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Construction failures of masonry and adobe buildings during the 2011 Van earthquakes in Turkey

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Abstract. On October 23, 2011, an earthquake of magnitude 7.0 struck Van, Turkey. This powerful earthquake caused the deaths of 604 people, more than 2,000 injuries, and a considerable loss of property. After this devastating earthquake, on November 9, 2011, another earthquake of magnitude 5.7 occurred. This moderate earthquake caused the deaths of 40 people. Partial and total collapse of the masonry and adobe buildings occurred in the rural areas of Van. In this paper, the acceleration records and response spectrums of the earthquakes were given and the structural deficiencies and reasons of the failures of the rural buildings were evaluated according to the Turkish Seismic Code. The observed failures showed that low quality of structural materials, poor workmanship, lack of engineering services and insufficient detailing of the structural elements are the main reasons of damages.

Keywords: masonry and adobe buildings; 2011 Van earthquakes; earthquake damage; structural deficiencies

1. Introduction

On Sunday, October 23, 2011, a destructive earthquake hit Van at 13:41 local time. This earthquake was felt in the cities of Erzurum, Ağrı, Mardin, Diyarbakır, Muş, Bitlis, Iğdır, Kars, Batman, and Siirt. The magnitude and focus depth of the earthquake were recorded as M_w=7.0 and h=19.02 km, respectively, by the Disaster and Emergency Management Agency (DEMA). Seventeen days after this powerful earthquake, an earthquake of M_w=5.7 hit the region at 21:23 local time, with the epicentre at Edremit, Van (DEMA 2011). The characteristics of the earthquakes, which are explained by different institutions, are presented in Tables 1 and 2.

Between October 23 and December 9, 5,628 aftershocks occurred. The number of earthquakes and their magnitudes are given in Fig. 1.

Many studies about the damages to masonry and adobe structures have been conducted. Humar *et al.* (2001) evaluated the performance of masonry and reinforced concrete buildings during the Bhuj earthquake in India on January 26, 2001. The structural behavior of buildings and lifeline systems was investigated during the December 26, 2003, Bam earthquake in Iran by Ahmadizadeh and Shakib (2004). Bayraktar *et al.* (2007) evaluated the performance of stone masonry buildings during the Aşkale, Erzurum earthquakes in Turkey on March 25 and 28, 2004. A statistical study

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Table 1 23.10.2011 Van earthquake characteristics

Institution	Latitude (N)	Longitude (E)	Depth(km)	M_w
DEMA[1]	38.68	43.47	19.02	7.0
KOERI[2]	38.76	43.36	5.00	7.2
USGS[3]	38.69	43.49	16.00	7.1
EMSC[4]	38.78	43.40	10.00	7.2

[1]Turkish Prime Ministry-Disaster and Emergency Management Presidency
[2]Kandilli Observatory and Earthquake Research Institute
[3]United States Geological Survey
[4]European Mediterranean Seismological Centre

Table 2 09.11.2011 Van - Edremit earthquake characteristics

Institution	Latitude (N)	Longitude (E)	Depth(km)	M_w
DEMA[1]	38.44	43.26	6.09	5.7
KOERI[2]	38.429	43.234	5.00	5.7
USGS[3]	38.349	43.403	4.00	5.7
EMSC[4]	38.42	43.29	6.00	5.7

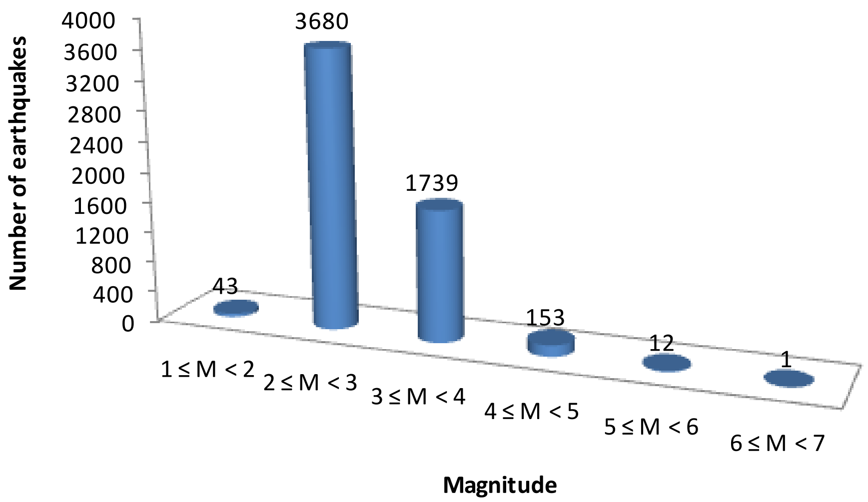


Fig. 1 Number and magnitude of the earthquakes that occurred in Van and the vicinity (DEMA, 2011)

