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Damages of minarets during Erciş and Edremit Earthquakes, 2011 in Turkey

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Abstract. This paper illustrates the damages of reinforced concrete and masonry minarets during October 23 (Erciş) and November 9 (Edremit), 2011 Van earthquakes in Turkey. Erciş and Edremit are townships located 90km and 18km from Van city center in Turkey, respectively. Ground accelerations and response spectrums for these earthquakes are given in this paper. A total of 63 reinforced concrete and masonry minarets are heavily damaged or collapsed in the city center and villages nearby after both earthquakes. Because of the fact that there is no Turkish standard and specification directly related to design of minarets, nearly all of the constructions are carried out by workers using only their own technical knowledge. So, all of the non-engineering reinforced concrete and masonry minarets completely collapsed or damaged heavily. From the study, it is seen that the damages are due to several reasons such as site effect, location, and length of the fault, reduction in cross section and formation of the discontinuity, use of plain reinforcement steel, use of concrete with insufficient strength, existence of short lap splices and incorrect end hook angle, larger mass and stiffness concentrations on some region, longitudinal reinforcements discontinuity, cracks at the cylindrical body, and damage of spire and end ornament. In addition to these reasons, the two earthquakes hit the minarets within seventeen days, causing progressive damage. So, the existing design and construction practices should be improved to provide sufficient earthquake performance. Also, it is recommended that there should be a safe distance between the minaret and surrounding structures to reduce the loose of life after earthquake.

Keywords: damages; reinforced concrete and masonry minarets; Van earthquakes 2011 in Turkey

1. Introduction

Release of energy waves called seismic waves in the crust of earth, leads to the creation of a natural disaster called earthquake. An earthquake is a sudden, rapid shaking of the earth caused by the breaking and shifting of rocks beneath the earth surface. Over time, stresses build beneath the Earth's surface. Occasionally, stress is released resulting in the sudden and sometime disastrous shaking. Earthquakes can be recorded using an instrument called as seismometer.

Turkey is one of the most active earthquake zones because it is located in an area where several

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tectonic plates are converging, and actively in motion. Turkey consists of the Anatolian Tectonic Plate which is surrounded by the Arabian Plate, The Eurasian Plate, and the African Plate (Fig. 1) (USGS 2012). The movement of these plates, which are still active today, results in hundreds of earthquakes each month. So, performance of the constructed structures must be determined carefully considering earthquake in the design phase and must be controlled during life time.

Tall structures by their nature are computationally intensive to analyze. They consist of thousands of degrees of freedom and when subjected to strong ground motion from a source, exhibit very complex response (Krishnan 2004). Minarets are one of the thin and tall engineering structures. They are distinctive architectural features of Islamic mosques and generally tall spires with onion shaped or conical crowns. Minarets are used for calling out the azan five times each day by a muezzin in order to signal people to come to prayers.

A typical minaret basically consists of three parts such as base, shaft, and gallery. Base is reached from hard rock soil to floor. Shaft is a thin and slim body of the minaret and stairs are taken place cylindrically in the shaft to conform the necessary structural support for highly elongated shafts. The gallery is a balcony which encircles the upper section where the muezzins call out to prayer (Fig. 2).

In many earthquake-prone or high strong wind areas, many of the minarets are partly or completely damaged. One reason for not designing minarets to better withstand these environmental loadings is that the dynamic behavior of the minarets is not adequately known. Especially, the damage pattern, the conservation and the structural safety assessment of tall and slender structures such as minarets and towers have become of increasing concern in the last decade, probably as a consequence of some dramatic events registered in Europe (Binda *et al*. 2000, Taşkın *et al*. 2003, Doğangün *et al*. 2006, Sezen *et al*. 2008, Bayraktar *et al*. 2011).

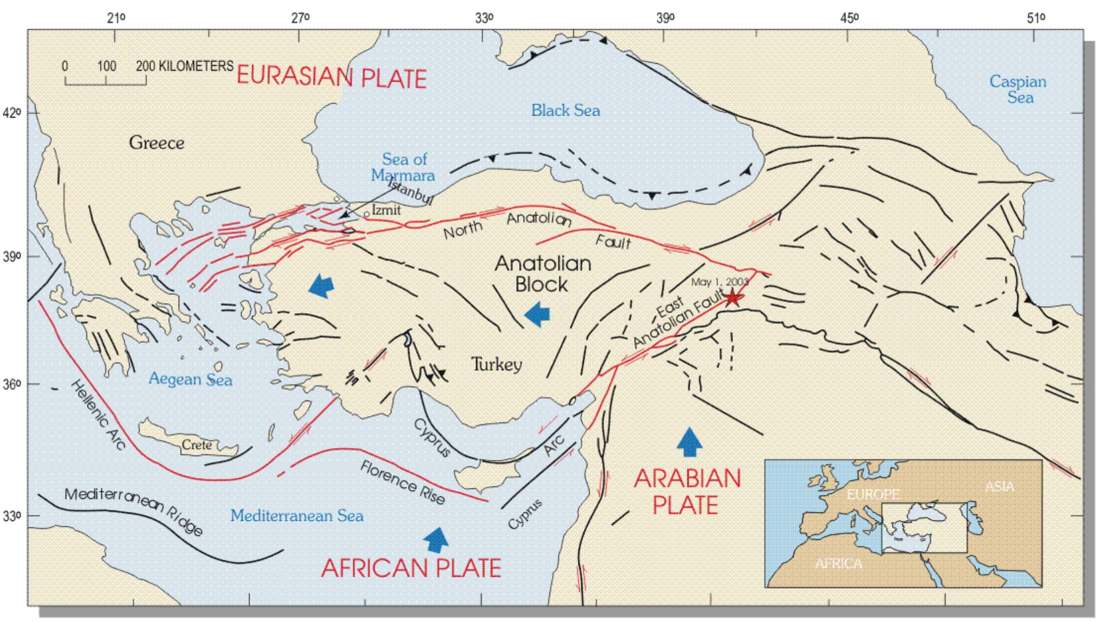
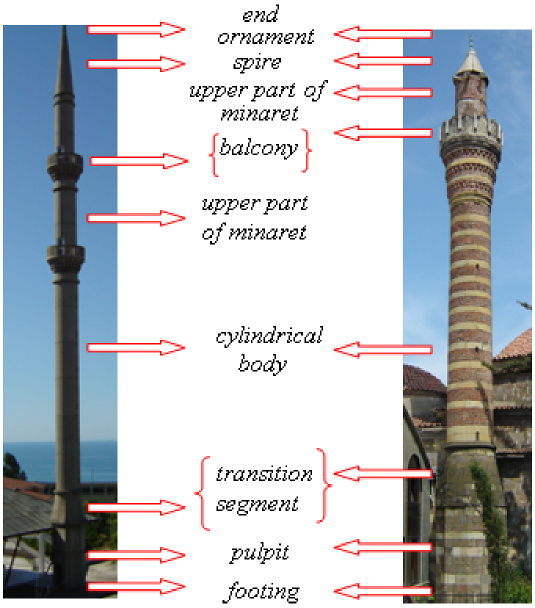


