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# Seismic response of buildings during the May 19, 2011 Simav, Turkey earthquake

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**Abstract.** On May 19, 2011 an earthquake struck Simav district of Kütahya which located west of Turkey. According to Disaster and Emergency Management Agency (DEMA), magnitude of this earthquake was $M_L$ = 5.7. In this earthquake 2 people lost their lives and considerably damages occurred in the city center and surrounding villages. Damaged structures in the earthquake area did not have adequate earthquake resistance since low quality materials, poor workmanship and improper selection of the structural system. In this study, reasons of damages and failure mechanism of reinforced concrete and masonry buildings were evaluated.

**Keywords:** Simav earthquake; reinforced concrete buildings; masonry buildings; ground motions

## 1. Introduction

Turkey is located on active faults. For this reason many earthquakes have been occurred frequently. Destructive earthquakes occurred in Kütahya and vicinities in the past. These earthquakes are 1944 Şaphane $M_w$ = 6.2 earthquake, 1970 Gediz $M_w$ = 7.2 and $M_w$ = 5.9 Çavdarhisar earthquakes. On May 19, 2011, an earthquake of moderate intensity occurred in Simav township of Kütahya located in west of Turkey at 23:15 (20:15 GMT) local time. In this earthquake 109 buildings were collapsed, 1258 buildings damaged heavily and 2 people lost their lives (KOERI, 2011). Magnitude and source characteristics of the earthquake are shown in Table 1 according to various institutions. In this table, $M_L$ and $M_w$ show local magnitude and moment magnitude, respectively. Also, $h_{hypo}$ is the depth of hypocenter of the earthquake.

The earthquake was perceived in almost all of west Anatolia. Loss of lives and injures with considerable structural damages had been occurred in Simav and vicinity villages. Intensity map with active faults is given in Fig. 1(a). According to seismic zone map which were prepared by Ministry of Public Works and Settlement, Turkey is divided into the 5 seismic zones. Simav township which is located 145 km south-west of Kütahya is at I degree in accordance with this map which is given in Fig. 1(b). According to Turkish Earthquake Code (TEC), I degree earthquake zone is the most hazardous and V degree is no hazard zone. The code requires a design acceleration of 0.4g for load-bearing walls and buildings located in I degree earthquake zone, ($g$ is the gravitational acceleration).

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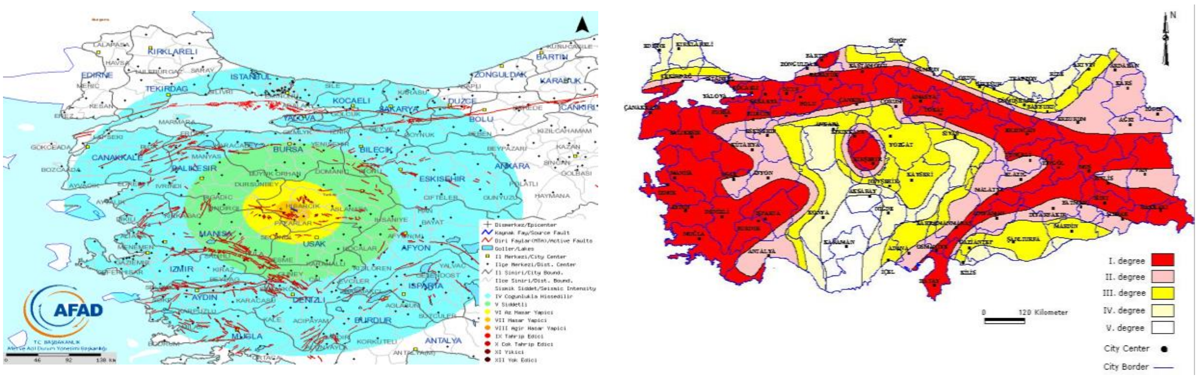
Table 1 May 19, 2011 Simav–Kütahya earthquake characteristics for various institutions

| Source | Time | Latitude (N) | Longitude (E) | $h_{hypo}$ | $M_L$ | $M_W$ |
|---|---|---|---|---|---|---|
| DEMA[1] | 23.15 | 39.1328 | 29.0820 | 24.46 | 5.7 | |
| KOERI[2] | 23.15 | 39152 | 29.088 | 7.6 | 5.9 | |
| USGS[3] | 23:15:24 | 39.137 | 29.0736 | 9.0 | | 5.8 |
| EMSC[4] | 23:15:22 | 39.15 | 29.10 | 7.0 | | 5.8 |




