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DAMAGE EVALUATION OF MASONRY HOUSES AFTER VAN EARTHQUAKES (23 OCTOBER 2011 AND 9 NOVEMBER 2011)

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Abstract. *Van located at South east of Turkey was hit by two earthquakes; with M = 7.2 on 23 October 2011 at 13:41 (local time), where epicenter was about 16 km north of Van (Tabanlı village) and with M = 5.6 on 9 November 2011 where epicenter was about 6 km south of Van (near Edremit town) that caused the loss of life and property. During these earthquakes 644 people were killed and 2608 people were injured. Approximately 4000 buildings were collapsed or seriously damaged.*

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 labor 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.

Seismic response and performance of masonry houses have been studied for a long time after each earthquake. After destructive earthquakes happened in Van city, damage levels of these types of buildings were investigated. In this paper the parameters affecting the seismic performance of the masonry buildings of this area will be presented according to the damage level of the buildings. The parameters as the construction year, masonry material, production method of the masonry units, construction method, the geometry of the masonry buildings, workmanship quality, type of roof, mortar between masonry blocks and foundation type will be studied in understanding damage reason.

1 INTRODUCTION

23 October 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 shoal hypocenter depth of about 10 km. Effective duration of the earthquake according to Muradiye station records, was 20s, according to Bitlis station records was 18s. 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 in the earthquake are 61 in the center, 66 in villages and in the vicinity and 477 in Ercis. The total economic loss is about 1 billion to 4 billion Turkish Lira (TL) which is approximately 555 million–2.2 billion USD. This would represent around 17% to 66% of the provincial GDP (Gross Domestic Product) of Van [1].

In 9 November 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 18s, according to Van-Edremit station records was 23s. 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].

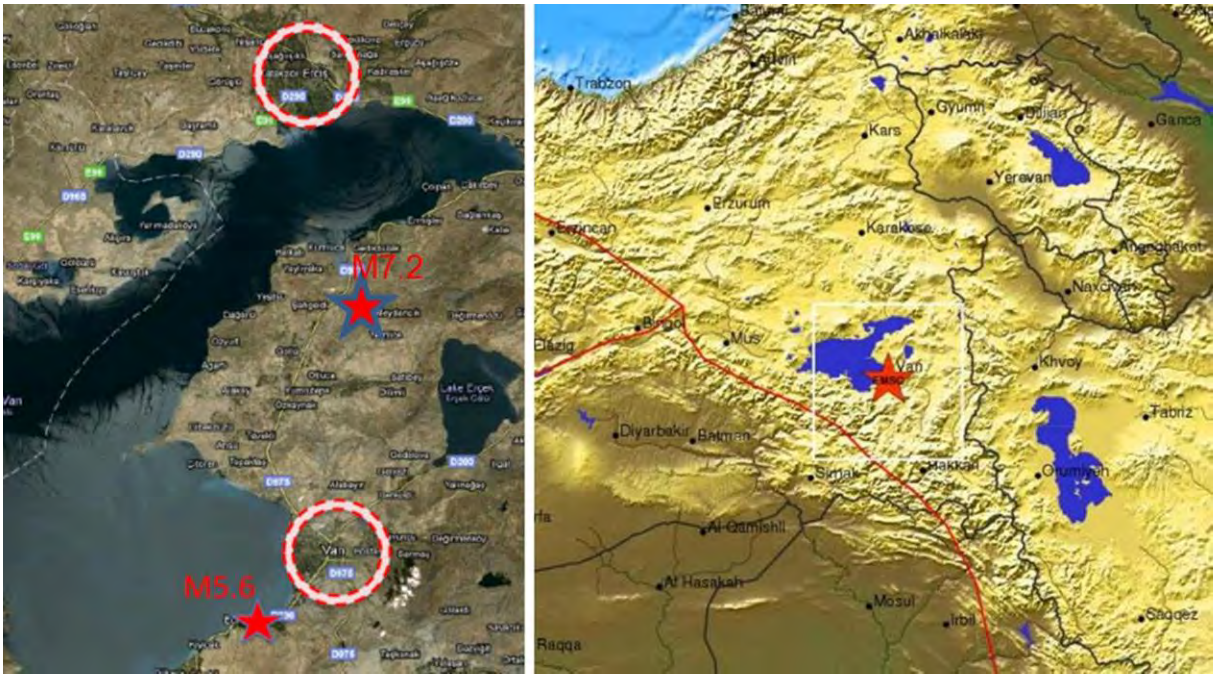

Figure 1: Location of earthquake epicenter

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 (toward Iran). The 23 October 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 Fault (Figure 2).

