Damages to masonry buildings during recent earthquakes in Turkey

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ABSTRACT

Turkey is located on active faults. For this reason many destructive earthquakes occurred throughout history. In recent years, earthquakes which occurred March 8, 2010 Elazığ-Kovancılar, June 23, 2011 Elazığ-Maden, September 23, 2011 Tabanlı-Van and November 9, 2011 Edremit-Van earthquakes caused human causalities and large damages with considerably loss of properties in Turkey. Especially masonry buildings in the rural area were damaged seriously due to these earthquakes. In this paper, the earthquake damages of masonry buildings were presented and reasons of damages were investigated.

INTRODUCTION

Many masonry structures collapsed or damaged during the recent earthquakes in Turkey. These earthquakes resulted in loss of lives and properties. These are: 2010 Kovancılar and Palu, 2011 Maden, 2011 Tabanlı and 2011 Edremit earthquakes. 2011 Tabanlı-Van earthquake with a magnitude of M_w =7.2 is one of the largest earthquakes in last century in Turkey. Magnitude and characteristic parameters of the earthquakes are given in Table 1. In this table, M is the local magnitude for first three rows and moment magnitude for the other rows.

Table 1 Characteristic of earthquakes

Location	Date	Latitude (N)	Longitude	Depth	M
Kovancılar	08.03.2010	38.7665	40.0712	5	5.8
Palu (Elazığ)	08.03.2010	38.7355	40.009	5	5.6
Maden (Elazığ)	23.06.2011	38.57	39.59	13.42	5.3
Tabanlı (Van)	23.10.2011	38.6890	43.4657	19.07	7.0
Edremit (Van)	09.11.2011	38.4472	43.2638	6.09	5.7

In Kovancılar earthquake which had moderate magnitude, 42 people lost their lives and 137 people were injured according to official sources. After this earthquake, an aftershock occurred in Palu district of Elazığ on the same day. In these earthquakes, 2870 buildings constructed of masonry material were damaged heavily. On June 23, 2011 at local time 10:34, an earthquake of M_L=5.3 struck Maden country of Elazığ. No casualties were reported for Maden earthquake. However, 261 residential buildings were damaged heavily. On October 23, 2011 an earthquake that is one of the largest earthquakes in Turkey hit Tabanlı district of Van. In this earthquake, 604 people died. 17 days after this devastating hazard, another earthquake

struck again area which epicentral location is Edremit region on November 9. The second earthquake caused loss of 40 lives. 1966 people were injured, 252 people were rescued under the debris of collapsed buildings and 38515 residential buildings are classified heavily damaged at the both Van earthquakes.

Turkey is divided into the 5 seismic zones according to seismic zone map which was prepared by Ministry of Public Works and Settlement. In this map, city center of Elazığ and Van, and Edremit is at second degree seismic zone although Kovancılar, Palu and Maden districts of Elazığ is at first degree seismic zone (Fig. 1-2). According to Turkish Seismic Code (TSC), I degree earthquake zone is the most hazardous and V degree is no hazard zone. The probability of exceeding an effective peak ground acceleration of 0.4g and 0.3g are 10 % in 50 years or the return period 475 years for seismic zone 1 and 2, respectively [1].