Fig. 1 Tectonic map of Turkey



(a) Reinforced concrete minare (b) Masonry minaret

Fig. 2 Typical reinforced concrete and masonry minarets in Turkey

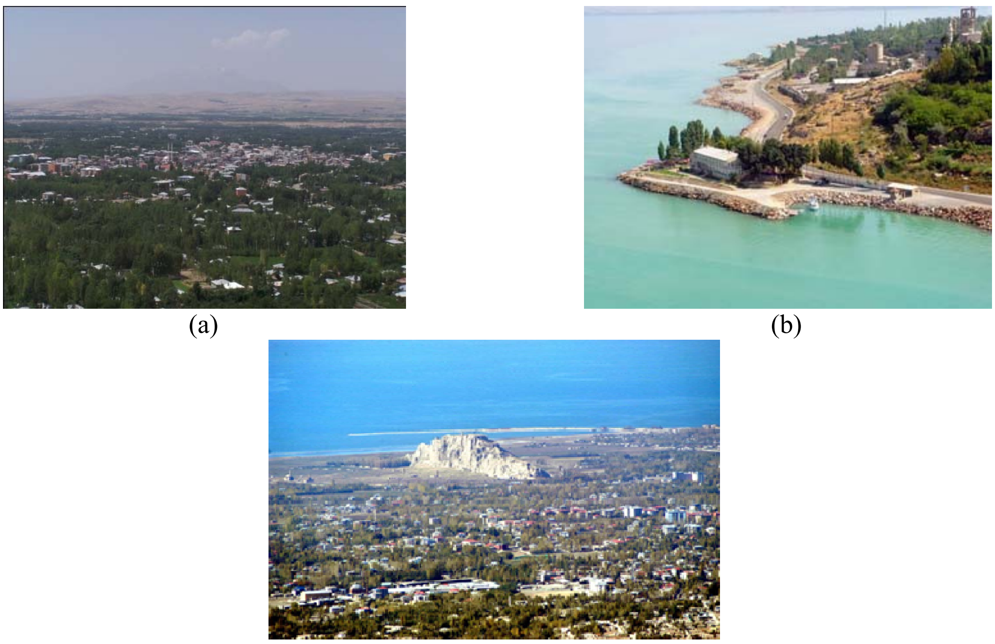
Considerable research efforts have been devoted to investigating the performance of engineering structures such as reinforced concrete buildings, minarets, masonry and wooden buildings, steel and harbour structures during earthquakes. Watanabe *et al*. (1998) introduced a study related to damages to steel structures during the 1995 Hyogoken-Nanbu earthquake. Sezen *et al*. (2008) performed to dynamic analysis and seismic performance of reinforced concrete minarets. Seismic code requirements are discussed and compared with observed details. Bayraktar *et al*. (2007a-b) presented the field investigations of masonry buildings during the March 25 and 28, 2004 Aşkale and July 2, 2004 Doğubayazıt earthquakes in Ağrı, Turkey. Mondal and Rai (2008) carried out the performance of harbour structures in Andaman Islands during 2004 Sumatra earthquake. Adanur (2010) reported the performances of masonry buildings during the December 20 and 27, 2007 Bala (Ankara) earthquakes in Turkey. Also preliminary reports are published shortly after the important earthquakes (Zifa 2008, ERRC 2011). It can be seen from the literature that field investigation of the engineering structures shortly after earthquakes to determine the performance is very important (Zhao *et al*. 2009, Celep *et al*. 2011). Some examples about the performance of reinforced concrete and masonry buildings during the October 23 and November 9, 2011 Van earthquakes in Turkey can be available from the literature (Baran *et al*. 2012, Erdik *et al*. 2012, Guney 2012). But, there is no enough studies about the performance of reinforced concrete and masonry minarets during the October 23 and November 9, 2011 Van earthquakes in Turkey. The October 23 and November 9, 2011 Van earthquakes damaged many reinforced concrete and masonry minarets in Van city center villages nearby. In order to understand the behaviour of these minarets and to observe their performance during the earthquakes, we visited in the affected region in a two-day reconnaissance study. Our observations and evaluations are presented below.

2. Seismological aspects

The earthquake with the magnitude of M_L=6.7 and M_w=7.2 occurred at local time 13:41 on Sunday, October 23, 2011 in the Erciş township of Van located in the eastern part of Turkey (Fig. 3(a)) (URL-1). The epicenter is about 30km to the north of the Van city center and its coordinates are reported as 38.68N-43.47E by the Earthquake Department of the Disaster and Emergency Management Presidency (AFAD). The depth of the earthquake is given as 19.02 km. Following the mainshock approximately 650 aftershocks occurred in the first 2 days. The aftershocks follow SW-NE trend.

The second earthquake with the magnitude of M_w=5.6 occurred at local time 21:23 on Wednesday, November 9, 2011 in the Edremit township of Van located in the eastern part of Turkey (Fig. 3) (URL-2). The epicenter is in the Edremit subprovince, about 16km to the south of the Van city center (URL-3). Its coordinates are reported as 38.429N-43.234E by the Kandilli Observatory and Earthquake Research Institute (KOERI) (URL-4). The depth of the earthquake is given as 5 km. This earthquake has a dominantly strike-slip mechanism.

According to the latest information, 604 people (61 in the center, 66 in villages in the vicinity and 477 in Erciş) as a result of first earthquake (October 23, 2011) and 40 people because of second earthquake (November 9, 2011) have died. 2608 people were injured after first earthquake (AFAD 2011). A total of 63 reinforced concrete and masonry minarets are heavily damaged or collapsed in the city center and villages nearby.



