive from the debris. AFAD informed that, by December 9th, 2011, 17’005 dwelling units were determined as collapsed and/or heavily damaged in Van City Center, Erciş and villages. AFAD has reported deaths, Injured, Medical Personnel and Search and Rescue trends between 23.10.2011 and 1.11.2011 as shown in Figure 2.

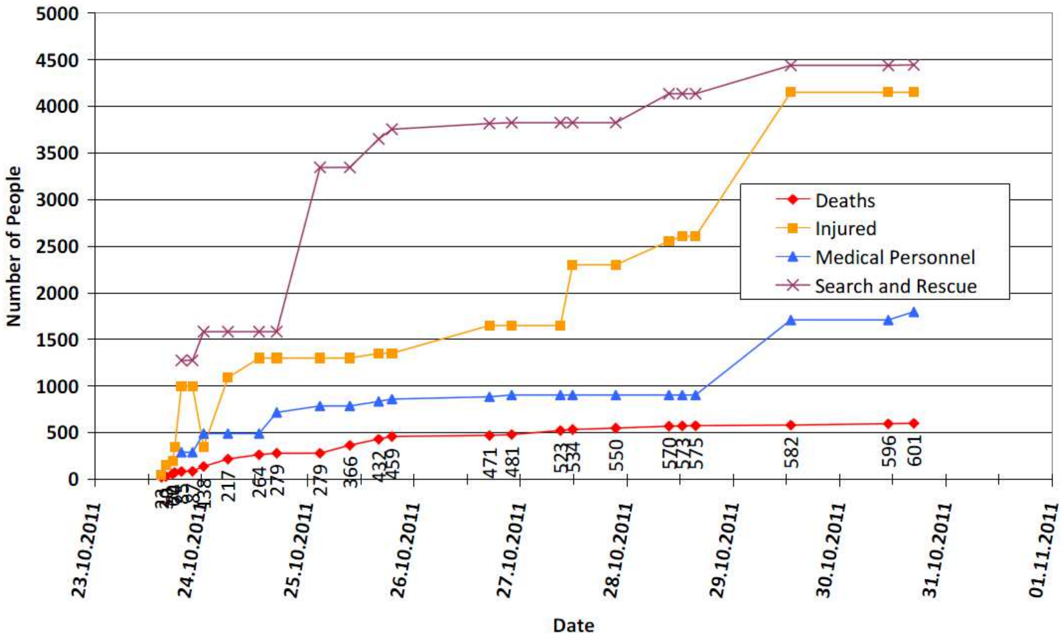

Figure 2. Deaths, Injured, Medical Personnel and Search and Rescue trends as of November 1st, 2011 (AFAD)

On November 9th, 2011, the second Van-Edremit centered earthquake occurred at 21.23 (18.23 GMT) of magnitude 5.6. The epicenter of the earthquake was near the Edremit town, south of Van (Figure 1). Effective duration of the earthquake according to Van station records was 18 sec, according to Van-Edremit station records was 23 sec. During the second earthquake 40 people lost their lives. This earthquake caused collapse or heavy damage of the buildings having slight or medium damage in Van city center and death of 40 people [1, 2]. On October 23rd, 2011, Van city in eastern Turkey was hit by a large earthquake at 13:41 (10:41 GMT), on Sunday afternoon of magnitude 7.2. This earthquake had a shallow hypocenter with a depth of about 10 km. Effective duration of the earthquake according to Muradiye station records, was 20 sec, according to Bitlis station records was 18 sec. The Van earthquake, where epicenter was about 16 km north of Van province, between Ercis county with population of about 77 000 and Van city with population of about 370 000, has devastated the area, demolished many buildings with hundreds of people dead and thousands injured under the ruins. The location of epicenter can be seen in Fig. 1. The earthquake mainly affected Ercis County that is 90 km away from Van city. Hundreds of buildings totally collapsed; thousands of them were heavily damaged and 644 people died (Table 1). The 604 deaths during the first earthquake are 61 in the center, 66 in villages in the vicinity and 477 in Ercis; 40 people died because of second earthquake. The total economic loss is about 1 billion Turkish Lira (TL) to 4 billion TL (approx. 555 million–2.2 billion USD). This would represent around 17 to 66% of the provincial GDP (Gross Domestic Product) of Van [1].