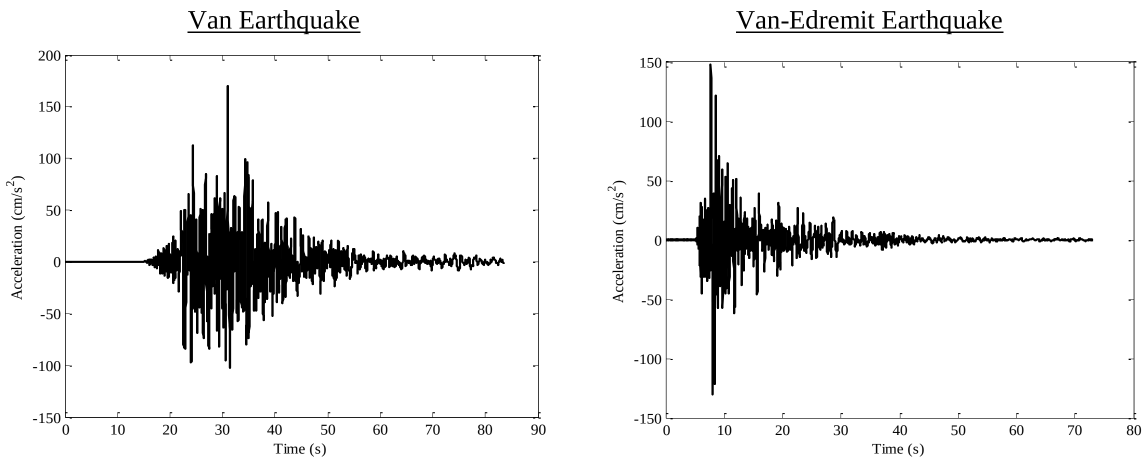
was performed after the Wenchuan earthquake, in which the buildings were classified into four groups, and building damage was investigated by Minzheng and Yingjie (2008). Maqsood and Schwarz (2010) carried out a study about the damages to rural buildings after Baluchistan earthquake that occurred in Pakistan in 2008. Dizhur *et al.* (2010) assessed the performance of unreinforced and retrofitted masonry buildings during Darfield earthquake that occurred on September 4, 2010. Augenti and Parisi (2010) evaluated the seismic performance of reinforced concrete and unreinforced masonry buildings during the L'Aquila earthquake that struck Italy in 2009. Chiou and Wang (2011) investigated traditional Chinese residences after Chi-Chi earthquake that occurred in Taiwan on September 21, 1999. Celep *et al.* (2011) carried out a study about failures of concrete and masonry structures after the Elazığ earthquakes occurred in Turkey on March 8, 2010. Mahmood and Ingham (2011) assessed the seismic vulnerability of unreinforced masonry buildings in Pakistan using three empirical (New Zealand, US and Indian) methods. Ingham and Griffith (2011) evaluated unreinforced masonry buildings after the Darfield earthquake on September 4, 2010 in New Zealand. Calayır *et al.* (2012) assessed different types of structures (masonry, adobe, hımış and reinforced concrete) after the Kovancılar, Elazığ earthquake occurred in Turkey on March 8, 2010. Sayın *et al.* (2013) studied the failures of masonry and adobe buildings during the June 23, 2011 Maden, Elazığ earthquake in Turkey. Bayraktar *et al.* (2013) evaluated performance of masonry buildings during the Van earthquakes. Yön *et al.* (2013) investigated seismic response of buildings on May 19, 2011 Simav earthquake in Turkey.

In this article, the failure mechanisms of masonry and adobe buildings are presented, and the reasons for the observed damages to these buildings in the earthquake area are evaluated.

2. Characteristic properties of the earthquakes

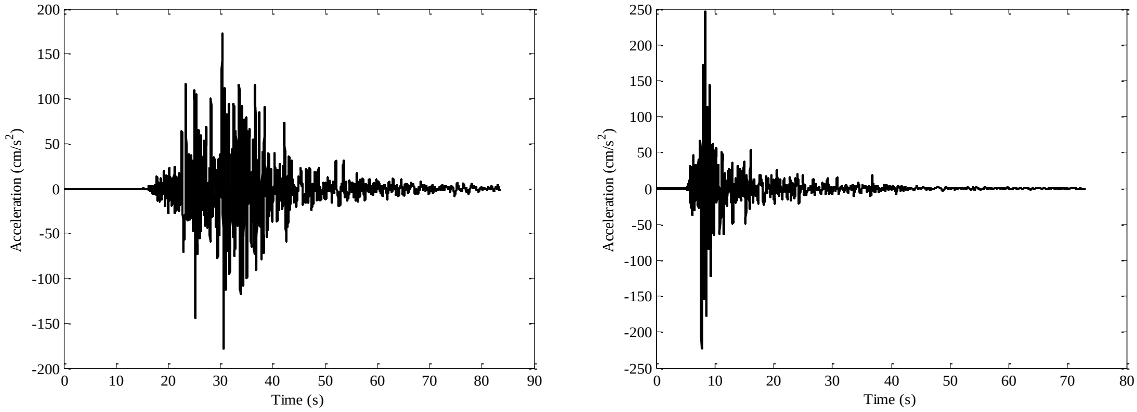
The acceleration records of the Van earthquake and Edremit-Van earthquake, which occurred on October 23 and November 9, 2011, were provided by Muradiye Station and Van Station, respectively. Fig. 2 presents the time histories of the earthquakes' acceleration. The peak ground acceleration values of the earthquakes are 178.50, 169.50 and 79.50 cm/s^2 and 148.08, 245.90 and 150.54 cm/s^2 for the north-south (N-S), east-west (E-W) and up-down (U-D) components, respectively.

