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Lessons learned from recent destructive Van, Turkey earthquakes

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Abstract. A destructive earthquake, the magnitude of this earthquake was 7.2, hit Van, Turkey on October 23, 2011. After this devastating earthquake, a moderate earthquake which had 5.7 magnitude on November 9, 2011 occurred in Edremit, Van. These earthquakes caused heavy damages and collapses in many reinforced concrete buildings with loss of lives. In this paper, characteristics of ground motions of these earthquakes were studied and, deficiencies in structural elements and engineering faults such as poor workmanship and quality of construction, soft and weak stories, strong beam-weak column, short column, large overhang, hammering and unconfined gable wall were investigated. According to the observations, it was seen that, low quality of structural materials, lack of engineering services, inappropriate design and construction with insufficient detailing of the structural elements were the main reasons of heavy damages.

Keywords: 2011 Van earthquakes; ground motion characteristics; reinforced concrete buildings; earthquake damages

1. Introduction

On October 23, 2011 earthquake that is one of the largest earthquakes in last century in Turkey struck Van. Magnitude of the earthquake was Mw=7.2. This earthquake caused partial and total collapses with considerably damages in the centre of Van and its countries, especially Erciş country. This earthquake was felt in a wide area including Erzurum, Ağrı, Diyarbakır, Muş, Bitlis, Iğdır, Kars, Batman and Siirt cities. According to the Turkish Statistical Institute, provincial population of Van which was affected by this earthquake is 1.035.418 as of 2010. While 539.619 people of total population live in Van the centre of the province and in the sub-provincial centres, 495.799 people live in villages.

After this destructive hazard a moderate earthquake, which has magnitude of M_w=5.7 and the epicentral location on Edremit district, hit again Van on November 9, 2011. According to the information given by Turkish Prime-Ministry Disaster and Emergency Management Presidency (AFAD 2011) 644 people lost their lives, 252 people were saved alive from the debris and in

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excess of 2000 people were injured in these earthquakes. Also it was informed that, by 9 December 2011, the number of aftershocks reached to 6284 and 17005 dwelling houses were determined as collapsed or heavily damaged in Van city centre, Erciş and villages.

Turkey is located in a seismically active region. The Arabian plate moves northward relative to Eurasia leads to lateral motion of the Anatolian block to the west and the Northeast Anatolian block to the east.

The movements are centred along the active fault zones, mainly the North Anatolian Fault, East Anatolian Fault. The earthquake took place east of the North and East Anatolian faults, on the Bitlis suture zone (www.emsc-csem.org). Epicentre of the earthquake occurred on 23 October, 2011 with seismic fault zone in Turkey is given in Fig. 1.

These seismological activities had been caused several destructive earthquakes in Van and vicinities in the past. These earthquakes are presented in Table 1.