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2. Seismic Properties of the Region

In the area of Lake Van and further east, tectonics is dominated by the Bitlis suture zone (in eastern Turkey) and Zagros fold and thrust belt (towards Iran). The October 23rd, 2011 earthquake occurred in a broad region of convergence beyond the eastern extent of Anatolian strike-slip tectonics. The focal mechanism of recent earthquakes is consistent with oblique-thrust faulting similar to mapped faults in the region. Given its tectonic history, a major earthquake in Anatolia is by no means an unusual event and other major earthquake events are to be expected in the region as the central block continues to be squeezed westwards and lateral movement occurs along the fault complexes of both North and East Anatolian Faults (Figure 3).

Major earthquakes such as this one have occurred in the year 1111 causing major damage and having a magnitude around 6.5-7. In the year 1646 or 1648, Van was again struck by a M 6.7 quake killing around 2000 people. In 1881, a M6.3 earthquake near Van killed 95 people. Again, in 1941, a M5.9 earthquake affected Ercis and Van killing between 190 and 430 people. 1945-1946 as well as 1972 brought again damaging and casualty-bearing earthquakes to the Van province.

In 1976, the Van-Muradiye earthquake struck the border region with a M7, killing around 3’840 people and causing around 51’000 people to become homeless. In recent years (according to historical records from 1900), there were 10 earthquakes which happened with a magnitude in between 5-6, three earthquakes with a magnitude in between 6-7, two earthquakes with a magnitude in between 7-7.5. The damages and human loss can be seen in Figure 4.

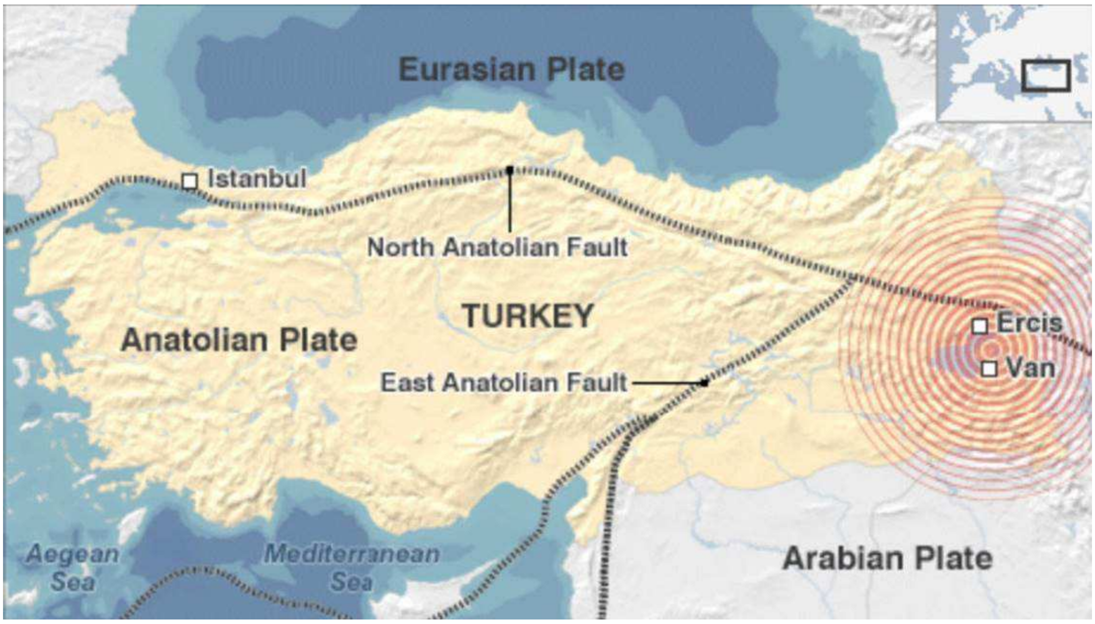

Figure 3. Van and Erciş are located in eastern Turkey by Lake Van [3]

The damages and human loss can be seen in Figure 3. The energy released by earthquake is calculated as 2.09x1015 Joule. This energy is 33.2 times more than Hiroshima atomic bomb explosion energy [4].