The components of the ground accelerations were used to prepare the acceleration response spectra according to ξ=0, 2, 5, 7 and 10% damping ratios (Fig. 3). The spectral amplification ratios were calculated as 3.64, 2.73 and 3.0 for the N-S, E-W and U-D components, respectively, for the Van earthquake, and these values were 2.96, 3.18 and 3.71, respectively, for the Van-Edremit earthquake for a damping ratio of 5%.

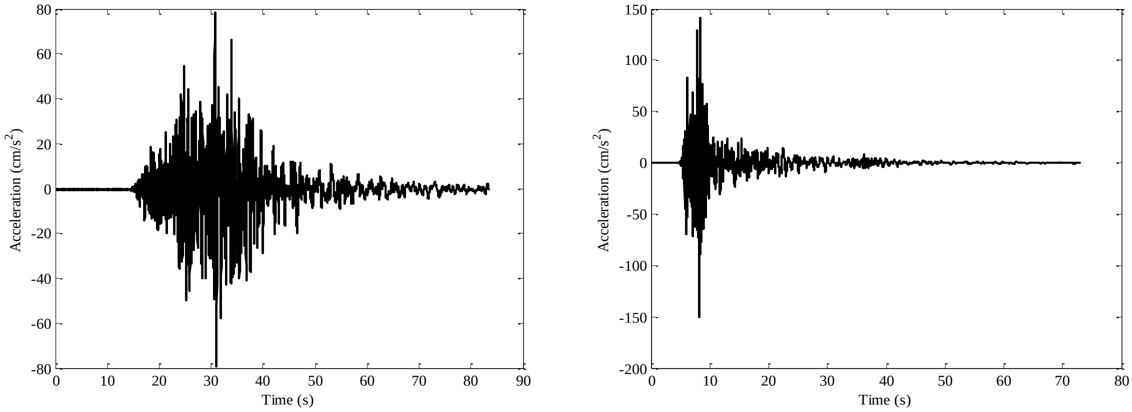


(a) North - South component

Fig. 2 Acceleration records of the earthquakes provided from the Muradiye and Van Stations