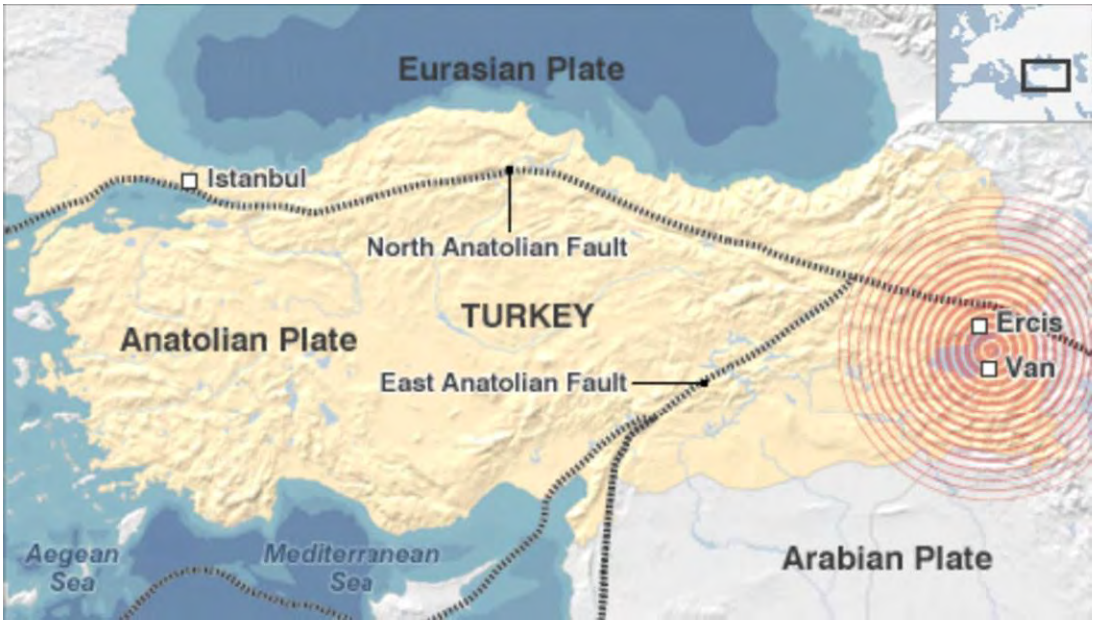

Figure 2: Van and Erciş are located in eastern Turkey by Lake Van [3].

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 M6.7 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 3840 people and causing around 51,000 people to become homeless. In recent past (according to historical records from 1900), there were 10 earthquakes happened with magnitude 5-6, three earthquakes with magnitude 6-7, two earthquakes with magnitude 7-7.5. The damages and human loss can be seen Figure 3. The energy released by earthquake is calculated as 2.09×10^{15} Joule. This energy is 33.2 times more than Hiroshima atomic bomb explosion energy [4].

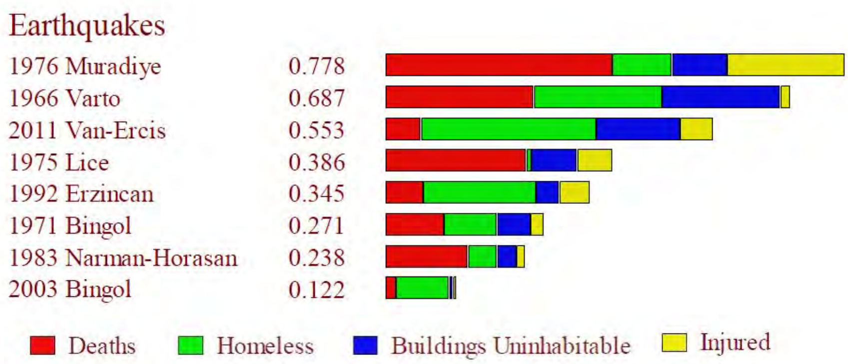

Figure 3: Loss score for historic earthquakes in eastern Turkey

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 labor 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 [5]. 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.