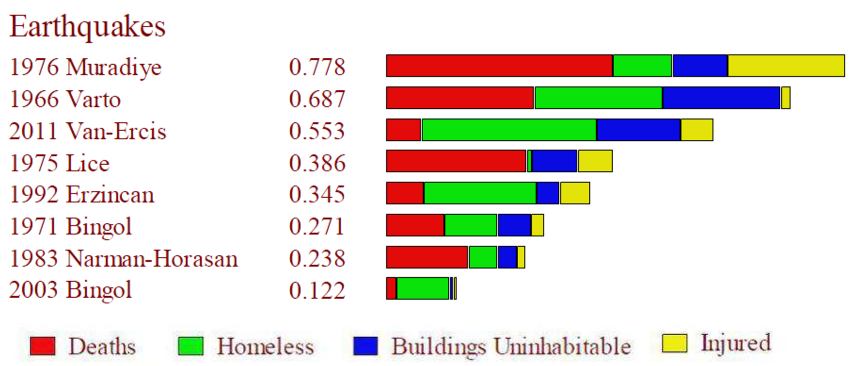

Figure 4. Loss score for historic earthquakes in eastern Turkey

As of the October 31st, 2011 reported from Turkish Red Crescent, of the 43'548 buildings that have been examined, 2'309 have collapsed, 11'847 have been severely damaged or are uninhabitable. 17'923 houses have been slightly or moderately damaged. In addition, 11'469 buildings have been undamaged as shown in Figure 5. A group of almost 200 staff have been undertaking preliminary assessment of the damaged buildings. In the Van City, the natural gas system (building collapse on a system regulator), water supply system (pipeline damage), the power and communication systems (general interruptions) were all affected, however were reported to be functional again within 24 hours after the earthquake. The Van-Ercis road was also reported to have been damaged in the form of road collapse and cracking.

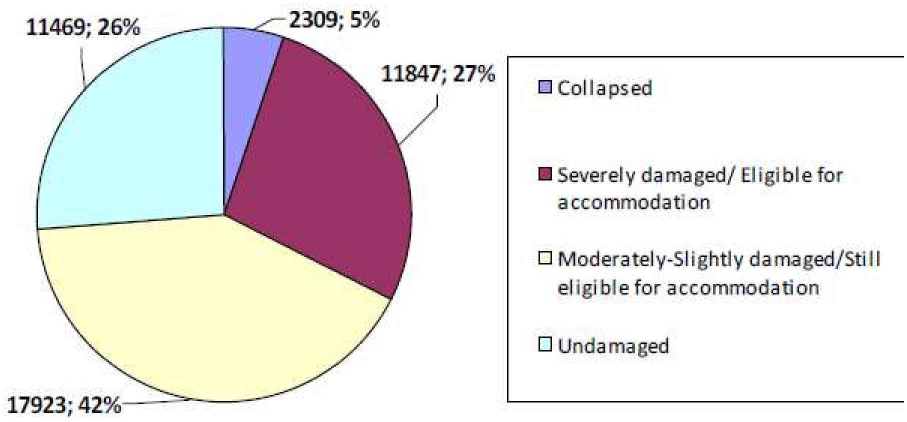

Figure 5. The current statistics of building damage as determined by different damage classes [5]