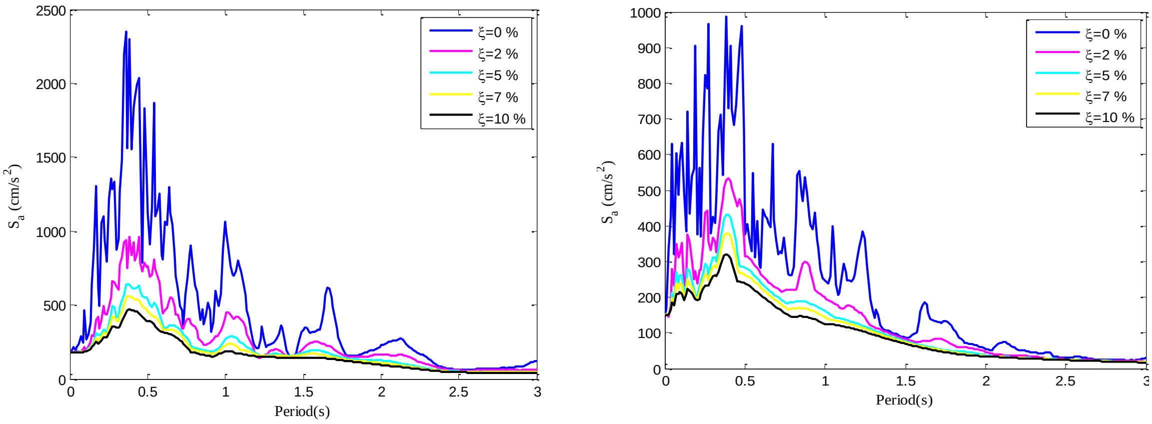
(b) East - West component



(c) Up - Down component

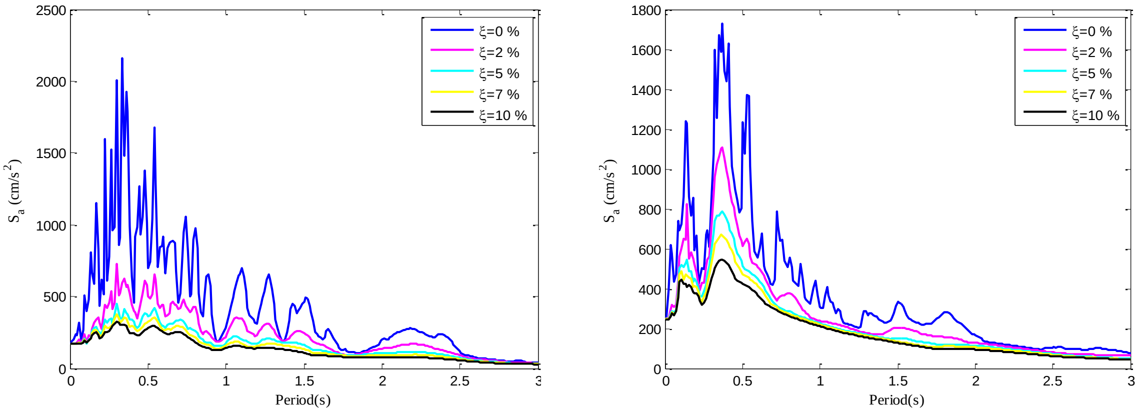
Fig. 2 Continued

<u>Van Earthquake</u> <u>Van-Edremit Earthquake</u>

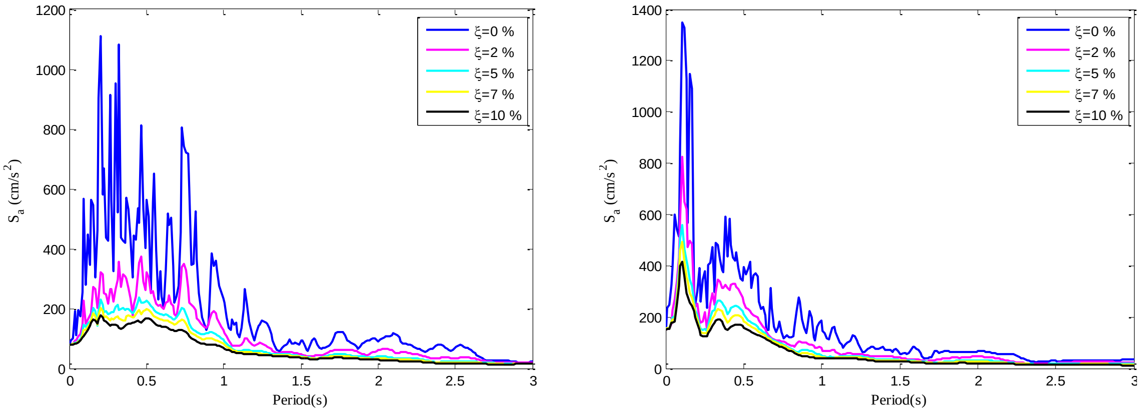


(a) North - South component

Fig. 3 Acceleration response spectra of the earthquakes provided from the Muradiye and Van Stations