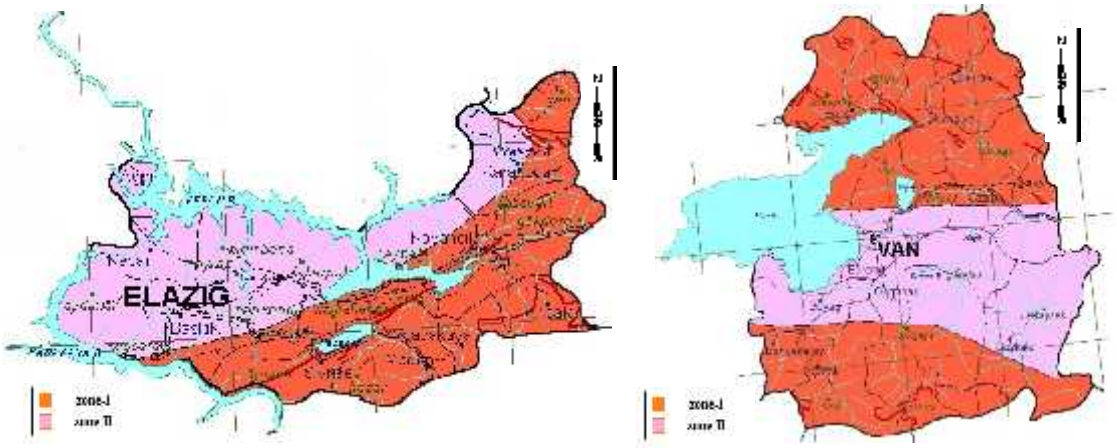
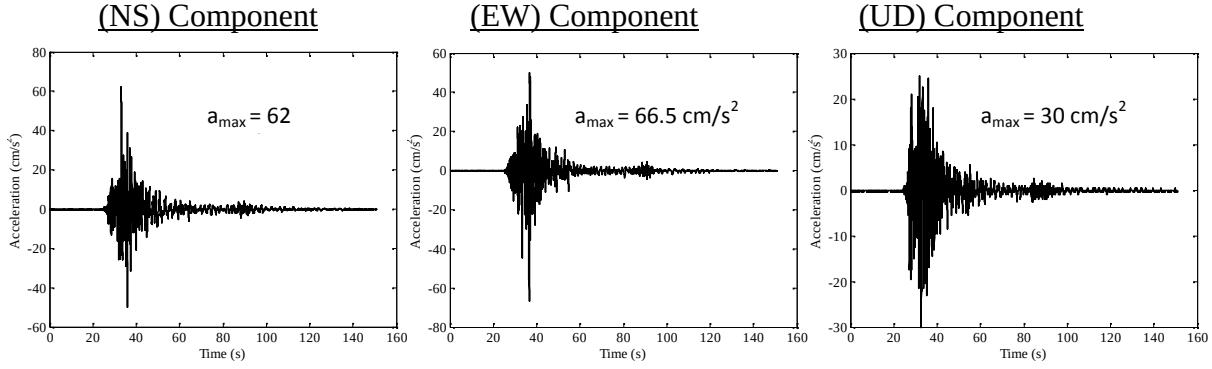
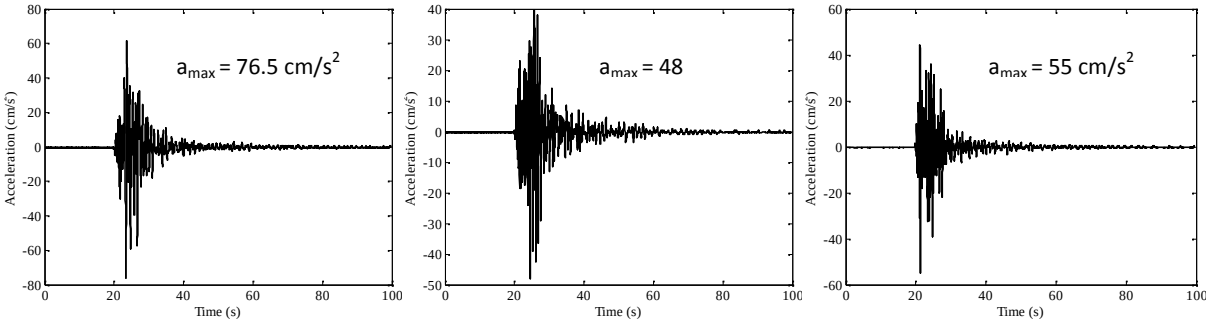


Figure 1 Seismic zone map of Elazığ and Van

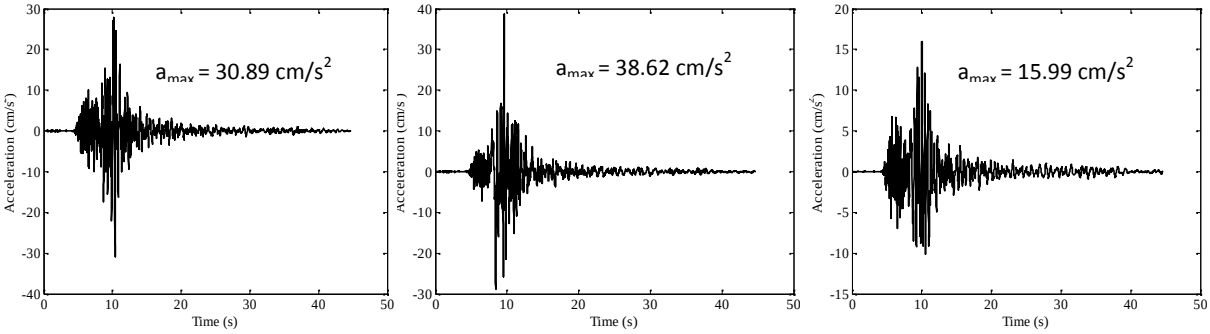
Ground motion records of the earthquakes were obtained from the National Strong Motion Recording Stations of Disaster and Emergency Management Agency (DEMA). The acceleration records were provided from Palu station for March 8, 2010 Kovancılar and Palu earthquakes and Maden station for June 23, 2011 Maden earthquake. Acceleration time histories are plotted in terms of three components (North-South (NS), East-West (EW) and Vertical (UD)) in Figure 2.