Unreinforced masonry has traditionally been the primary construction method of rural areas in Turkey. Though reinforced concrete was introduced during the first decade of 1900, the adobe, stone and later concrete in rural houses using local materials and unskilled labour continued to be constructed. In the region, there are many houses and public buildings constructed with stone, brick, adobe and concrete blocks. Some of them were heavily affected where some had slight damages. Most of the buildings in the region were built without any design, control or supervision. In addition to lack of design and control of mixed buildings, the material and workmanship quality was much less than desired level [6]. This earthquake caused extensive damages not only to the reinforced concrete structures but also unreinforced masonry buildings. Many of the damaged building types were stone, brick or briquette masonry or adobe with low construction and material quality. In this paper, the results of the site surveys are presented and the lessons learned from the earthquake and structural damages are discussed.

3. Earthquakes and Consequences

On October 23rd, 2011 Van-Merkez earthquake is unique from several aspects. Very high number of aftershocks within short period after the event was not experienced previously. Within the first week of the earthquake, there happened 114 earthquakes with magnitudes between 4.0 and 4.9 and 7 earthquakes with magnitudes bigger then M l:5.0. Within the first month after the event daily average aftershock number is around 180 earthquakes. By December 9th, 2011, the number of aftershocks reached to 6284. Focal depths of aftershocks vary between 2.5 km to 25 km (AFAD). The area between Van and Erciş is tectonically complex and there are several faults with different characteristics. The reason for such big amount of aftershocks and diversity of the focal mechanism solutions are due to this tectonic complexity. Very generally, earthquake with Mw:7.0 at 19 km. depth activated this systems and small scaled faults triggered one and each other within this period and increased the earthquake activity. It was observed, as a result of the field studies, the fault (N60,70E) that caused earthquake was a buried fault. Morphological trace of fault is observed on the shaded relief map and 3D digital elevation model map as shown in Figure 6.

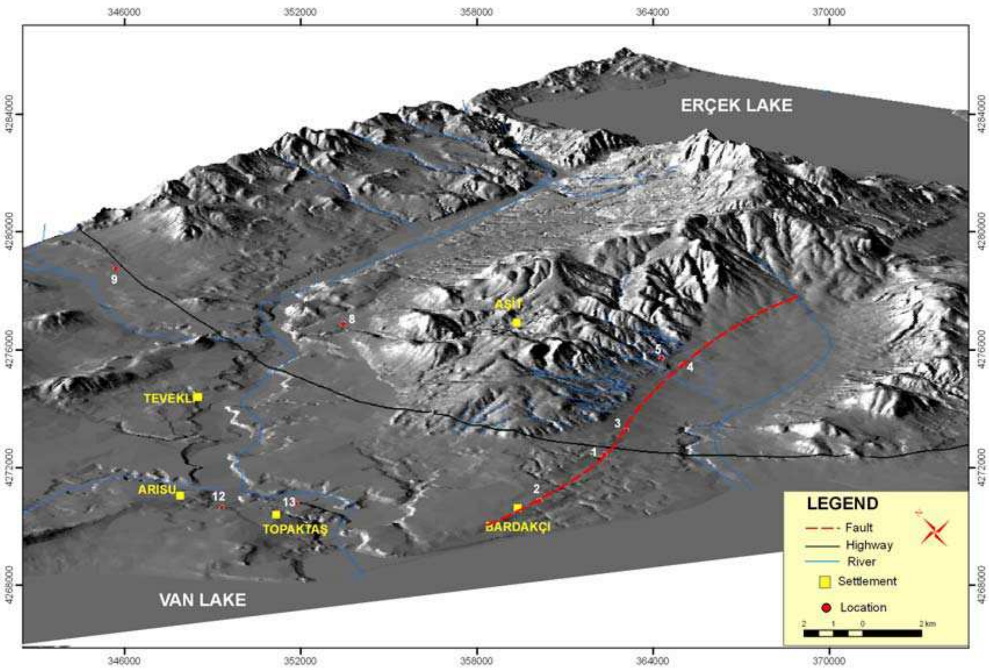

Figure 6. 3D Digital elevation model map (AFAD)

To describe earthquake force; Acceleration, velocity and displacement response spectrum of acceleration records are calculated by AFAD. In order to Ml=6.7 Van-Merkez earthquake and Ml=5.6 Van-Edremit earthquake, response spectrum that is obtained from acceleration records were calculated for 5%, 10% and 15% damping ratios. The results can be followed from Figure 7a and 7b.