(b) East - West component



(c) Up - Down component

Fig. 3 Continued

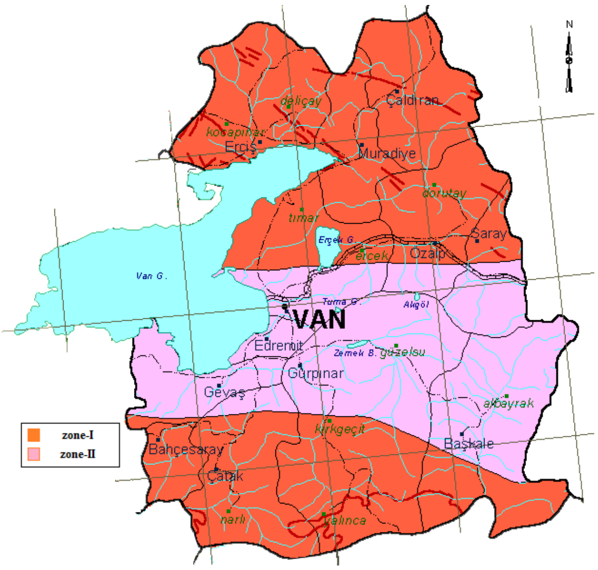


Fig. 4 Seismic zone map of the region

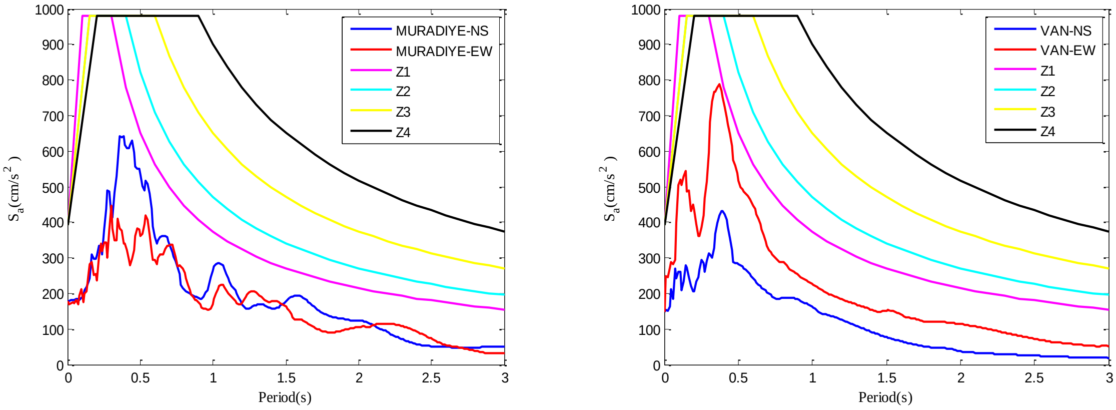


Fig. 5 Comparison of the design and response spectra of the earthquakes

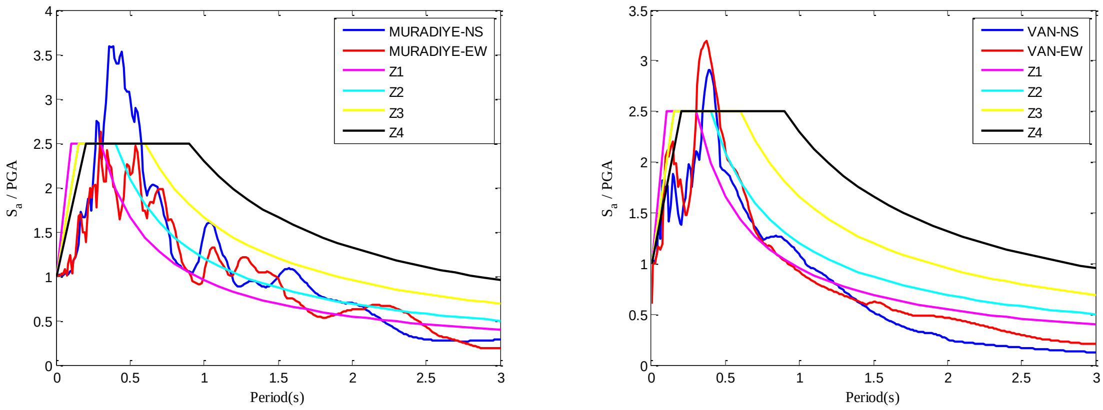


Fig. 6 Comparison of the normalized design and response spectra of the earthquakes

According to the seismic hazard map prepared by the Ministry of Public Works and Settlement of the region, Van consists of first and second degree earthquake zones. In this map, the first and second degree zones require a peak ground acceleration of 0.4 g and 0.3 g for buildings, respectively, where g is the gravitational acceleration. This map is given in Fig. 4.

The acceleration response spectra of the N-S and E-W components according to the design spectra of all soil classes defined in the Turkish Seismic Code (TSC, 2007) are presented in Fig. 5 for a damping ratio of 5%. The design spectra, which calculated for the first seismic zone according to all soil classes, are larger than the response spectra of the earthquake records, as seen in Fig. 5.

In addition, normalized spectral curves of the maximum acceleration are presented in Fig. 6. PGA and Z represent the peak ground acceleration and local soil class, respectively. According to the TSC, the stiffness of the soil class decreases from Z1 to Z4. Furthermore, Fig. 6 demonstrates that the amplification factors of these normalized earthquake acceleration records exceed the limit (2.5) of the design code. The significant loss of life and heavy damages resulting from these earthquakes indicate that the design spectra requirements which defined in the TSC were not provided.

Fig. 7 Damaged buildings due to a heavy earthen roof

3. Damages to adobe and masonry buildings

The Van earthquakes occurring on October 23 and November 9, 2011 caused serious damage to the masonry buildings in the rural settlements of Van. These buildings consist of adobe, stone, and briquette masonry with cement or mud mortar. Most of the buildings were old and affected by environmental conditions, such as freeze-thaw. These one- and two-story buildings were built by local people without any engineering knowledge. The building failures found in our field observation are presented in the following sections.

3.1 Earthen roof damages

One- and two-story adobe buildings are common in the region because they require easy workmanship and are built using local materials. These buildings are vulnerable to ground motions. Generally, earthen roofs are constructed over wooden logs to provide thermal and water insulation. However, these roofs lose their effectiveness because of weather conditions, such as rain and snow. To repair these roofs, the residents place a new earthen cover on top of the existing roof. Thus, the weight and thickness of the roof increase over time. According to the TSC, a soil roof should not be made in the first and second seismic zones for adobe buildings. This type of roof increases the mass of the building and causes large inertial forces during earthquakes. Our field observations indicated that a thick and heavy earthen roof (approximately 40-60 cm) caused heavy damages. Fig. 7 illustrates these failures.

3.2 Corner damages

This type of mechanism generally occurs at wall to wall and wall to roof connections when subjected to out-of-plane displacements. The stress concentrations at the intersection of the walls increase during an earthquake. To decrease these effects, the TSC requires reinforced concrete vertical bond beams, which increase the seismic performance of masonry buildings. Fig. 8 shows vertical bond beams at load-bearing walls. In these beams, the compressive strength of concrete should be at least 16 Mpa and Ø8 stirrups, and a maximum spacing of 200 mm should be used together with longitudinal reinforcement.

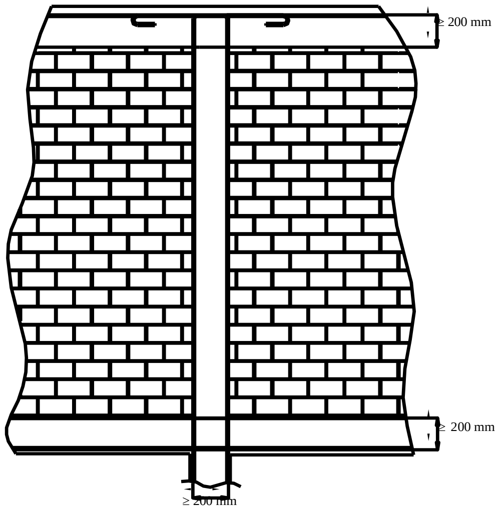


Fig. 8 Vertical bond beams at load-bearing walls

Fig. 9 Corner damage of adobe buildings

These bond beams should be used for the entire height on the corners of buildings, along the intersections of the load-bearing walls, and on both sides of the openings. The cross section of these beams should be equal to the thicknesses of the walls that intersect at the corners of the buildings. Furthermore, the other cross-sectional dimension should not be less than 200 mm. Corner damages were common in the adobe and masonry buildings in the earthquake region. Poor connections between adjacent walls and the absence of bond beams caused serious damages. In addition, there were no appropriate connections at the corner of the walls in damaged buildings. This type of damage for adobe and masonry buildings is shown in Figs. 9 and 10, respectively.