(a) Intensity contour map for May 19, 2011 Simav-Kütahya earthquake (DEMA 2011)

(b) Seismic zone map of Turkey

Fig. 1 Intensity map of the earthquake and seismic zone map of Turkey

Structural failures and damages had been investigated by many researchers in past earthquakes Adalier and Aydingun (2001) analyzed observed structural damages according to strong ground motion characteristics, the geological conditions and the building codes on June 27, 1998 Adana–Ceyhan (Turkey) earthquake. Yoshimura and Kuroki (2001) assessed damages of unreinforced adobe and brick buildings after January 13, 2001 El Salvador earthquake. Sezen *et al.* (2003) and Doğangün (2004) investigated the performance of reinforced concrete structures after August 17, 1999 Kocaeli and May 1, 2003 Bingöl earthquakes in Turkey, respectively. Kaplan *et al.* (2004) evaluated the reasons of damages of reinforced concrete structures after May 1, 2003 Bingöl-Turkey earthquake and some suggestions were made to prevent such damages in the future. Ahmadizadeh and Shakib (2004) carried out a study about December 26, 2003, southeastern Iran earthquake in Bam. They evaluated the structural behavior of buildings and lifeline systems in earthquake region. Aslan and Korkmaz (2007) investigated and discussed behavior of reinforced concrete buildings after recent earthquakes in Turkey. Apostolakis *et al.* (2007) assessed seismological characteristics, geotechnical and structural damage, and the causes of the observed failures or collapses after July 16, 2007 Niigata-Chuetsu Oki earthquake. Bayraktar *et al.* (2007) carried out a study about Ağrı-Doğubeyazıt earthquake, July 2, 2004. Rossetto and Peiris (2009)

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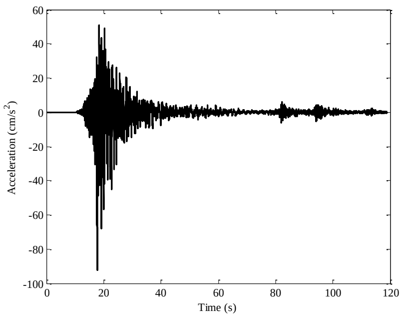
evaluated the performance of residential, commercial and government buildings after Kashmir earthquake of October 8, 2005. Taucer *et al.* (2009) investigated the behavior of non-engineered structures after August 15, 2007 Peru earthquake. Zhao *et al.* (2009) evaluated the buildings performance during the 12 May 2008 Wenchuan earthquake in China, in particular of reinforced concrete frame, masonry, industrial, local vernacular and historical buildings. Augenti and Parisi (2010) investigated actual performance of older and more recently constructed building structures during the 2009 L'Aqulia earthquake in Italy. Naseer *et al.* (2010) evaluated the seismic behavior of reinforced concrete and masonry buildings during the October 8, 2005 Kashmir earthquake. Lieping *et al.* (2010) carried out a study based on seismic damage of reinforced concrete buildings after the 2008 Wenchuan earthquake. Akkar *et al.* (2011) investigated building damages and ground motions during the March 8, 2010 Kovancılar (Turkey) earthquake. Celep *et al.* (2011) assessed damages of existing buildings (adobe, masonry and reinforced concrete) after the same earthquake. Ricci *et al.* (2011) carried out a study about behavior of reinforced concrete buildings after April 6, 2009 L'Aquila earthquake, Italy. Antonopoulos and Anagnostopoulos (2012) investigated inelastic earthquake response of existing reinforced concrete buildings which have an open ground story designed according to the old Greek codes. Ural *et al.* (2012) investigated the seismic damage in unreinforced masonry structures during the December 20 and 27 Bala earthquakes (Ankara), Turkey. Calayır *et al.* (2012) carried out a study about failures of adobe, masonry, hımış, and reinforced concrete structures, and minarets after the March 8, 2010 Elazığ-Kovancılar earthquake, Turkey.

In this paper, the ground motions and response spectra of the Simav-Kütahya earthquake was illustrated. Reasons of failure and observed damages of buildings in the earthquake area were evaluated.