a) Kovancılar (Elazığ) earthquake



b) Palu (Elazığ) earthquake

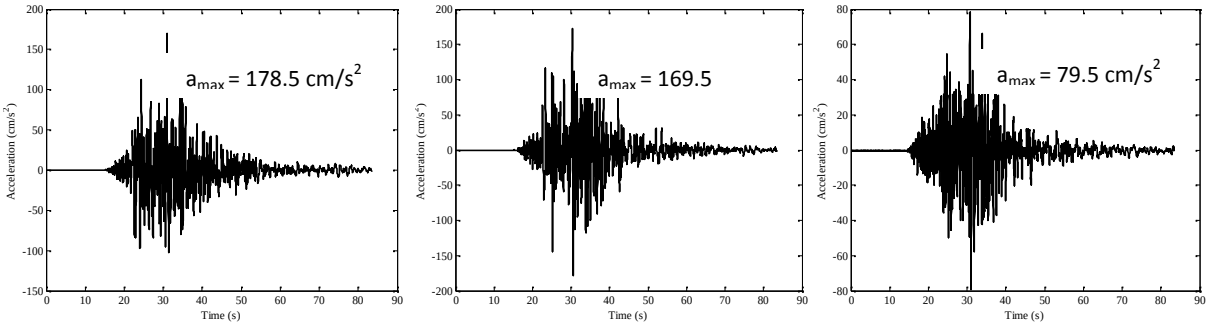


c) Maden (Elazığ) earthquake

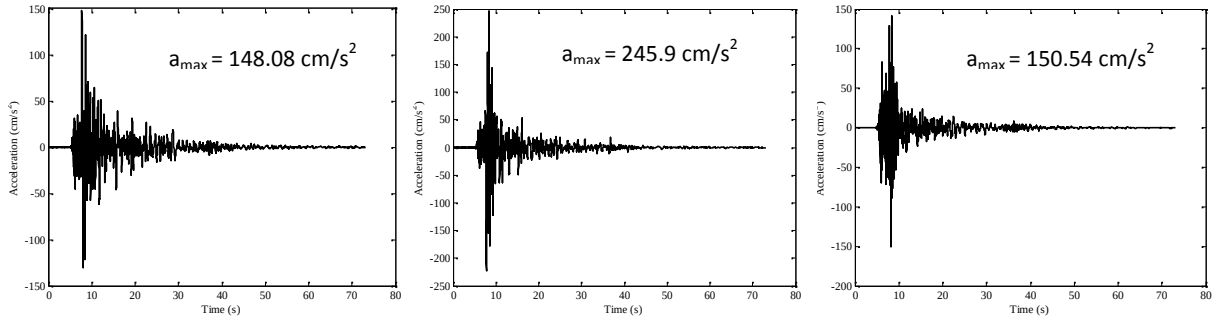
Figure 2 NS, EW and UD components of the earthquakes acceleration records

The acceleration records of September 23, 2011 Tabanlı and November 9, 2011 Edremit earthquakes were obtained from Muradiye and Van Station, respectively. Figure 3 shows the acceleration and time histories records of three components of the earthquakes.

(NS) Component (EW) Component (UD) Component



a) Tabanlı (Van) earthquake



b) Edremit (Van) earthquake

Figure 3 NS, EW and UD components of the earthquakes acceleration records

Structural damages had been assessed for the past earthquakes in various regions by many researchers [2-11]. In this paper, damages to masonry structures were evaluated after the recent earthquakes in Turkey.

STRUCTURAL DAMAGES

In Turkey, buildings are commonly constructed as reinforced concrete (R/C), unreinforced masonry, adobe and hımış (consist of timber frame with masonry infill such as bricks adobes etc.). Masonry buildings are common building type in the rural parts of Turkey due to easy workmanship and economic reasons.

These buildings are the most vulnerable buildings during an earthquake. In the earthquake regions, large part of the building stock had been constructed as masonry.