Compare with acceleration response spectrum and design spectrum (according to Turkish Earthquake Resistant Code (TDY) 2007) of October 23rd, 2011 Van earthquake Ml=6.7 and November 9th, 2011 Van-Edremit earthquake Ml=5.6 are given in Figs. 8a and 8b. When examined at the calculated

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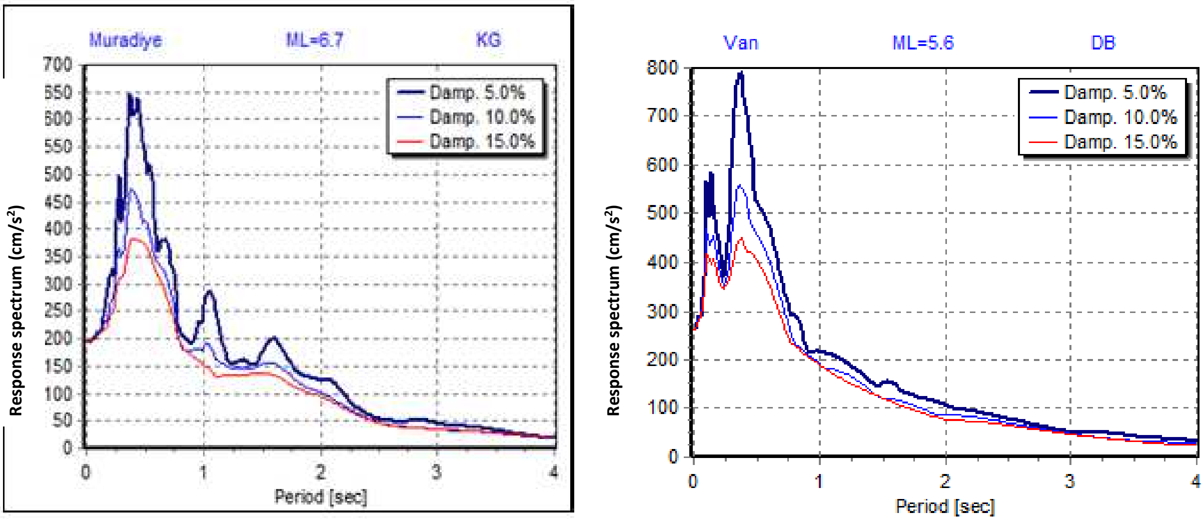
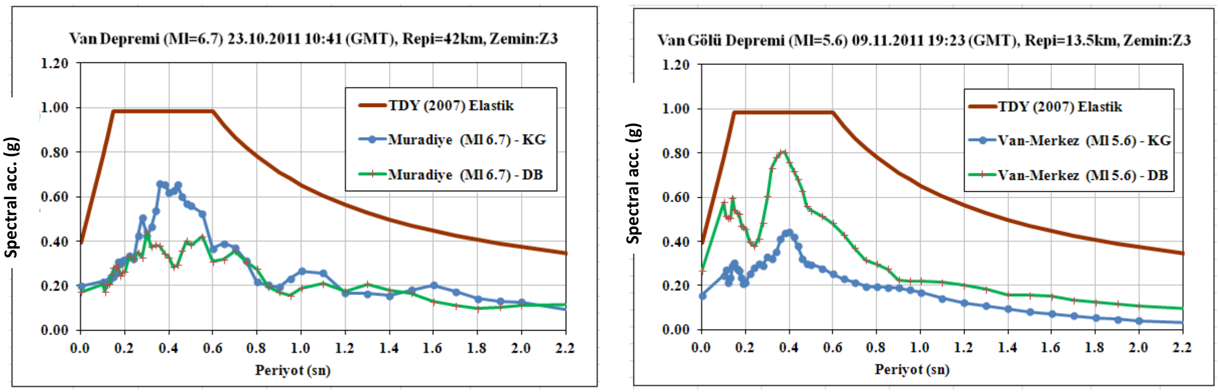
response spectrum curve, it is seen that each one of two ground motions under the design spectrum that identified for first degree earthquake zone.