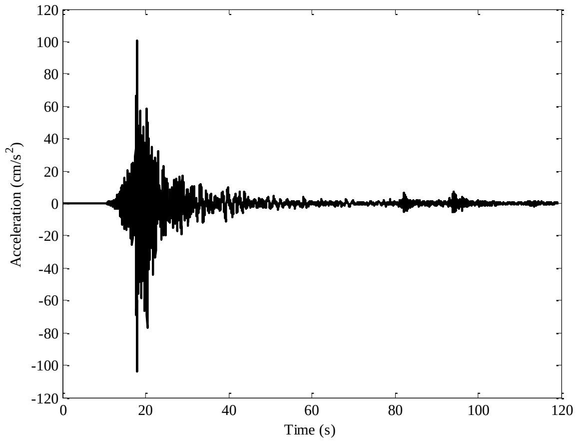
## 2. Evaluation of the ground motion

Ground motion records of the earthquake, were provided from the National Strong Motion Recording Stations of DEMA belong to Gediz-Kütahya Station located approximately 24.46 km to the epicenter of the Simav-Kütahya earthquake and were presented in Fig. 2. Three components, North-South (NS), East-West (EW) and Vertical (UD), of the peak ground accelerations values of this record are 92.33, 103.92 and 67.83 cm/s$^2$, respectively.

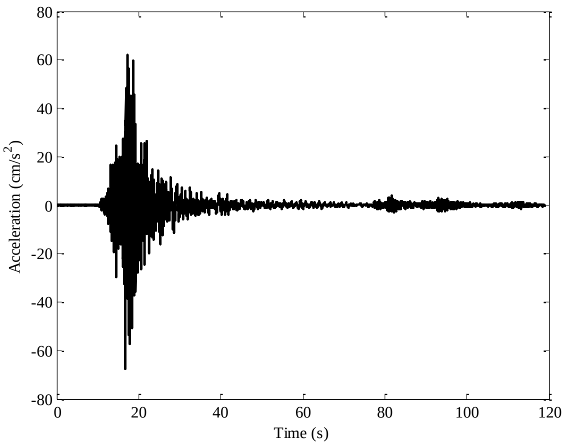



(a) NS component

Fig. 2 May 19, 2011 Simav-Kütahya earthquake acceleration records obtained from the Gediz-Kütahya station




(b) EW component

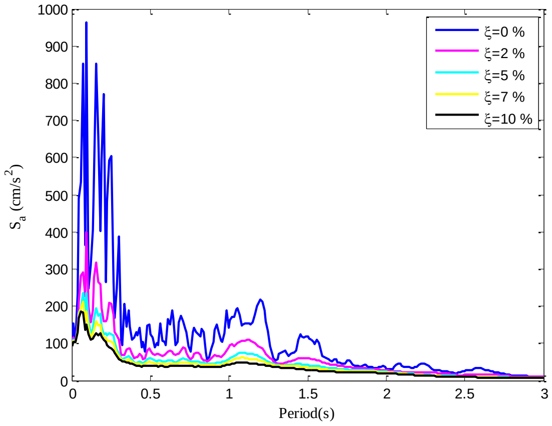



(c) UD component

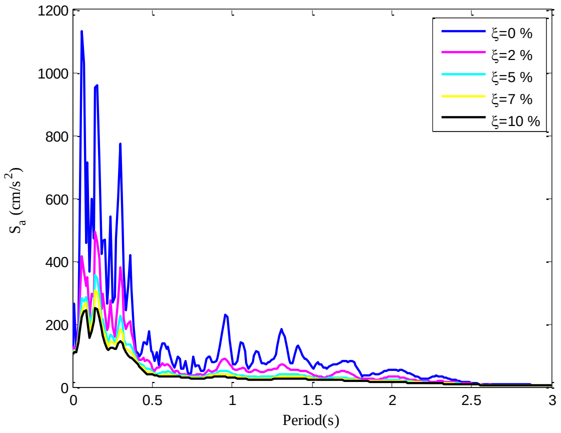
Fig. 2 Continued

Response spectra of the each component of Gediz-Kütahya station acceleration records for damping ratios of 0, 2, 5, 7 and 10% were computed and given in Fig. 3. The spectral amplification ratios obtained from damping ratio of 5% are approximately 2.5, 3.5 and 4.0 for the NS, EW and UD components, respectively.