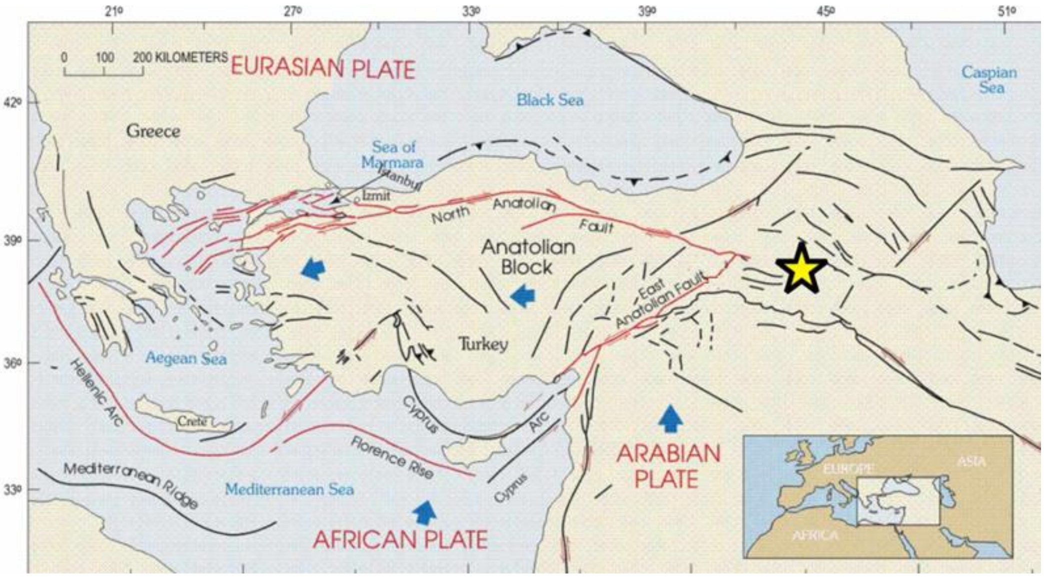


Fig. 1 Epicentre of Oct 23, 2011 earthquake with seismic fault zone in Turkey (www.emsc-csem.org/Earthquake/202/Earthquake-M7-2-Eastern-Turkey)

Table 1 Seismological activities in Van and vicinities in the past

Date	Latitude (N)	Longitude (E)	M_W
28.04.1903	39.14	42.65	6.3
06.05.1930	38.22	44.66	7.2
10.09.1941	39.45	43.32	5.9
20.11.1945	38.63	43.33	5.2
25.06.1964	39.13	43.19	5.3
24.11.1976	39.05	44.03	7.2
17.01.1977	39.27	43.70	5.1
25.06.1988	38.50	43.07	5.0
15.11.2000	38.51	43.01	5.7

The last earthquakes are evidence of continuity of these activities. Van, 2011 earthquakes' magnitude and source characteristics are shown in Table 2 and Table 3 according to various institutions.

According to seismic zone map prepared by Ministry of Public Works and Settlement, Turkey is divided into the 5 seismic zones. In this map, centre of Van and Erciş country are classified as I and II in seismic hazard zone respectively (Fig. 2) where the probability of exceedance of a peak ground acceleration of 0.4 g and 0.3 g is 10 % in 50 years (g represents acceleration of gravity).

Many researchers studied and evaluated structural damages of reinforced concrete (R/C) buildings after the past earthquakes in different regions. Watanabe (1997) studied behaviour of R/C buildings during the Hyougoken-Nanbu earthquake and evaluated the damage reasons of reinforced concrete buildings. Adalıer and Aydıngün (2001) evaluated the structural damages and the geological conditions for 1998 Adana-Ceyhan earthquake in Turkey. Bruneau (2002) investigated seismic behaviour of structures after August 1999 Kocaeli earthquake and formulated some general lessons obtained from this earthquake. Doğangün (2004) carried out a study about the reasons of damages of reinforced concrete structures during the May 1, 2003 Bingöl-Turkey earthquake. Ahmadizadeh and Shakib (2004) focused on the structural performance of buildings and lifeline systems after December 26, 2003 Bam earthquake in Iran. Ghobarah *et al.* (2006) conducted a field investigation in Thailand after December 26, 2004 Southeast Asia earthquake and tsunami. For this purpose, they evaluated the effects of the event on buildings, bridges and infrastructure. Arslan and Korkmaz (2007) carried out a study about R/C buildings during recent earthquakes in Turkey. Zhao *et al.* (2009) focused on description of building performance after the May, 12 2008 Wenchuan earthquake in China. Rossetto and Peiris (2009) evaluated the

Table 2 Characteristic of Oct 23, 2011 10:41 (GMT) Van earthquake

Institution	Latitude (N)	Longitude (E)	Depth(km)	M_W
AFAD[1]	38.68	43.47	19.07	7.0
KOERI[2]	38.7578	43.3602	5.00	7.2
USGS[3]	38.691	43.497	16.00	7.1
EMSC[4]	38.78	43.40	10.00	7.2
GFZ[5]	38.674	43.581	15.00	7.1
GCMT[6]	38.67	43.42	15.40	7.1

[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
[5]German Research Centre for Geosciences
[6]Global Centroid Moment Tensor

Table 3 Characteristic of Nov 09, 2011 19:23 (GMT) Edremit-Van earthquake

Institution	Latitude (N)	Longitude (E)	Depth(km)	M_W
AFAD[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