a) **b)**

Figure 7. Response spectra of October 23rd, 2011, a) Ml=6.7 Van-Merkez earthquake Muradiye record NS component, b) Ml=5.6 Van-Edremit earthquake Van-Merkez record EW component (AFAD)



a) **b)**

Figure 8. Comparison of NS and EW component response spectrum and TDY 2007 design spectrum a) October 23rd, 2011 Van earthquake Ml=6.7 and b) November 9th, 2011 Van-Edremit earthquake (AFAD)

Building stock in Van and Erciş Center generally consists of 4-8 storey reinforced concrete structures, which is very common in Turkey. In most of the buildings asmolen slab (infilled joist slab) is used. Especially in collapsed buildings, commercial parts such as shops or markets having almost two times normal floor height has been determined. In rural areas, most of the existing building stock is comprised of adobe, stone and brick masonry buildings with ages longer than their service life. They are constructed as one or two-storey by local people without taking into consideration any regulation, standard and earthquake resistant design rules. It is observed in the masonry structures at this region that horizontal and vertical supporting members, used to distribute loads safely, are made from wood, number of these members is inadequate and they are placed irregularly. Also, it is determined that lengths of their connections to load carrying walls are very short and weak. Briefly, poor quality construction material, structures with non-conforming earthquake code and lack of inspection are the main reasons of damage in the region.

4. Damage Mechanism of Unreinforced Masonry Buildings

According to site investigations, unreinforced masonry building houses are more common building type in the region hit by earthquake. The distribution of the buildings according to construction types and location is given in Table 2. As shown in the table, 75% of the buildings in Van (towns and villages included) is unreinforced masonry. The unreinforced masonry building ratio in Ercis is 63%, in Muradiye is 81%, in the city center of Van is 82%.

Table 2. Distribution of investigated buildings

	Van (Total)	Ercis	Muradiye	Center
Number of buildings	78.000	10.700	3.600	35.200
RC Buildings	12.7 %	27 %	5 %	5 %
Unreinforced masonry	75 %	63 %	81 %	82 %
Adobe	9.5 %	8 %	12 %	9 %
Rubble stone	2.8 %	2 %	2 %	4 %

Unreinforced masonry buildings mean that masonry infills in non-ductile reinforced concrete frames can be found in many places around the world. Masonry infills have been widely used because of their good thermal and acoustic insulation properties both for aesthetic reasons and fire resistance. Although in design masonry infills are considered as non-structural elements, they can develop a strong interaction with the bounding frames when subjected to earthquake loads and, therefore, contribute significantly to the lateral stiffness and load resistance of the structure.

Architectural characteristics of unreinforced masonry buildings are similar in the region: the rectangular plan, single door, and small lateral windows are predominant. Quality of construction in urban areas is generally better than construction in rural areas. The foundation, if present, is made of medium to-large stones joined with mud or coarse mortar. Walls are made with briquette or hollow brick with mud or cement mortar. The size of briquette varies from region to region. Generally the size of briquette is about 12x15x34 cm and the weight is about 10-18 kg. Average size of hollow brick is about 19x13.5x19 cm and the weight is about 2.6-3.0 kg [8]. Average size of adobe block size varies between 30x15x10 cm and 35x17x12 cm and the weight is about 6-8 kg.