(a) (b)

(c)

Fig. 3 A view of Erciş Township (a) and Edremit Township (b) of Van (c)

Seismic Zoning Map published by the Ministry of Public Works and Settlement of Turkey in 1996 considering maximum acceleration and the whole country is divided into the 5 zones, as shown in Fig. 4(a). The majority of the Van city is at the first degree earthquake zone and the other regions at the second degree earthquake zone (Fig. 4(b)) (AFAD 2011). The Erciş and Edremit earthquakes occurred on October 23 and November 9, 2011, respectively took place on a blind fault, did not occur on a fault previously indicated and discussed in the literature. The regional active fault map is shown in Fig. 5. This map developed and updated with the suggestions of some researches (KOERI 2011).

Many earthquakes over magnitude 5 (M≥5) were recorded in the city of Van and its vicinity where tectonically active regions. Destructive earthquakes occurred in these regions in the last century are given in Table 1. The distribution of the historical earthquakes from 1990 to present in these regions is shown in Fig. 6.

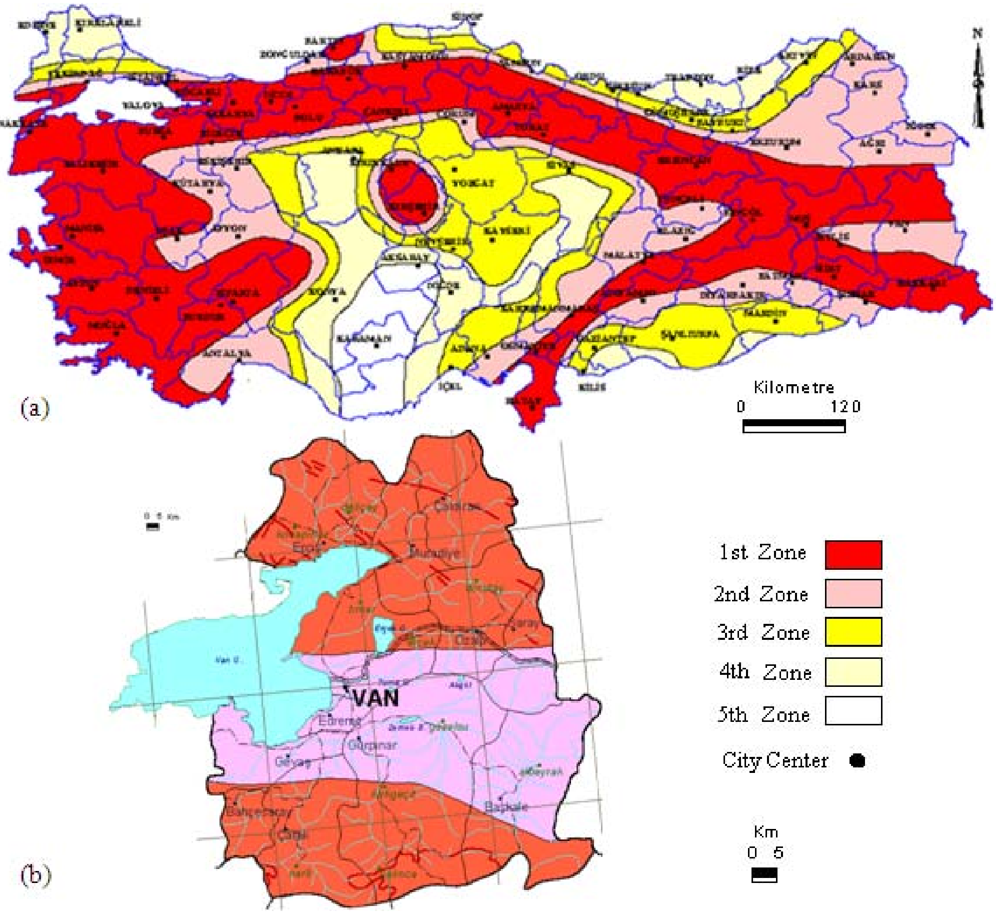


Fig. 4 Seismic zoning map of Turkey (a) and Van (b)

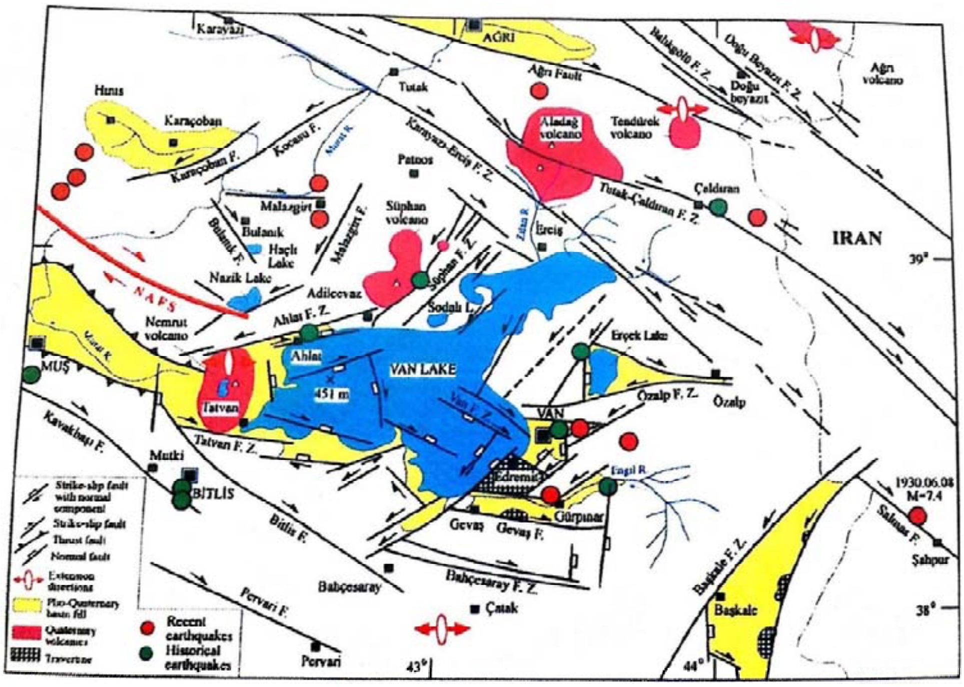


Fig. 5 The regional active fault map of Van

Table 1 Destructive earthquakes in Van and its vicinity

Date (DD/MM/YYYY)	Time	Region	Magnitude (M)	Latitude (N)	Longitude (E)
28/04/1903	*23:39*	*Malazgirt*	*6.3*	*39.14*	*42.65*
06/05/1930	*22:34*	*Salmas*	*7.2*	*38.22*	*44.66*
10/09/1941	*21:53*	*Erciş*	*5.9*	*39.45*	*43.32*
20/11/1945	*06:27*	*Van*	*5.2*	*38.63*	*43.33*
25/06/1964	*00:11*	*Erciş*	*5.3*	*39.13*	*43.19*
24/11/1976	*22:15*	*Çaldıran*	*7.2*	*39.05*	*44.03*
17/01/1977	*19:24*	*Erciş*	*5.1*	*39.27*	*43.70*
25/06/1988	*15:38*	*Van*	*5.0*	*38.50*	*43.07*
15/11/2000	*05:34*	*Van*	*5.7*	*38.51*	*43.01*