2 MASONRY BUILDINGS IN THE REGION

Architectural characteristics of 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 to that 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 as shown in Figure 4. Average size of hollow brick is about 19x13.5x19 and the weight is about 2.6-3.0 kg.

Figure 4: Briquette and hollow brick

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.

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 1. As shown in the table, 75% of the buildings in Van (towns and villages included) are unreinforced masonry. The unreinforced masonry building ratio in Ercis is 63%, in Muradiye is 81% and in the city center of Van is 82%.

Table 1: 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 %

3 SEISMIC PERFORMANCES OF UNREINFORCED MASONRY BUILDINGS

Even though the magnitude and spectral acceleration values of the earthquakes were not so large compared with code defined spectra, many brick and adobe masonry buildings were completely collapsed or heavily damaged caused by above-mentioned construction applications and poor construction material. Total building stock distribution in Van is given in Figure 5. The area hit by earthquake was surveyed and detailed studies were carried out on the damaged buildings to analyze the reasons of the weak performance of the masonry buildings [6].

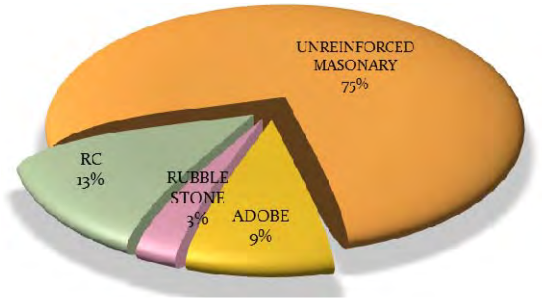

Figure 5: Total building stock in Van

Generally existing unreinforced masonry buildings in the region were one or two-story with a very heavy earth roof over wooden beams. This type of heavy earth roofing significantly increases the mass of the building that increases the seismic forces during earthquake.

As shown in Figure 6, inadequate foundation conditions leaded vertical separation and local collapse of buildings. Besides, earth mortar used to connect briquettes was also another reason for damage.

Figure 6: Damaged briquette masonry building

Typical modes of masonry building failure subjected to earthquake loads are in-plane shear cracking, out-of-plane overturning of the walls, separation of walls at the corners. Separation of floors/roofs from the walls is result of the other types of failures, and in most cases, leads to collapse. Cracking is almost certain to occur during major seismic ground motions as the stresses in the wall exceed the tensile capacity of the material.

The out-of-plane motion of walls often results in horizontal cracking where the vertical location depends upon the loads induced by the weight of the wall or other tributary loads. Vertical or diagonal cracks at the wall intersections may be due to the out-of-plane motion of the walls that cause excessive bending and tension reactions at these locations. Non-load bearing walls that don’t carry floor/roof joists often are the first to collapse when there is no restraint provided at the roof or floor connections (Figure 7). The bearing walls carrying the floor/roof joists may also progressively move out from under the beams and collapse, where there is no adequate connection between roof or floor beams and the wall top. The primary factors affecting the out-of-plane stability of a masonry wall during the earthquake are its absolute thickness, its slenderness ratio (height/thickness ratio), and the degree of restraints that may limit the deflection at the top and added gravity loads from roof or floor framing.

Figure 7: Damages on non-load bearing walls

Generally in-plane earthquake forces lead diagonal cracks on masonry walls (Figure 8). When the cracks intersect each other, each wall becomes independent cracked blocks where in-plane motions and gravity loads lead the broken sections of the wall to fall out.

Figure 8: Cracks on masonry walls

Another common reason for damages in the buildings hit by earthquake is the inadequate distance between two openings and the inadequate wall length (Figure 9). The buildings having bonding beams at the top of the walls may diminish the damage level of the wall.

Figure 9: Damage caused by distance between the wall openings

Although the bond beams on top of the walls are very crucial for seismic resistance, damaged unreinforced masonry buildings did not have this type of beams on the top. In addition, a heavy earth roof with inadequate in-plane stiffness does not provide a rigid diaphragm effect, which is also one of the important reasons for this kind of failure (Figure 10). Because walls, bond beams and roofs were not properly connected to each other. They could not transfer the seismic loads to each other. These walls performed beyond the desired level for they behaved as free-standing walls.