3.3 Out-of-plane mechanism

A lack of bond beams, poor connections among the walls and the roofs, and large unsupported

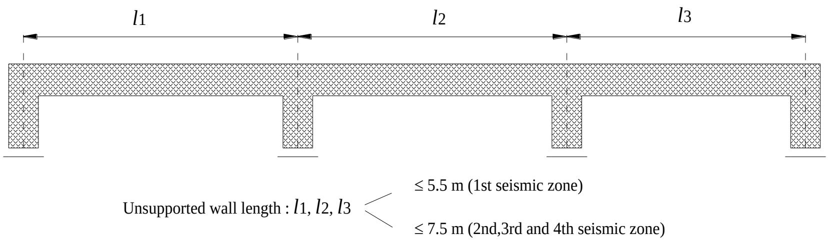
Fig. 10 Corner damage of briquette masonry buildings

Fig. 11 Out-of-plane mechanism of adobe buildings

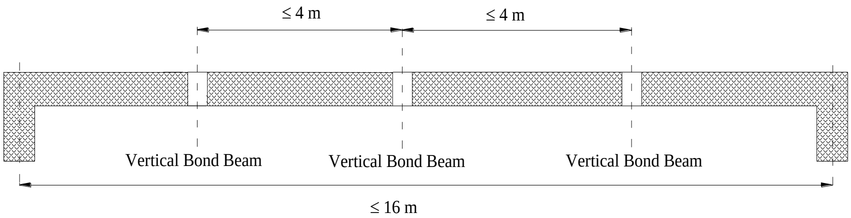
wall lengths cause the separation of walls and cause damage to occur via the of out-of-plane mechanism. Thus, the whole of the wall or a significant part of it falls down during the earthquake. Wooden logs that bear the weight of the floor of the building are placed on load bearing walls in only one direction. Thus, earthquake loads are transferred to perpendicular walls to wooden logs. The walls that are not supported by the wooden logs may easily overturn out-of-plane. This failure mechanism was commonly observed in the earthquake region. Figs. 11 and 12 illustrate the out-of-plane mechanism of the adobe and briquette masonry buildings, respectively.

To prevent this type of damage to adobe buildings, the TSC requires using timber bond beams. These timber beams should be two elements of square sections of 100×100 mm and should be placed with the outer faces coinciding with the exterior and interior wall surfaces. These pieces should be tied to each other every 500 mm with nail jointed timber elements with a cross section of 50×100 mm. However, there were no bond beams in the damaged adobe buildings. Fig. 12 illustrates that the exterior load bearing walls that are parallel to the wooden logs were overturned out-of-plane because of the lack of bond beams, poor connections, and unsupported wall lengths.

Fig. 12 Out-of-plane mechanism of briquette buildings

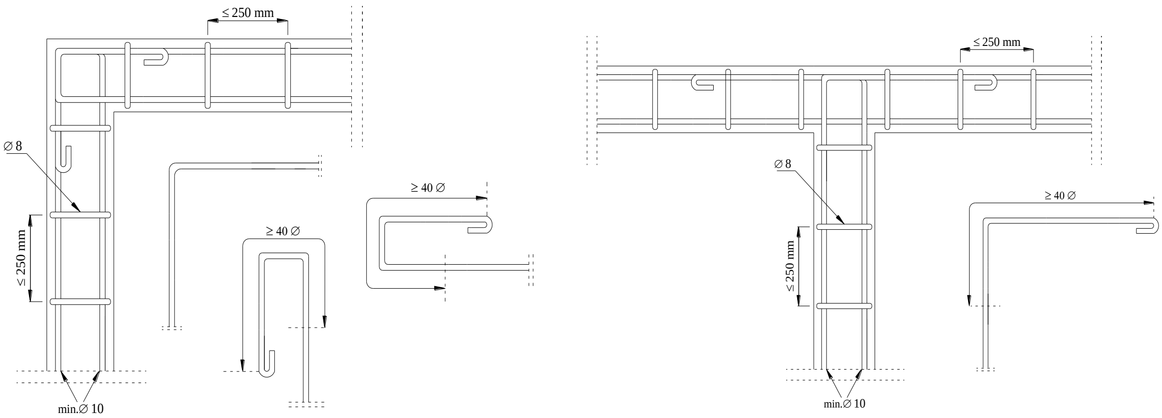


(a)



(b)

Fig. 13 Maximum unsupported wall length and span between vertical bond beams



(a) (b)

Fig. 14 Details of the horizontal bond beams

(a) (b)

Fig. 15 Gable wall damages

Furthermore, to prevent these damages in masonry buildings, the TSC requires that the maximum unsupported length of a wall should not exceed 5.5 m in the first seismic zone and 7.5 m in the second, third and fourth seismic zones in the plan. However, this unsupported length should not exceed 4.5 m in adobe buildings in all seismic zones (Fig. 13(a)). In addition, if these requirements are not provided, reinforced concrete vertical bond beams should be constructed along the full storey height at the corners. Furthermore, these beams should be used every four meters along the wall in plan and the unsupported wall length should not exceed 16 m (Fig. 13(b)).