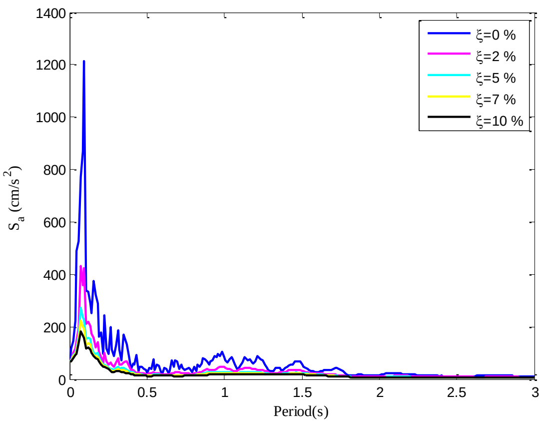
Fig. 4(a) shows the acceleration response spectra of NS and EW components for damping ratio of 5% according to design spectrum of the TEC for all soil classes. Fig. 4(b) shows the normalized spectral curves in accordance with the maximum acceleration. In this Figure, the peak ground acceleration is defined as PGA. In the Fig. 4(a-b), local soil classes are indicated as Z1, Z2, Z3 and Z4. In this figure Z1 represents the stiffest soil and Z4 the softest. When Fig. 4(a) is investigated, it is seen that the spectra of the earthquake acceleration records are substantially under the design spectra for the first seismic zone indicated in the TEC. Also, the amplification factors in the two normalized spectrum curves of the earthquake records exceed 2.5. This situation is shown in the Fig. 4(b).




(a) NS component



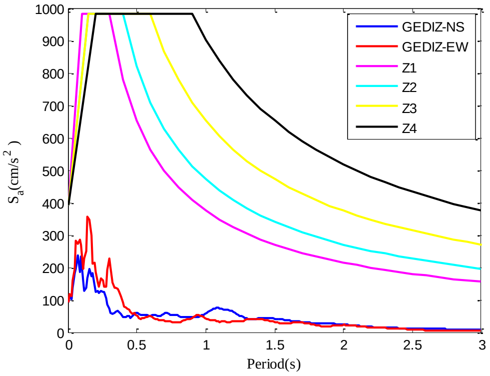

(b) EW component



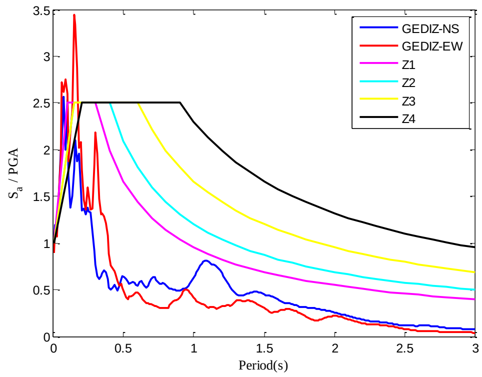

(c) UD component

Fig. 3 Acceleration response spectra for NS, EW and UD components of Gediz-Kütahya station acceleration records

Though the response spectra of the earthquake is low compared to the design spectra, loss of lives and the magnitude of the structural damages occurred in the region clearly reveal due to the structural deficiencies.




(a) NS component




(b) EW component

Fig. 4 Comparison of response and design spectrums

## 3. Structural damages in the affected area

There are various structural systems in the region affected by earthquake. These structural systems are reinforced concrete (R/C), unreinforced masonry, hımış (that is a type of construction consisting of timber frame with masonry infill such as bricks adobes or stones) and buildings having mixed material. Main reasons of structural damages in the buildings during the May 19, 2011 Simav-Kütahya earthquake are discussed below.

### *3.1 Reinforced concrete buildings*

There are generally multistory R/C buildings in centre of Simav township. At investigated buildings, many structural deficiencies and engineering mistakes such as, soft stories, poor concrete quality, short columns, unconfined gable walls, inadequate transverse reinforcement, hammering were observed and explained.

#### *3.1.1 Short columns*

Short columns are constructed to provide openings in infill walls between columns of structures. When the length of column decreases by various reasons the column to be more rigid than the others and subjects to more earthquake loads. In Simav earthquake, many columns damaged seriously since this reason. However, improper and inadequate stirrups increased damage level. Fig. 5 shows short column damages in various buildings.