Figure 10: Out-of-plane failure of briquette masonry house due to long span (Güveçli village, Van)

In Suphan district, 20 unreinforced buildings were investigated. They were all single storey buildings. Masonry elements of all these buildings were of briquette. As function, 71% of investigated buildings were residential, 12% was simple shops or store and 17% was animal sheds (Figure 11). Mud or cement was used as mortar material between masonry blocks. The mortar types of the investigated buildings were 50% cement and 50% mud mortar. Because of economic reasons, mud mortar was commonly used in the region although its strength is very poor. The damage level of investigated buildings at the region had heavy damage of 25%, moderate damage of 65% and slight damage of 10% (Figure 12).

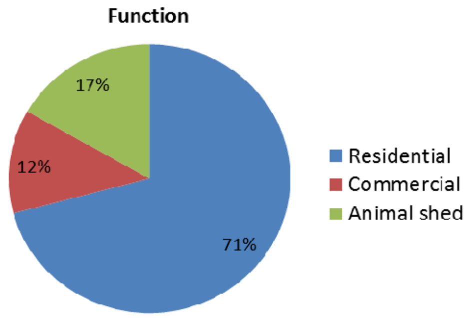

Figure 11: Function of investigated unreinforced masonry buildings

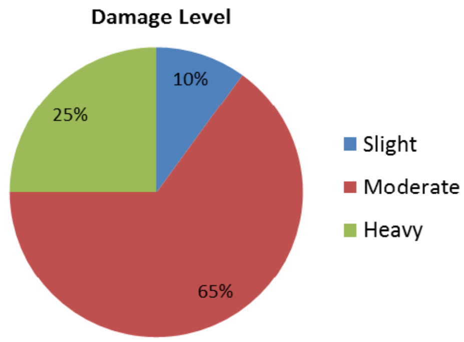

Figure 12: Damage level of investigated unreinforced masonry buildings

In this region agriculture and livestock are very important for local economy. However, many animals shed built by briquette masonry experienced serious damage in the area. Many of them collapsed or were seriously damaged. Compared with the residential houses, these sheds were poorly constructed (Figure 13). They had long spanning walls due to lack of partitioning walls. These long unsupported walls collapsed under out-of-plane earthquake loads.

Figure 13: Damages on animal sheds

Although most of the masonry buildings had damages, there was also adobe, brick or stone masonry buildings that had no damage (Figure 14). When their construction year is investigated, it is seen that the buildings constructed before 1970s has no or slight damages. The reason might be in the organization of the foundation. Building masters, being aware that rigid building on rigid soil might be dangerous for the building, had introduced special techniques to change the natural frequency of soil or provided flexible footings at high seismic zones [7]. As also pronounced by old villagers, the foundations of masonry village houses were constructed on a layer of ~40cm sand till 1960s. The thick layer of sand, gravel or stone pieces provided a change in the natural frequency of soil as well as adequate subsurface permeability to avoid a high water table condition [8]. Because this traditional construction method was forgotten, many masonry buildings had suffered during these earthquakes.

Figure 14: Undamaged masonry buildings in the region

4 CONCLUSIONS

Unreinforced masonry is widely used building type in 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 desired level. Until 2011, National Construction Control and Supervising Law was not a mandatory regulation in the region [9]. 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 any 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. One of the most important reasons for heavy damage is the ignorance of the traditional construction methods. Another important reason is the lack of interlocking element between external and internal leaves of the wall sections and the lack of connection between crossing walls. Both of them resulted in an increase in the possibility of out-of-plane failure since their formation increases net length of the walls or leaves. Another common reason for failures was the lack of bond beams at the wall tops. For example, a heavy earth roof was put directly on the beams resting on the walls which increased the seismic demands and resulted in failures. Improper placement of openings was also another important reason for the commonly seen damages. Concentrated serious cracks were observed around or between the doors and windows. The poor performance of building during earthquake was also resulted from poor quality of construction material.

Traditional masonry buildings, regardless of their important architectural or cultural value, are also prone to suffer 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 and appreciation of the traditional construction methods will increase seismic resistance of unreinforced masonry buildings. Construction of the houses should be controlled and supervised by experienced engineers and architects charged by government. It is necessary to develop guidelines for the construction of unreinforced masonry buildings in rural areas.

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