The TSC requires that reinforced concrete horizontal bond beams should be used on the walls that support floors. These bond beams should be cast monolithically with the floors. The width of the horizontal bond beams and wall should be equal. The height of the horizontal bond beams should not be less than 200 mm. The concrete quality for the bond beams should be at least 16 Mpa and Ø 8 hoops, and a maximum spacing of 250 mm should be constructed together with the longitudinal reinforcement. Figs. 14(a) and (b) present the horizontal bond beams at the corner and intersection of the walls, respectively.

The gable walls of some masonry buildings were affected by the out-of-plane mechanism. The main reasons for the damage to the gable walls include their height, poor connections (wall to wall and wall to roof), and lack of bond beams. Fig. 15(a) illustrates the out-of- plane mechanism that occurred together with the load bearing walls and gable walls, and Fig. 15(b) illustrates the gable wall damage only.

To prevent damage to the gable wall, the TSC requires that the height of the gable wall resting on the horizontal bond beam at the top storey exceed 2.0 m. Furthermore, vertical and inclined reinforced bond beams should be constructed in these walls. Fig. 16 shows the construction details of the gable wall.

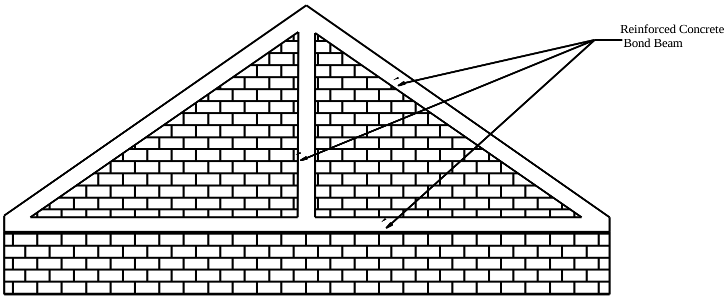


Fig. 16 Recommended details for gable walls

Fig. 17 Diagonal shears cracking near the openings

Fig. 18 Horizontal and stepped failures

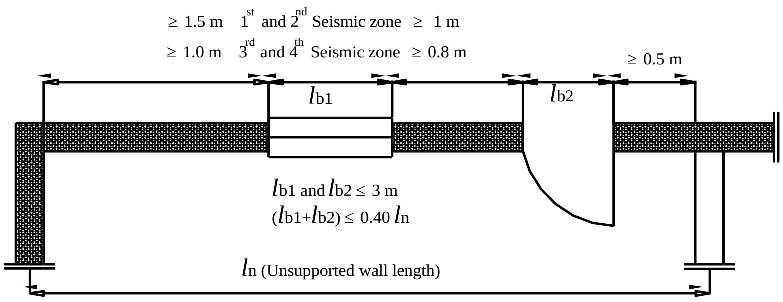


Fig. 19 Maximum openings in load-bearing walls according to the TSC

3.4 In-plane mechanism

The seismic performance of masonry buildings relates to the in-plane stiffness of the walls. In-plane mechanism is generally observed in most of the masonry buildings that are affected by shear cracking. Shear forces increase because of earthquake loads, and can damage walls and their connections. Because of the lack of bond beams that distribute the lateral forces uniformly, these damages generally occur near openings. Three failure modes of the shear damages in masonry

Fig. 20 Disintegration in stone masonry buildings

buildings are generally observed in the earthquake area, namely, diagonal shear failures that proceed through masonry units and mortar (Fig. 17), sliding consisting of straight failure at the horizontal bed joints, and stepped failures from the head to bed or bed to head joints (Fig. 18).

Our observations in the earthquake region indicated that most masonry buildings did not have sufficient and proper bond beams to enhance the lateral strength of the walls. Furthermore, large openings that decrease the stiffness of the walls increased the shear effects. To limit this type of failure, the TSC requires that the reinforced concrete bond beams should be used (Figs. 8 and 14). The requirements of the openings of load-bearing walls are illustrated in Fig. 19.

3.5 Disintegration of stone masonry walls

This type of failure commonly occurs because of earthquakes. Some reasons such as the quality of construction, poor workmanship, and the use of improper materials increase the intensity of the disintegration. Fig. 20 presents this failure in stone masonry buildings.

The main reason for the failure in the region was due to the as multi-layers of the walls, in which there was no adequate connection between the layers. Large coarse stones were used as the outer layers of the walls, while small size stones were used as the inner layer of the wall. Mud mortar was used as a binder instead of cement mortar. Therefore, inadequate connections occurred between the inner and outer layers of the walls, and the layers of these walls separated during the earthquake.