Figure 9. Briquette, hollow brick, adobe, stone

In addition to briquette and hollow brick buildings, adobe, brick, stone masonry or timber houses are also common in the region. Generally the masonry houses are built without wooden confinements. When horizontal and vertical ties do not exist, horizontal forces cannot be taken by thin adobe walls and damage occurs.

A typical masonry wall consists of piers between openings plus a portion below openings (sill masonry) and above openings (spandrel masonry), as shown in Figure 10a. When subjected to in-plane earthquake shaking, masonry walls demonstrate either rocking or diagonal cracking. Rocking is illustrated in Figure 10b, and is characterized by the rotation of an entire pier, which results in the crushing of pier end zones. Alternatively, masonry piers subjected to shear forces can experience diagonal shear cracking (also known as X-cracking), as shown in Figure 10c. Diagonal cracks develop when tensile stresses in the pier exceed the masonry tensile strength, which is inherently very low. This type of damage is typically observed in the bottom story of a building. Several factors influence the in-plane failure mechanism of stone masonry buildings, including pier dimensions; wall thickness, building height, and masonry shear strength. Rocking behavior is more desirable than diagonal shear cracking. [9]

Out-of-plane wall collapse is one of the major causes of destruction in stone masonry buildings, particularly in buildings with flexible floors and roofs. The connections between structural components are important for maintaining building integrity [10]. Integrity is absent or inadequate when the walls are not connected at their intersections and there are no ties or ring beams at the floor and roof levels. As a result, each wall vibrates on its own when subjected to earthquake ground shaking and is therefore likely to total or partial collapse. The typical failure mode in these structures was out-of-plane wall failure due to the absence of diaphragms tying the walls together. In multi-story buildings, this type of collapse usually takes place at the top floor level due to the significant earthquake accelerations there.

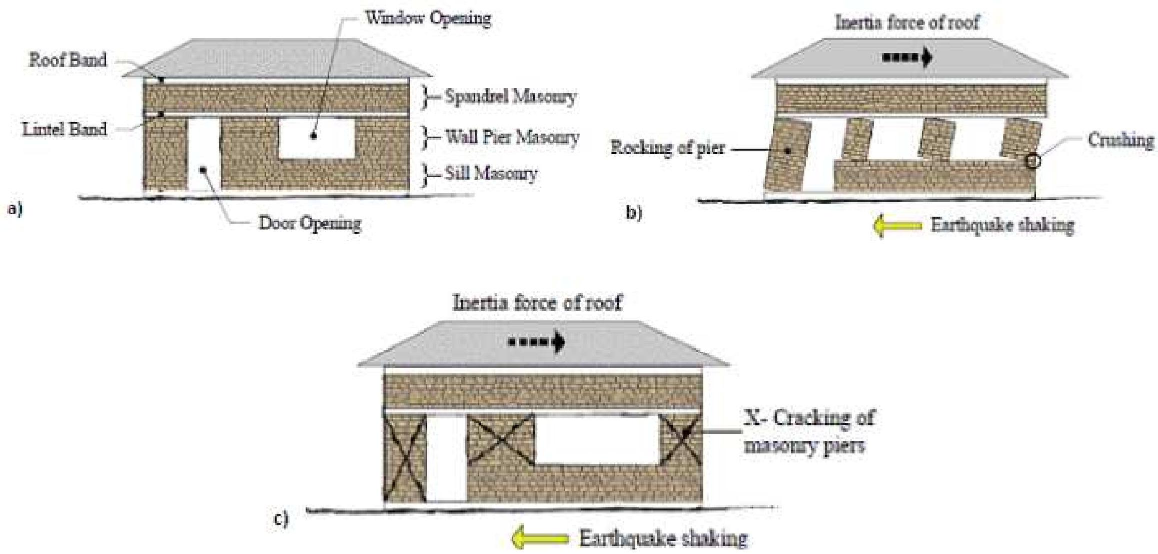


Figure 10. In-plane damage of stone masonry walls: a) typical wall with openings; b) rocking failure, and c) diagonal shear cracking [10]

Unreinforced masonry buildings are very common in the region because of socio-economic reasons. Annual income average in this region is far lower than the other regions of Turkey. In addition to this, education level is too low. Therefore people do go to the engineers or architects for preparing their projects. Generally they prefer local uneducated or uncertified constructors for construction of their buildings. Unfortunately local authorities do not properly control and supervise construction activities in the region. Damage observed in masonry infilled frame structures varied from small cracking to severe damage (diagonal cracks, out-of-plane failure etc) and collapse.