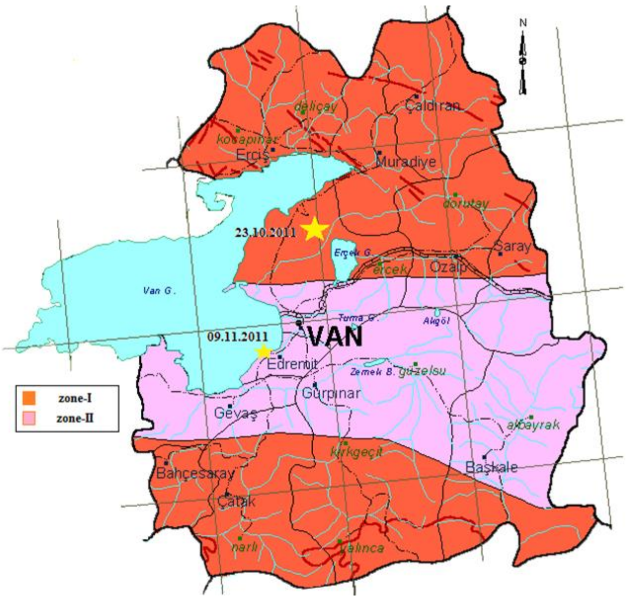


Fig. 2 Seismic zone map of Van

performance of government, commercial, and residential buildings after the 8 October 2005 Kashmir earthquake in Pakistan. Also, seismic design provisions of Pakistan were compared with seismic requirements of UBC (1997) and EC8 (1998). Celep *et al.* (2011) assessed the damages of concrete and masonry buildings after the 8 March, 2010 Elazığ earthquakes in Turkey. Ricci *et al.* (2011) conducted a study about behaviour of R/C buildings after L'Aquila earthquake which occurred 6 April 2009 in Italy. Braga *et al.* (2011) investigated the behaviour of non-structural elements, particularly masonry infills in reinforced concrete frames at the 2009 L'Aquila earthquake. Kam and Pampanin (2011) assessed the performance of R/C buildings during February 22, 2011 Christchurch earthquake in New Zealand. Calayır *et al.* (2012) studied the damages of various structures during the March 8, 2010 Elazığ-Kovancılar earthquake in Turkey. Yön *et al.* (2013), investigated the seismic performance of reinforced concrete and masonry buildings after 2011 Simav (Turkey) earthquake. Bayraktar *et al.* (2013) and Ateş *et al.* (2013) evaluated the reinforced concrete building damages during the 2011 Van earthquakes. In this paper, the characteristic parameters of the Van earthquakes were given and failures of different R/C buildings were assessed in the earthquake regions.

2. Characteristics of the earthquakes

Records of acceleration of the first earthquake were obtained from Muradiye Station located in Directorate of Meteorology Building and records of second earthquake obtained from centre of Van Station located in local office of the Ministry of Public Works and Settlement. Figs. 3 and 4 show the first and second earthquake acceleration records. The peak acceleration values of the first and second records are 178.50, 169.50 and 79.50 cm/s^2 and 148.08, 245.90 and 150.54 cm/s^2 for North-South (N-S), East-West (E-W) and Vertical (U-D) components, respectively.