4. Conclusions

Two earthquakes hit Van on October 23 and November 9, 2011. The magnitudes of these earthquakes were 7.0 and 5.7, respectively. In these earthquakes, 644 people died, and more than 2,000 people were injured. Partial and total collapses in the adobe and masonry buildings occurred because of earthquakes in the rural areas of Van. In this study, the reasons for the damages to adobe and masonry buildings were presented, and the structural deficiencies were evaluated with respect to the TSC. According to our field observations, the main reasons for the damage to these buildings were the use of improper local materials, poor workmanship, and lack of engineering services, insufficient detailing of the structural elements and not following the basic principles of the TSC. Furthermore, most of the investigated buildings were old and insufficiently earthquake resistant, and the condition of these buildings was degrading further because of environmental conditions. Thick and heavy earthen roofs were another reason for the damages. Their incorrect application increased the mass at the roof level of the buildings. The walls of the buildings could not support this heavy mass during an earthquake, and the heavy roof partially or completely collapsed. Our field observations indicated that a thick and heavy earthen roof (approximately 40-60 cm) caused heavy damages. Corner damages were observed frequently in the earthquake area. Insufficient wall to wall connections and lack of horizontal and vertical bond beams caused this type of damage. In addition, there were no appropriate connections at the corner of the walls in damaged buildings. An increase in the stress concentrations at the intersection regions of the perpendicularly constructed walls had degraded the corner stability of the buildings. Furthermore, another reason for the damages was the out-of-plane mechanism. The main reasons for this mechanism were the lack of bond beams, poor connections among the walls and roofs, and large unsupported wall lengths. The use of wooden logs settled only in one direction at the floor levels had increased the effect of this mechanism. In addition to these reasons, the gable walls of some masonry buildings were affected negatively by the out-of-plane mechanism. However, a lack of bond beams and large openings that decrease the stiffness of the walls had increased the shear effects and caused in- plane failures, such as diagonal shear failures, sliding consisting of straight cracks and stepped failures. The disintegration of stone walls due to the construction of multi-layer walls with inadequate connections along the wall thickness was observed at stone masonry buildings. Using mud mortar caused insufficient adherence between the walls. Thus, the layers of the walls separated during the earthquake.

The Van earthquakes showed many of the seismic problems in masonry buildings constructed without seismic code requirements. To prevent or decrease life and property losses, existing buildings must be strengthened and new buildings must be constructed according to the code. Furthermore, people especially construction workers and local masons should be informed about earthquakes and construction of earthquake resistant buildings in rural areas. These guidelines should be controlled by the local government and authorized engineers.

References

Ahmadizadeh, M. and Shakib, H. (2004), "On the December 26 2003 southeastern Iran earthquake in Bam region", *Eng. Struct.*, **26**, 1055-1070.

Augenti, N. and Parisi, F. (2010), "Learning from construction failures due to the 2009 L'Aquila Italy earthquake", *J. Perf. Const. Fac.*, **24**(6), 536-555.

Bayraktar, A., Coşkun, N. and Yalçin, A. (2007), "Performance of masonry stone buildings during the March 25 and 28, 2004 Aşkale (Erzurum) earthquakes in Turkey", *J. Perf. Const. Fac.*, **21**(6), 432-440.

Bayraktar, A., Altunışık, A.C. and Muvafik, M. (2013), "Field investigation on the performance of masonry buildings during the October 23 and November 9, 2011 Van earthquakes in Turkey", *J. Perf. Const. Fac., ASCE*, doi: 10.1061/(asce)cf.1943-5509.0000383.

Calayır, Y., Sayın, E. and Yön, B. (2012), "Performance of structures in the rural area during the March 8 2010 Elazığ-Kovancılar earthquake", *Nat. Hazards*, **61**(2), 703-717.

Celep, Z., Erken, A., Taskin, B. and Ilki, A. (2011), "Failures of masonry and concrete buildings during the March 8 2010 Kovancılar and Palu (Elazığ) earthquakes in Turkey", *Eng. Fail. Anal.*, **18**, 868-889.

Chiou, C.W. and Wang, H. J. (2011) " Damage to Chinese Courtyard Houses during the September 21 1999 Chi-Chi Earthquake in Taiwan", *J. Earthq. Eng.*, **15**(5), 711-723.

Dizhur, D., Ismail, N., Knox, C., Lumantarna, R. and Ingham, J.M. (2010), "Performance of unreinforced and retrofitted masonry buildings during the 2010 Darfield earthquake", *Bull. NZ Soc. Earthq. Eng.*, **43**(4), 321-339.

Humar, J.M., Lau, D. and Pierre, J.R. (2001), "Performance of buildings during the 2001 Bhuj earthquake", *Can. J. Civil Eng.*, **28**, 979-991.

Ingham, J. and Griffith, M. (2011), "Performance of unreinforced masonry buildings during the 2010 Darfield (Christchurch NZ) earthquake", *Australian J. Struct. Eng.*, **11**(3), 1-17.

Mahmood, H. and Ingham, J.M. (2011), "Seismic vulnerability assessment of Pakistan unreinforced masonry buildings at a national scale", *Seismol. Res. Lett.*, **82**(5), 676-685.

Maqsood, S.T. and Schwarz, J. (2010), "Building vulnerability and damage during the 2008 Baluchistan earthquake in Pakistan and past experiences", *Seismol. Res. Lett.*, **81**(3), 514-525.

Minzheng, Z. and Yingjie, J. (2008), "Building damage in Dujiangyan during Wenchuan earthquake", *Earthq. Eng. Eng. Vib*., **7**, 263-269.

Sayın, E., Yön, B., Calayır, Y. and Karaton, M. (2013), "Failures of masonry and adobe buildings during the June 23 2011 Maden-(Elazığ) earthquake in Turkey", *Eng. Fail. Anal.*, **34**, 779-791.

Turkish Seismic Code (TSC) (2007), Ministry of Public Works and Settlement, Ankara.

Van Earthquake Report (2011), Turkish Prime Ministry-Disaster and Emergency Management Presidency (DEMA), Ankara. (in Turkish)

Yön, B., Sayın, E. and Köksal, T.S. (2013), "Seismic response of buildings during the May 19, 2011 Simav, Turkey earthquake", *Earthq. Struct.***,** **5**(3), 343-357.