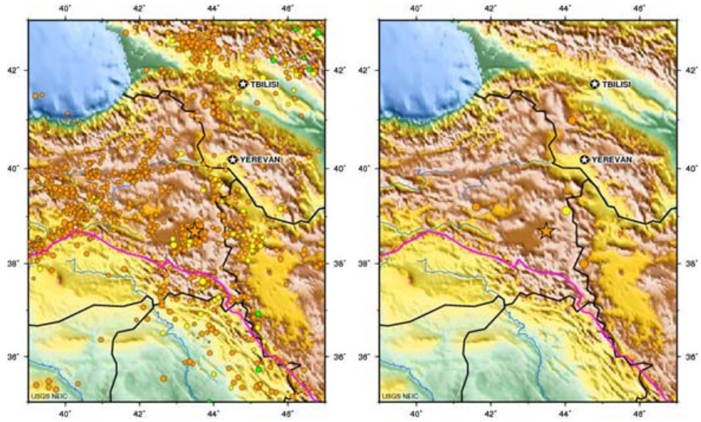
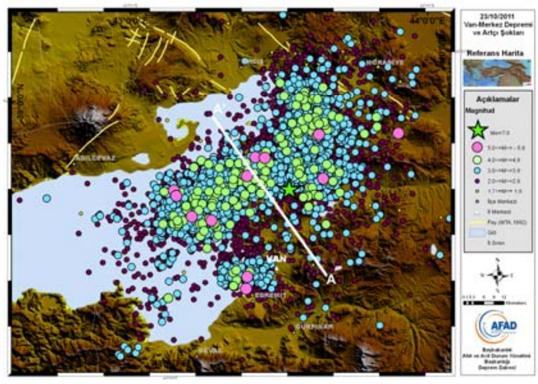
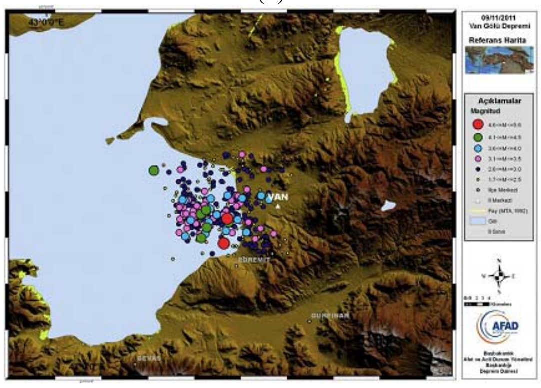


Fig. 6 Historical and instrumental seismicity of the Eastern Turkey. (a) Seismicity 1990 to present, (b) magnitude 7 and greater earthquake since 1900. Major tectonic boundaries: subduction zones-purple, ridges-red and transform faults-green (USGS 2011)



(a)



(b)

Fig. 7 The view of Erciş and Edremit earthquakes and aftershocks distributions. (a) Erciş earthquake and aftershocks: pink 5.0≤M≤5.8, green 4.0≤M≤4.9, cyan 3.0≤M≤3.9, pink 2.0≤M≤2.9, yellow 1.7≤M≤1.9. b) Edremit earthquake and aftershocks: red 4.6≤M≤5.6, green 4.1≤M≤4.5, blue 3.6≤M≤4.0, pink 3.1≤M≤3.5, dark blue 2.6≤M≤3.0, yellow 1.7≤M≤2.5

According to the latest information data (December 9, 2011), a total of 6284 aftershocks occurred after October 23 and November 9, 2011 earthquakes between 1.7 and 5.8 magnitude. Views of Erciş and Edremit earthquakes and aftershocks distributions are shown in Fig. 7.

3. Ground motions and response spectra

The reported parameters for October 23 and November 9, 2011 Erciş and Edremit earthquakes are given in Table 2 (URL-5). The three components of ground acceleration records for both earthquakes obtained at Muradiye station are given in Figures 8 and 9. The accelerations were not recorded in the city center.

As seen from these figures, the peak ground accelerations (a_{max}) are 178.5 cm/s^2 in the North-South direction, 169.5 cm/s^2 in the East-West direction, and 79.5 cm/s^2 in the vertical direction for October 23, 2011 Erciş earthquake. Also, it is seen that the peak ground accelerations (a_{max}) are 148.08 cm/s^2 in the North-South direction, 245.90 cm/s^2 in the East-West direction, and 150.54 cm/s^2 in the vertical direction for November 9, 2011 Edremit earthquake.

The seismic zone of the city of Van is classified as 1 and 2, where the probability of exceeding an effective peak ground acceleration of 0.3 g - 0.4 g is 10 percent in 50 years. As can be seen in Figs. 8 and 9, the peak value of acceleration occurred 178.5 cm/s^2 in the N-S direction for October 23, 2011 Erciş earthquake and 245.90 cm/s^2 in the E-W direction for November 9, 2011 Edremit earthquake. It should be noted that peak ground accelerations recorded at Muradiye station not exceeded the seismic hazard defined as to be 0.3 g - 0.4 g for the area in the seismic zone map of Turkey. However, it is thought that soil amplification occur in the region.

The computed response spectra with damping ratio of 0, 2, 5 and 10 for the lateral (N-S, E-W) and vertical (U-D) components are given in Figure 10 for October 23, 2011 Erciş and October 23, 2011 Erciş earthquakes. Fig. 10 shows that shaking of both earthquakes should be most effective on structures having a natural period of approximately up to 1.0s.