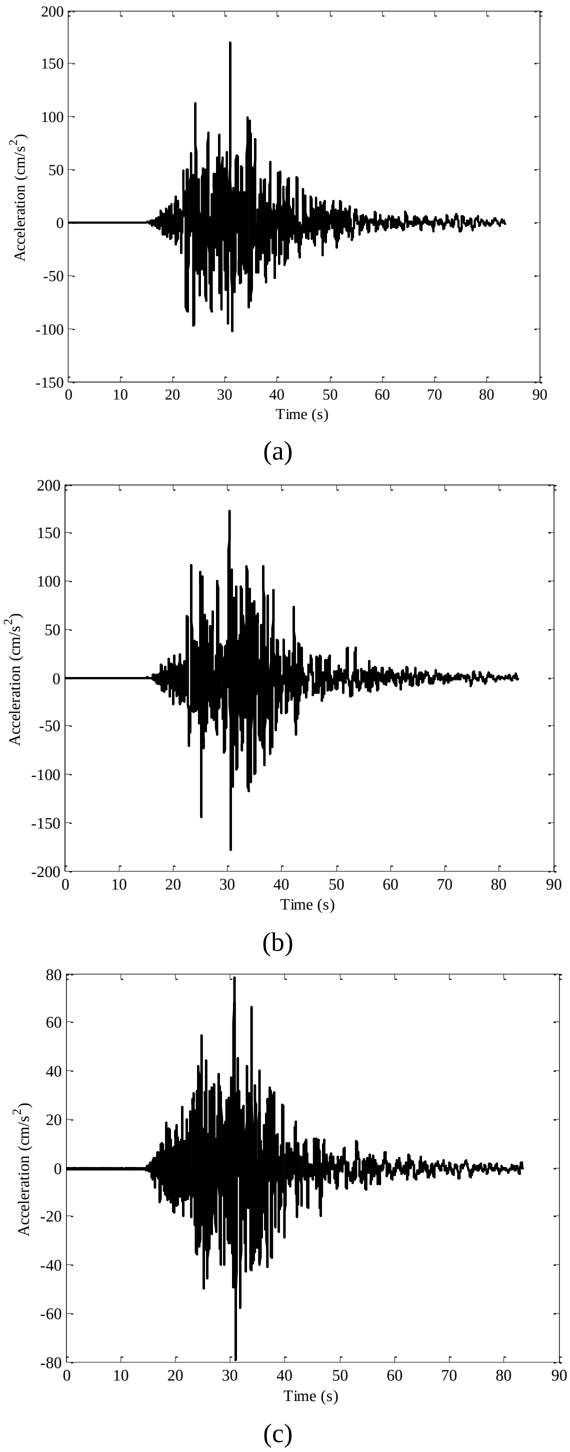
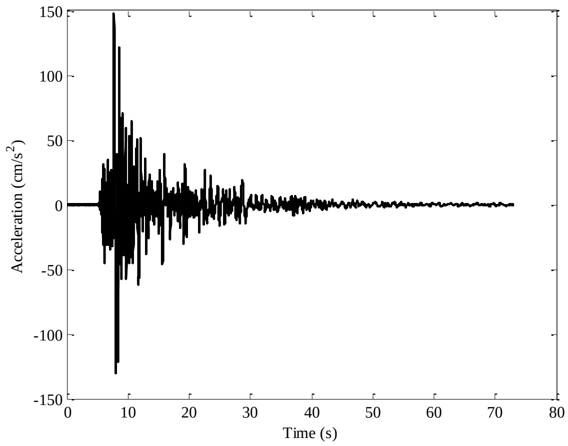
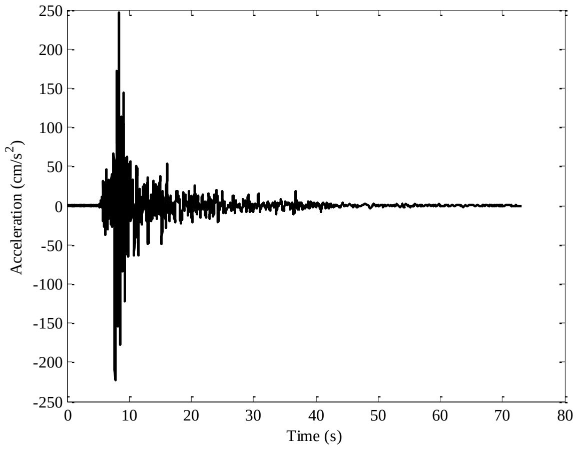