The masonry buildings in the region hit by the earthquakes were constructed by mud bricks, stones/pebbles taken from the river banks, soft natural stone blocks and lime hollow/solid blocks.

Adobe buildings were constructed from adobe bricks made by formation of mud with wooden bracings. These materials have been used as structural material; however, they do not fulfill code or any provision requirements [11].

After October 23rd, 2011 and November 9th, 2011 earthquakes, a detailed site investigation was performed in the region hit by earthquakes. Especially damaged or collapsed unreinforced masonry buildings were observed to discover their damage reasons.

One of the most important reasons was the use of improper construction material. Rubble stone, briquette and soft stone blocks were the masonry materials widely used in the damaged or collapsed buildings. Their quality is low and production is out of standard. Therefore low quality materials caused serious damages as shown in Figure 11.

Figure 11. Low quality briquette and adobe

The use of mud mortar for adobe and briquette blocks cause low lateral force resistance. Mud as mortar has low strength and has poor bonding characteristics. As a result of this, masonry buildings performed very poor lateral resistance to seismic forces and damaged or collapsed easily as shown in Figure 12.

Figure 12. Improper mortar use such as mud

In addition to previous reasons, construction method is also against basic structural design criteria. Wall-to-wall and wall-to-floor connections are very poor. Therefore infill walls collapsed easily during the earthquake as shown in Figure 13.

Figure 13. Poor wall-to-wall and wall-to-floor connections

Many damaged buildings have flexible floor diaphragm, which prevents the transfer and distribution of lateral forces in a uniform manner as shown in Figure 14.

Figure 14. Flexible floor diaphragm

Improper placement of door and window openings in walls caused serious damages in the region, which creates vulnerable and weak zones in the structure as shown in Figure 15.

Figure 15. Improper placement of door and window openings

5. Conclusions

Unreinforced masonry is a widely used building type all over the world and also in the investigated area. In rural areas, it is preferred because of economic, easy, simple workmanship construction type. However; seismic performance of the unreinforced masonry buildings is generally less than the desired level. National Construction Control and Supervising Law was not a mandatory regulation in the region until 2011. In rural areas of Turkey, seismic codes for buildings were not strictly enforced as much as they were enforced in urban areas. Therefore; the buildings in the region didn't have adequate engineering assistance. Most of the houses used different construction materials and systems in the same building.

Unreinforced masonry houses in the villages of the Van city were seriously affected from the earthquake. Similar to adobe buildings, improper low quality reinforced concrete or unreinforced masonry houses experienced serious damages in the region.

The serious damage of masonry infill walls subjected to out of-plane accelerations makes load-bearing masonry buildings very vulnerable to seismic damage and possible collapse. Due to the dynamic interaction between the vibrating structure, slab diaphragms and the infill wall loaded out-of-plane, enormously increased accelerations occur on the face of loaded infill wall, resulting in greatly increased inertia forces.

Traditional masonry buildings, regardless of their important architectural or cultural value, are also prone to suffering damage during strong earthquakes. Thus, it is important to provide adequate preservation methods to ensure safety and their authenticity. Using simple and economic confinement techniques, seismic performance of the unreinforced houses can be provided. In order to reach to this target, education of local workers and contractors is very important. Skilled workmanship will increase seismic resistance of unreinforced masonry buildings. Construction of the houses should be controlled and supervised by experienced engineers and architects assigned by the government. It is necessary to develop guidelines for the construction of unreinforced masonry buildings in rural areas.

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