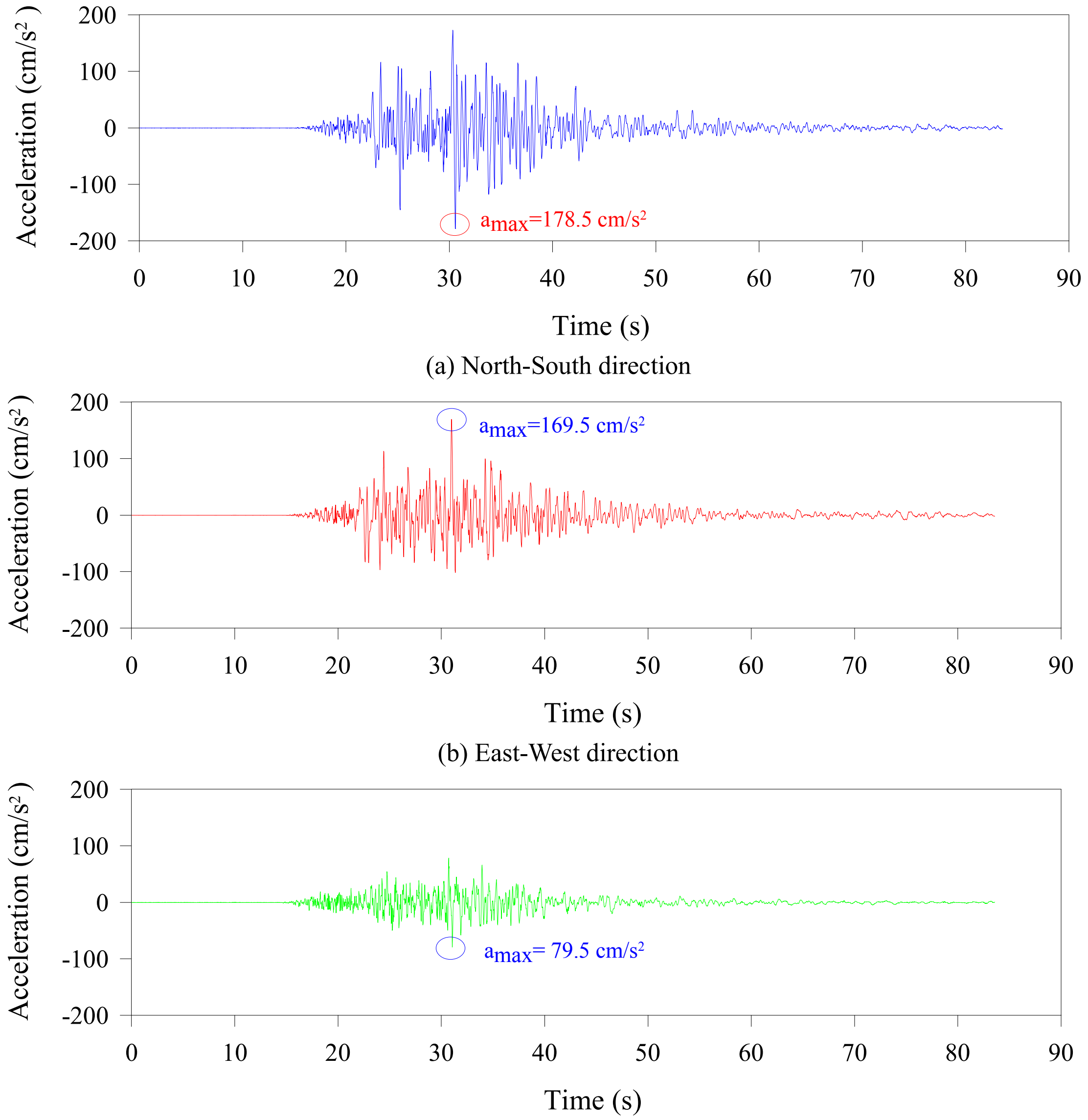
Table 2 Parameters of October 23, 2011 Erciş and November 9, 2011 Edremit earthquakes (URL-5)

Station Code	Date	Time	Depth (km)	N-S (cm/s^2)	E-W (cm/s^2)	U-D (cm/s^2)	Latitude (N)	Longitude (E)	Region
6503	*23/10/2011*	*13:41*	*19.02*	*178.5*	*169.5*	*79.5*	*38.680*	*43.470*	*Erciş*
6501	*09/11/2011*	*21:23*	*5.00*	*148.08*	*245.90*	*150.54*	*38.429*	*43.234*	*Edremit*

4. Damages on the minarets

The 23 October and 9 November 2011 Erciş and Edremit earthquakes caused significant damage to Van and its vicinity. The two earthquakes hit the minarets within seventeen days, causing progressive damage.

A total of 63 reinforced concrete and masonry minarets are heavily damaged or collapsed in the city center and villages nearby after both earthquakes. Almost all the minarets are affected in the region. Nearly all of the minarets in the affected villages were not designed and constructed in accordance with Turkish earthquake code (TERDC 2011).



(a) North-South direction

(b) East-West direction

(c) Vertical direction

Fig. 8 Three components of ground accelerations of October 23, 2011 Erciş earthquake recorded at Muradiye station. (a) North-South direction, (b) East-West direction and (c) Vertical direction