#### *3.1.2 Soft-storey mechanism*

Soft-storey mechanism has been the most common mode of failure which causing to the partial or total collapse at the ground floor level in mid-rise R/C buildings. However, in Turkey many mid-rise R/C buildings have soft storeys. In these buildings, ground floors have glass partitioning windows instead of infill walls due to these storeys are used as stores and commercial areas. However, the infill walls are constructed above the soft storeys for separating rooms for the residential usage. While a building designed or constructed, contribution of the infill walls to lateral rigidity generally are ignored by designers. But these walls increase the rigidity of the structure and limit the storey drift. When infill walls are not constructed at the ground floor level, lateral strength and stiffness have to be provided by the frames alone. Also, the storey height of this floor is approximately 40-50% more than the upper storeys. Thus, during an earthquake effective shear forces and moments occur on the end of columns at the ground floor. In Simav earthquake, this wrong application caused damages at buildings. Fig. 6(a) shows the collapsed building due to the soft-storey mechanism.

Another example of soft story mechanism is illustrated in Fig. 6(b). Also, this building was constructed with inadequate gap sizes. Thus, hammering effect occurred together with soft story mechanism. Therefore this building suffered seriously from these wrong applications.

(a) (b)

Fig. 5 Short column damages


(a) (b)

Fig. 6 Soft story mechanism in various buildings

(a) (b)

Fig. 7 Concrete quality of various buildings

Fig. 8 Corrosion in a column of a building

#### *3.1.3 Poor concrete quality and corrosion*

Concrete quality is very important for structural performance. In Turkey, using of ready mix concrete did not common until last twenty years. Handmade concrete was generally used for construction of buildings. Due to using of hand made concrete and lack of using vibrator for compaction, homogeny mixing had not been obtained and expected strength not provided. In this earthquake, it was seen that, one of the main reasons of damages was poor concrete quality and workmanship. Although TEC requires that minimum characteristic compressive strength of concrete should be 20 MPa at least for buildings, our field observation showed that concrete quality of investigated buildings was considerably under this value. Fig. 7 shows concrete quality of various buildings in the earthquake area.

Also, it was seen that, concrete cover was very thin for preventing reinforcement to corrosion. Thus, tension strength of reinforcement decreased and lost bond strength between concrete due to decreasing in area of the reinforcing bars. Corrosion in a column of a building is shown in Fig. 8.

#### *3.1.4 Inadequate transverse reinforcement in columns*

In Simav, structural elements of old buildings which constructed before the current seismic code had insufficient detailing. Especially columns of the buildings had inadequate stirrups and longitudinal bars in the plastic hinge region. Therefore, shear strength and axial load carrying capacity of these structural elements had been diminished, considerably. Wide spacing of the between stirrups caused buckling of longitudinal rebar and spalling off concrete cover during an even low moderate earthquake. According to TEC, hoops of stirrups and cross ties must be bended $135^{\circ}$. But, at columns of damaged buildings in the earthquake area, stirrups were generally smooth reinforcing bars and bended $90^{\circ}$. Also, it was seen that, spacing of stirrups in the columns were approximately 25-30 cm. But TEC requires that, the maximum tie spacing should not be exceed 10 cm in plastic hinge region for columns of reinforced concrete buildings in all seismic zones. Fig. 9 shows columns of damaged buildings due to inadequate transverse reinforcement.

#### *3.1.5 Out-of-plane failure of unconfined gable walls*

This failure mode is observed commonly in earthquakes due to poor connection and workmanship. In Simav earthquake, lack of lateral supporting walls and tie beams, poor wall to floor and wall to wall connections caused out of plane failures or partial collapse of the gable walls. Although, the TEC requires vertical and horizontal tie beams for masonry gable walls that exceed 2 m, it was seen that gable walls of observed buildings were not constructed properly as regards the available building code. Fig. 10 shows common gable wall failures observed in the earthquake area.

#### *3.1.6 Damages of infill walls*

In R/C buildings, infill walls generally consist of unreinforced brick masonry using cement mortar in Turkey. Infill walls contribute to structural performance of buildings by increasing rigidity and limit storey displacement. But, unreinforced brick masonry walls have lower deformation capacities than the R/C structural members. For this reason, during an earthquake diagonal cracks at infill walls occur due to large deformations. Fig. 11(a) shows diagonal cracks in plane wall in Simav earthquake. Sometimes, infill walls are constructed two layers due to heat and sound isolation. But, it was seen that this type of masonry infill walls failed out of-plane mechanism due to the weak connections between the interior and the exterior layers (Fig. 11(b)).

(a) (b)

(c) (d)

Fig. 9 Damages at columns due to inadequate transverse reinforcement

(a) (b)

Fig. 10 Gable wall damages

(a) (b)

Fig. 11 Damages in infill walls

### *3.2 Masonry buildings*

Masonry buildings which have generally one or two storeys exist in Simav. These buildings are brick masonry and buildings having different materials. Reasons of failures of various masonry buildings are given below.