Adobe buildings were constructed by their own residents without receiving any engineering services in the earthquake regions. These buildings had heavy earthen roof placed on over wooden slabs which supported two walls of the buildings. These roofs were preferred by the residents because of heat insulation according to seasons. The thicknesses of the roofs were approximately 50-60 cm and wall to roof connection was poor. These heavy roofs increase lateral inertial forces on the walls during an earthquake. For this reason, TSC does not permit soil roofs in first and second seismic zones for adobe buildings and this thickness should not be more than 15 cm in third and fourth seismic zones. Some of the adobe buildings had two storey in the earthquake area. But TSC allow only one story for adobe buildings in all seismic zones. Also, TSC suggests to construct of horizontal wooden tie beams which may be prevent out of plane behavior and corner damage of the walls for these buildings. But many damaged adobe buildings had not horizontal tie beams or discontinuous tie beams had been used. Figure 4 shows damaged adobe buildings in the earthquake regions.

a) March 8, 2010 Elazığ-Kovancılar earthquake

b) June 23, 2011 Elazığ-Maden earthquake

c) 2011 Van earthquakes

Figure 4 Structural damages in adobe buildings

Important part of the stone masonry buildings were affected seriously in these earthquakes. Most of them had been constructed rubble stone walls. The thickness of the walls of these buildings was approximately 50-70 cm. These walls were constructed as two layers. The exterior layers of these walls were generally constructed large stones with relatively proper geometry. The void between the layers had been filled small rubble stones and mortar. Low strength mortar such as mud or lime mortar was used as binding material to joint stone. Therefore, the exterior and inner layers of the walls easily separated each other along the wall thickness during the ground motion. This situation was caused damages at these earthquakes. TSC requires that, lime mortar enhanced with cement (cement/lime/sand volumetric ratio=1/2/9) or cement mortar (cement/sand volumetric ratio=1/4) must be used in load-bearing walls. Some of these buildings had heavy earthen roof carried by wooden tie beams similar to adobe buildings. These ties beams were placed on the two walls which were perpendicular to these beams. In this case, the walls which are not supported with these beams are more vulnerable against out-of-plane mechanism than the other walls. Also, these tie beams are used for transfer the loads, limit the damage and increase the stability of the walls. But these wooden tie beams were either absent or discontinuous especially at the corners at most of the stone masonry buildings. Figure 5 shows damages to stone masonry buildings.

a) March 8, 2010 Elazığ-Kovancılar earthquake

b) June 23, 2011 Elazığ-Maden earthquake

c) 2011 Van earthquakes

Figure 5 Structural damages in stone masonry buildings

There were also brick and briquette masonry buildings which had generally one story in the earthquake regions. Foundations of these buildings were constructed using stones. Important parts of these buildings did not have vertical and horizontal R/C bond beams which ensure integrity and to increase earthquake resistance of buildings. Therefore, TSC requires R\C vertical and horizontal bond beams. The vertical bond beams should be constructed at the corner of the buildings, vertical cross-section of load bearing walls and on both sides of the openings. Cross section dimension of the beam which is perpendicular to wall length should be equal to thickness of the wall; the other dimension of the beam should not be less than 200 mm. Also, the horizontal bond beams should be cast monolithically with the slabs. The height of bond beams at least should be 200 mm and width of them must be equal to the width of the wall. But, R/C vertical and horizontal bond beams had not been constructed in the damaged buildings which observed in this paper. Thus, these walls had been subjected to out-of-plane behavior and the whole or the important part of these walls had been overturned during the earthquake. However, similar to stone masonry buildings mud mortar had been used between the masonry units at most of these buildings. Figure 6 shows damages to brick and briquette masonry buildings.

a) March 8, 2010 Elazığ-Kovancılar earthquake

b) June 23, 2011 Elazığ-Maden earthquake

b) 2011 Van earthquakes

Figure 6 Structural damages in brick and briquette masonry buildings

CONCLUSION

The recent earthquakes caused to collapse or damage of a large proportion of masonry buildings because of low seismic performance of these buildings. The main reasons of observed failures of the buildings were heavy earthen roof, lack of vertical and horizontal bond beams, insufficient wall to wall and wall to roof connections which may cause out-of-plane failure of the walls, using of inappropriate material and poor workmanship. Also, most of these buildings had not been built according to the main rules of the TSC. In order to prevent loss of life and property, existing masonry buildings should be strengthened and new buildings should be constructed according to Seismic Codes, and should be provided engineering services.

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