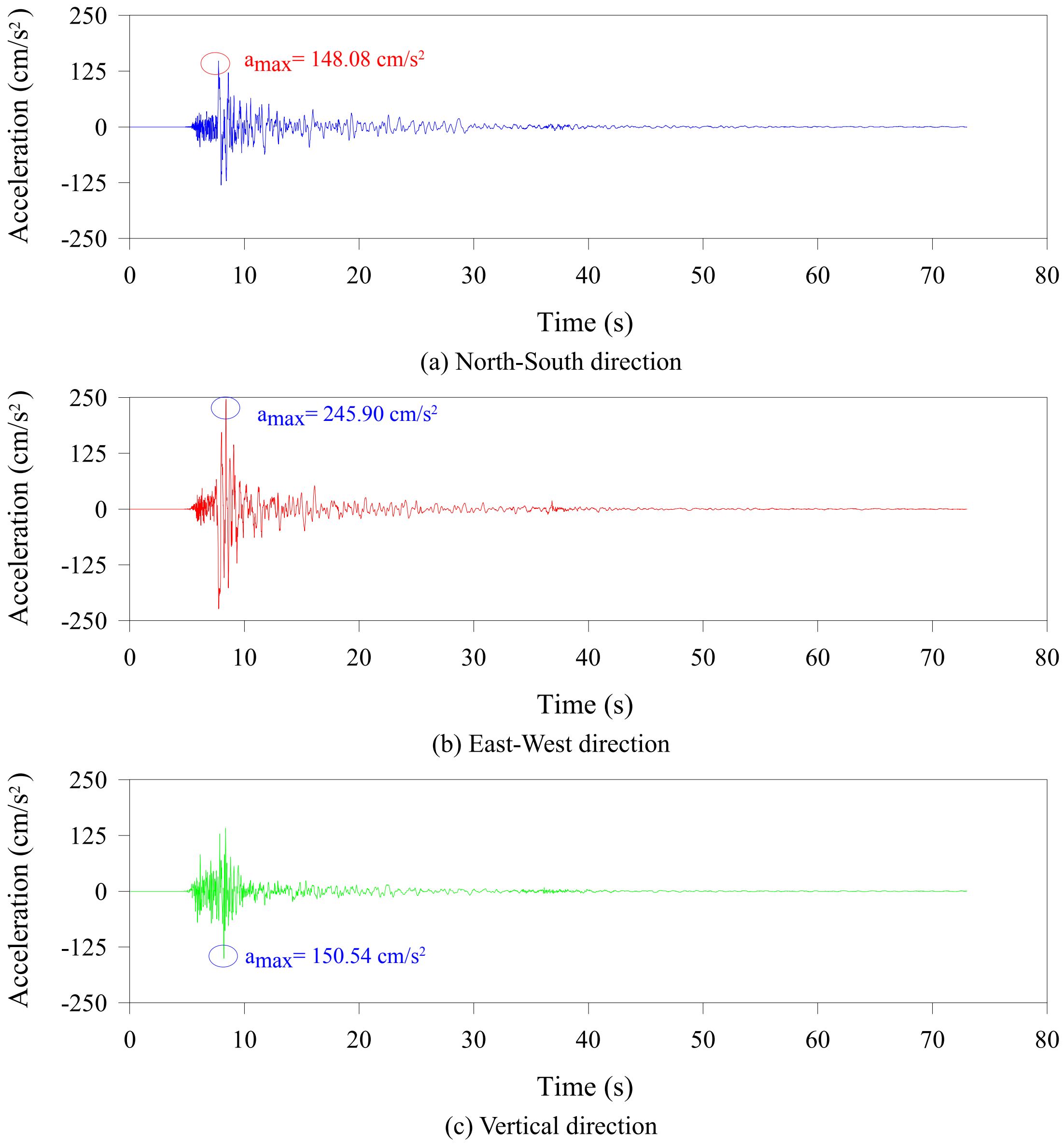
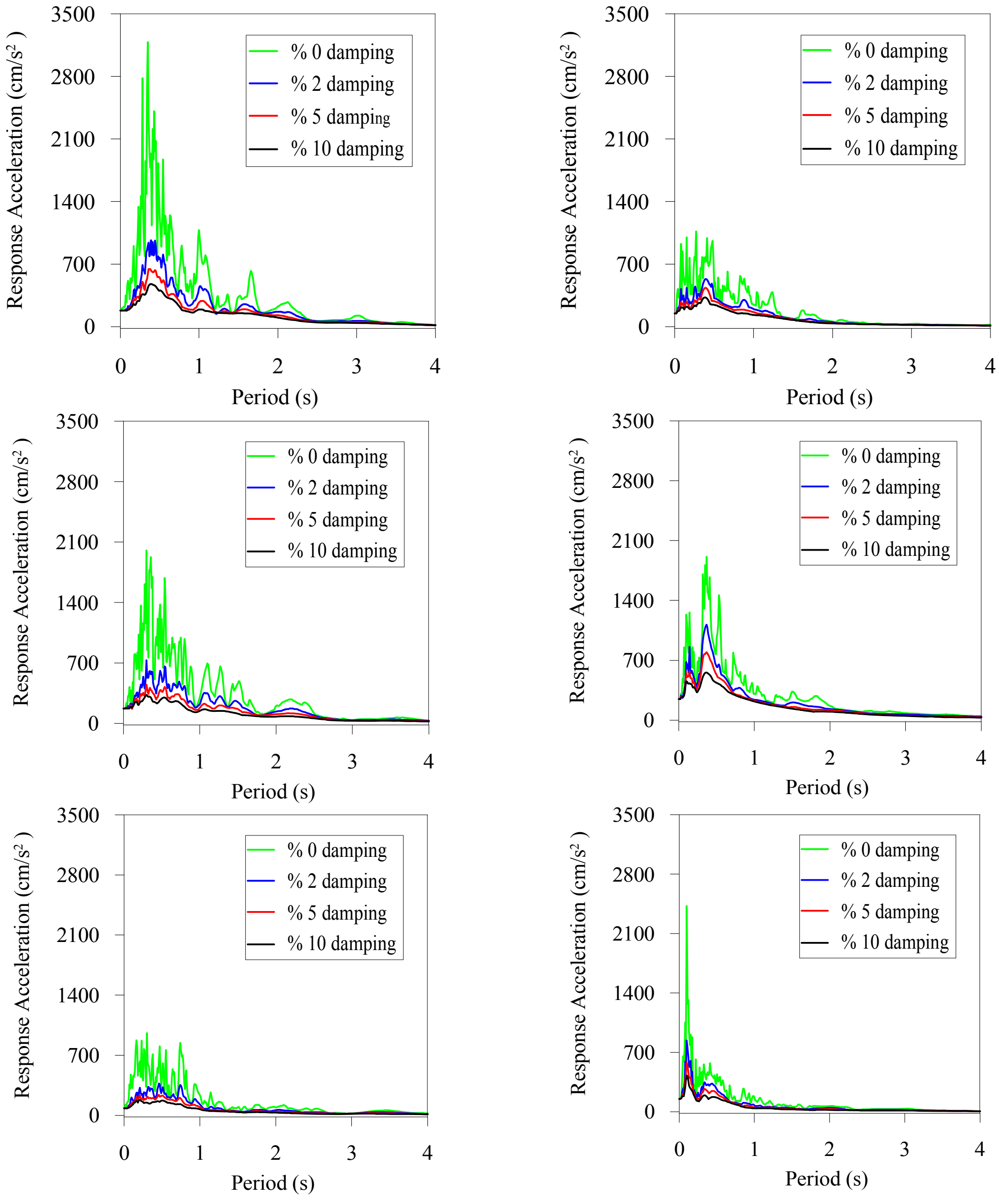