#### *3.2.1 Brick masonry buildings*

These buildings in the earthquake region were generally unreinforced and most of them did not have sufficient and proper tie beams. Tie beams are used for increasing the lateral strength of walls. Absence of these beams causes not orderly distributing of the lateral forces. Thus, diagonal cracks occur near openings with effect of shear forces. Fig. 12 shows diagonal cracks in various brick masonry buildings in which diagonal cracks start from the corner of windows. To prevent this kind of failures TEC requires that, reinforced concrete vertical tie beams should be constructed in full storey height on the corners of buildings, along the vertical intersections of the load–bearing walls and on both sides of the door and window openings. In addition to this, reinforced concrete horizontal tie beams should be constructed with the reinforced concrete slabs and width of these beams should be equal to the width of wall, and their height should not be less than 20 cm.

#### *3.2.2 Buildings having different materials*

In the earthquake area, some of the buildings were constructed by the different materials such as stone-brick, and stone-hımış together. When different materials are used together in a building, rigidity and strength problems occur. Thus, earthquake load sharing problems and additional torsional moments occur. Fig. 13 shows damaged building examples having stone and hımış. First floor of these buildings had been constructed by using rubble stones without tie beams. These buildings were suffered from crushing failure that occurs exceeding of the compressive strength of masonry wall affected by the vertical component of seismic motion.

(a) (b)

Fig. 12 Damages at brick masonry buildings

The code requires that lime mortar which supported with cement (cement/lime/sand volumetric ratio = 1/2/9) or cement mortar (cement/sand volumetric ratio = 1/4) should be used in load–bearing walls. However, due to economical reasons clay mortar which has low binding performance had been used instead of cement mortar among the stones as binder. Ground walls of the buildings had been constructed as multilayer. This situation caused behaving independently of the outer and inner of the walls.

Second floor of these buildings were constructed with hımış style. In such construction type, vertical timber elements which connect to each other with horizontal and cross timbers are used to provide rigidity of the buildings. In these buildings the first floor that constructed by rubble stones without tie beams were damaged, but the second floor that built hımış style were not damaged relatively first floor.

The other masonry building in earthquake area had been constructed with stone and brick. Out-of-plane mechanism occurred in this kind of buildings due to lack of tie beams and poor connections between walls. Each wall of the buildings behaved independently out-of-plane direction during the earthquake. In Fig. 14, total and partial collapses are seen due to out-of-plane failure at various buildings.

(a) (b)

Fig. 13 Damages at buildings having stone and hımış material

(a) (b)

Fig. 14 Damages at buildings having stone and brick material

## 4. Conclusions

On May 19, 2011 an earthquake of magnitude 5.7 hit Simav-Kütahya. The earthquake caused human causalities and considerably damages. In this study, reinforced concrete and masonry (brick masonry, adobe, hımış and having different materials) buildings which damaged due to the earthquake were evaluated. Reasons of damages of observed buildings were investigated and presented in this paper.

Main reason of damages for reinforced concrete buildings was using of low quality material, poor workmanship and not being constructed properly with respect to the available building code. Concrete quality of observed buildings was poor and consisted of improper gradation of aggregate. Concrete had been obtained by hand mixing. Thus, expected strength and homogeneity had not been obtained. However, adequate confinement of transverse reinforcement and $135^o$ hooks indicated in TEC were not observed. Hooks of stirrups and cross ties had been bended $90^o$. In addition to this, wide spacing between stirrups increased damage level. Especially end of columns damaged seriously since these reasons. Also, various wrong applications such as soft story phenomenon, short column application, and inadequate gaps between adjacent buildings enhanced damages and collapses.

Observed masonry buildings had generally been constructed without paying necessary attention. Absence of tie beams in the buildings had been increased damage.

Building having different materials is the other building type in the earthquake region. Using of different materials together had been caused rigidity and strength differences in these buildings.

Also, observed walls of some buildings had been built as multi layers. Thus, the layers of the wall had been behaved independently and separated.

It was observed that, the most of the reinforced concrete and masonry buildings in the earthquake areas had not been constructed according to the essential requirements of the TEC. Thus, severe damages at the buildings had been observed in this moderate earthquake. In order to prohibit the loss of lives and property, buildings must be constructed by take care of the requirements of the earthquake code and provided receiving engineering services.

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