Fig. 9 Three components of ground accelerations of November 9, 2011 Edremit earthquake recorded at Van Central Department of Public Works and Settlement station (a) North-South direction, (b) East-West direction and (c) Vertical direction



(a) October 23, 2011 Erciş earthquake (b) November 9, 2011 Edremit earthquake

Fig. 10 Response acceleration of N-S, E-W and U-D components of October 23, 2011 Erciş and November 9, 2011 Edremit earthquakes

4.1 Reinforced concrete minarets

It is seen from the field investigations that the damages on the reinforced concrete minarets is usually concentrated in some points;

- *Reduction in cross section and formation of the discontinuity,*
- *Use of plain reinforcement steel,*
- *Use of concrete with insufficient strength,*
- *Existence of short lap splices and incorrect end hook angle,*
- *Larger mass and stiffness concentrations, longitudinal reinforcements discontinuity,*
- *Cracks at the cylindrical body,*

One of the most common types of the damage pattern in the reinforced concrete minarets is random horizontal cracks and concrete spalling near the bottom of the cylindrical body. There are two main reasons of this type of damage; reduction in cross section from the pulpit to cylindrical body and formation of the discontinuities in this region due to the lap spliced longitudinal steel bars (Fig. 11).

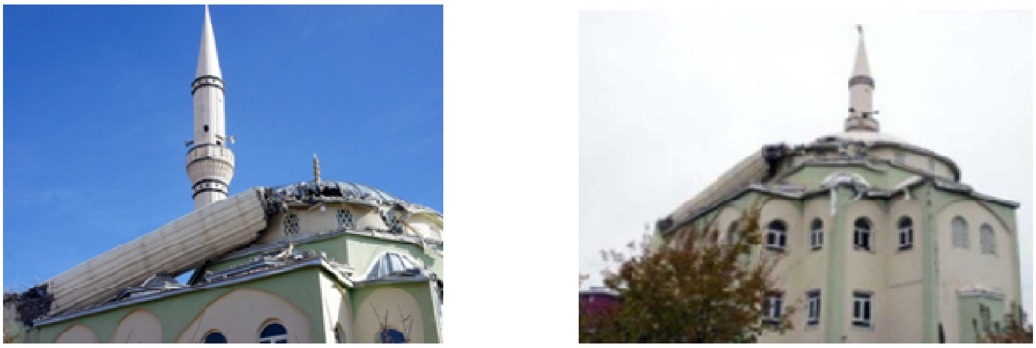


Fig. 11 Examples of failures near the bottom of the cylindrical body (URL-6, 7)

Fig. 12 Examples of the use of plain reinforcement steel

In the Turkish Earthquake Resistant Design Code, Part 3.2, it is stated that *"Unribbed reinforcement steel cannot be used exempt hoops and crossties with flooring reinforcement. With the exception of elements, reinforcing steel with strength exceeding that of S420 shall not be used reinforced concrete structural elements."* The use of plain reinforcement steel was observed within the cylindrical body as shown in Fig. 12. This was another source of damage that may cause to weaker bond between concrete and steel.

In the Turkish Earthquake Resistant Design Code, Part 3.2, it is stated that *"In all buildings to be built in seismic zones, concrete with strength less than C20 (compressive strength of 20MPa) shall not be used."* The use of concrete with insufficient strength was observed in the minarets as shown in Fig. 13. This was another source of damage that may decrease the structural performance during an earthquake.

It is observed that one of the most important reasons of the damage in reinforced concrete minarets is existence of short lap splices and incorrect end hook angle. The lap splice length at the bottom of the cylindrical body was observed approximately between 60 cm and 90 cm. Also, the ends of the longitudinal reinforcement steel bars had nearly 180^o end hooks. So, the combinations of plain reinforcement steel bars, inadequate lab splice length and incorrect end hook angle emerged a non-rigid and sensitive region near the bottom of the cylindrical body (Fig. 14).

Fig. 13 Examples of the use of concrete with insufficient strength

Fig. 14 Examples of inadequate lab splice length and incorrect end hook angle

Fig. 15 An example of damage around the middle region of cylindrical body

In addition to these, the damages around the middle region of the cylindrical body have been observed in some of the reinforced concrete minarets (Fig. 15). The damages are related to some irregularities such as larger mass and stiffness concentration around these regions especially around the balconies. As seen from the Fig. 15, it is thought that longitudinal reinforcement steel bars may be lap spliced and not anchored well at this location. There is no damage at other locations. So, the lap splices creating the longitudinal reinforcements discontinuity cause of this damage.

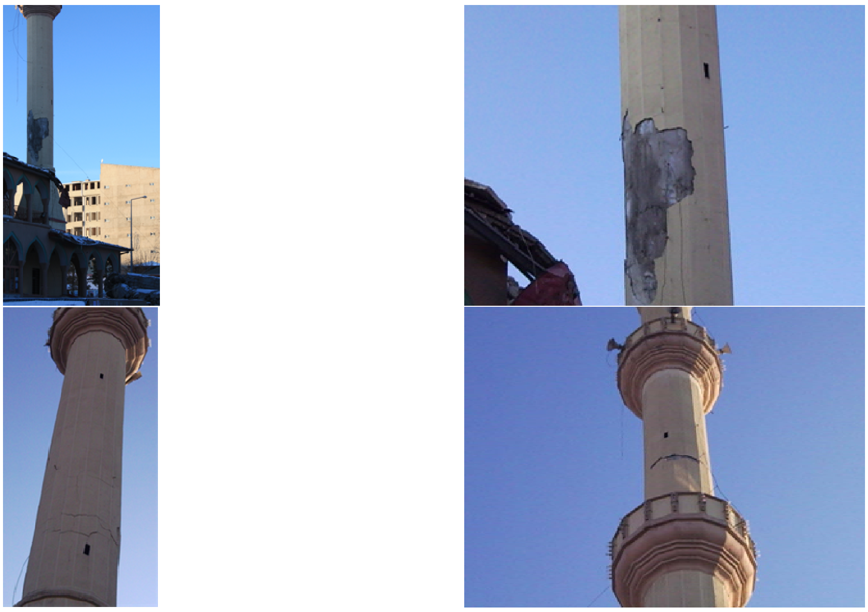


Fig. 16 Cracks occurred at the region between transition segment and cylindrical body

Fig. 17 Examples of undamaged reinforced concrete minarets

In addition to these, the cracks at the cylindrical body have been observed in 60-75% of the reinforced concrete minarets (Fig. 16). It is though that these minarets reflect the probable and positive behaviour. When the scientific articles related the earthquake performance of reinforced concrete minarets examined carefully, it is seen that the maximum and minimum principal stresses occurred at the region between the transition segment and the cylindrical body.

However, there was also some reinforced concrete minarets performed well in the affected areas. Here, only three of them are given in Fig. 17. This was mainly due to the proper care, quality of material and good workmanship during construction.

4.2 Masonry minarets

It is seen from the field investigations that the damages in the masonry minarets is usually concentrated in some points;

- *Damage of the transition segment,*
- *Reduction in cross section,*
- *Use of cut stone with insufficient strength,*
- *Larger mass and stiffness concentrations,*
- *Failure at the cylindrical body,*
- *Damage of spire and end ornament,*

Pulpit is the most rigid region of minarets and it is not expected any damage in this region during earthquake. But transition segment, which connect the pulpit and cylindrical body, reduce the stiffness and strength of the minarets along to the height of this region. So, damages over the transition segment can be observed. Fig. 18 shows one such case where cut stones cracking and spalling was concentrated just below the cylindrical body.

One of the most common types of the damage pattern in the masonry minarets is random cut stone cracks and spalling near the bottom of the cylindrical body. The main reason of this type of damage is reduction in the cross section from the pulpit to cylindrical body (Fig. 19).

In the Turkish Earthquake Resistant Design Code, Part 5.4 (20), it is stated that *"According to gross pressure area, minimum pressure strength of natural and artificial masonry units to be used in load-bearing walls shall be 5.0 MPa at least. Pressure strength of natural stones to be used in basement stories shall be 10.0MPa at least. In the case where concrete walls are constructed in basements, minimum quality of concrete to be used shall be C16 (compressive strength of 16MPa)."* The use of cut stone with insufficient strength was observed in the minarets as shown in Fig. 20. This was another source of damage that may decrease the structural performance during an earthquake.

Fig. 18 Examples of damages on the transition segments

Fig. 19 An example of failure near the bottom of the cylindrical body (URL-8)

In addition to these, the damages around the middle region of cylindrical body have been observed in some of the masonry minarets (Fig. 21). The damages are related to some irregularities such as larger mass and stiffness concentration around these regions especially around the balconies.

In addition to these, the failures at the cylindrical body have been observed in 60-75% of the masonry minarets (Fig. 22). It is though that these minarets reflect the probable and positive behaviour. When the scientific articles related the earthquake performance of minarets examined carefully, it is seen that the maximum and minimum principal stresses occurred at the region between the transition segment and the cylindrical body.

Fig. 20 Examples of the use of cut stone with insufficient strength

Fig. 21 Examples of damages around the middle region of cylindrical body

The damages and failures at the spire and end ornament have been observed in 40-60% of the the masonry minarets (Fig. 23).

Also, some damages were observed at the connection points of mosque walls and its surroundings as shown in Fig. 24.

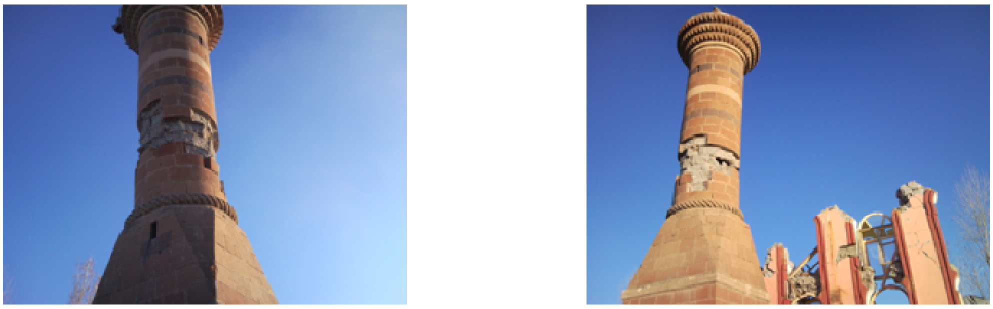


Fig. 22 Failures occurred at the region between transition segment and cylindrical body

Fig. 23 Example of damages and failures at the spire and end ornament

Fig. 24 Some damages at the connection points of mosque walls and its surroundings

5. Conclusions

This paper illustrates the damages of reinforced concrete and masonry minarets during October 23 (Erciş) and November 9 (Edremit), 2011 Van earthquakes in Turkey. A total of 63 reinforced concrete and masonry minarets are heavily damaged or collapsed in the city center and villages nearby after both earthquakes. Based on the observations of the damages caused to both type of minarets during October 23, 2011 Erciş and November 9, 2011 Edremit earthquakes, the following conclusions could be drawn:

- All of the non-engineering reinforced concrete and masonry minarets completely collapsed or damaged heavily.
- Nearly all of the reinforced concrete and masonry minarets in the affected area were not designed and constructed in accordance with Turkish Earthquake Resistant Design Code.
- Damages in the reinforced concrete minarets can be classified into some points such as reduction in cross section and formation of the discontinuity, use of plain reinforcement steel, use of concrete with insufficient strength, existence of short lap splices and incorrect end hook angle, larger mass and stiffness concentrations, longitudinal reinforcements discontinuity, and cracks at the cylindrical body.
- Damages in the masonry minarets can be classified into some points such as damage of transition segment, reduction in cross section, use of cut stone with insufficient strength, larger mass and stiffness concentrations, failures at the cylindrical body, and damage of spire and end ornament.
- Two earthquakes struck the minarets only seventeen days. All of the collapsed minarets in the second earthquake have already been damaged in the first earthquake.
- Existing design and construction practices should be improved to conform sufficient earthquake performance.
- It is recommended that there should be a safe distance between the minaret and surrounding structures to reduce the loose of life after earthquake.

Finite element analysis and experimental measurements are used to predict likely damages in the reinforced concrete and masonry structures during earthquakes. This process represents a complexity and difficulty. It is aimed to give a contribution to predict local damage and failure mechanisms of the reinforced concrete and masonry minarets during earthquakes in this paper.

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