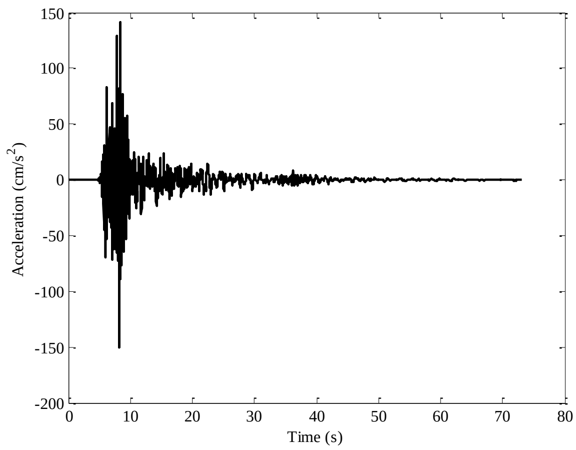
Fig. 3 Records of acceleration of October 23, 2011 Van earthquake obtained from the Muradiye station (a) N-S component, (b) E-W component and (c) U-D component



(a)



(b)

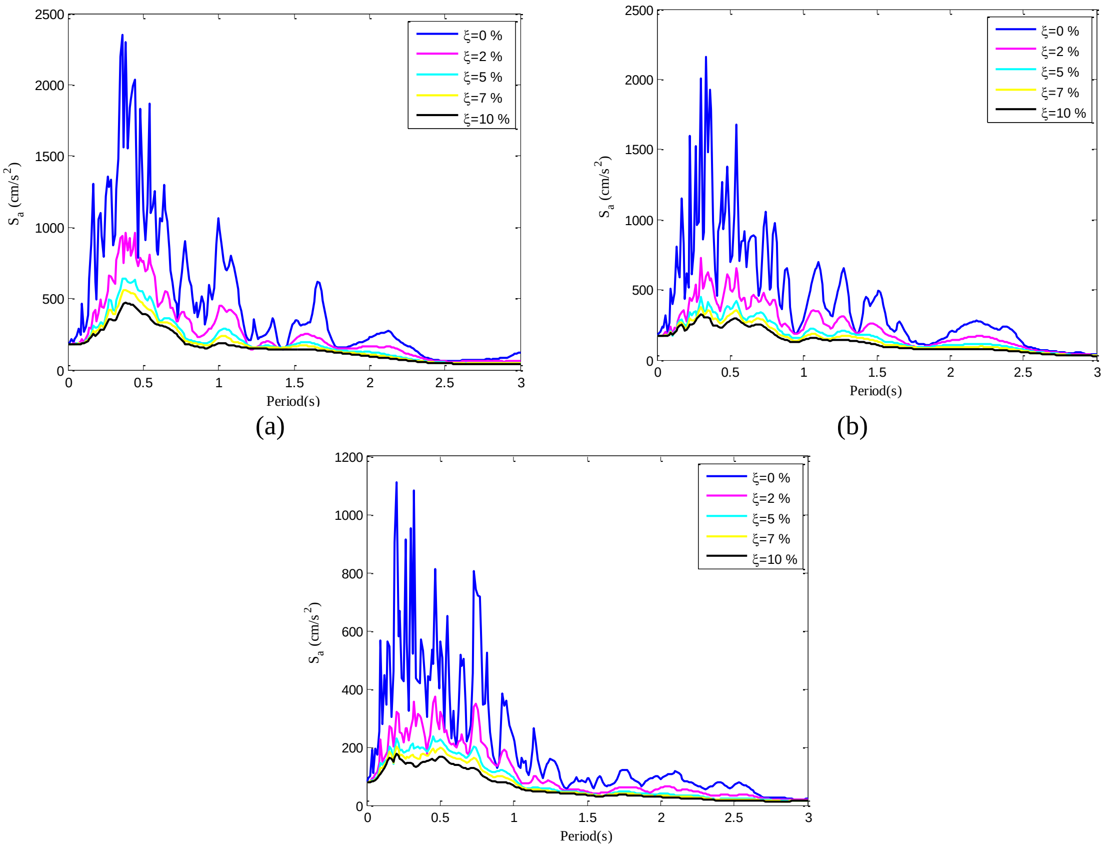


(c)

Fig. 4 Records of acceleration of November 9, 2011 Edremit earthquake obtained from the Van station (a) N-S component, (b) E-W component and (c) U-D component

The acceleration response spectra were calculated for ξ=0, 2, 5, 7 and 10% damping ratios using the each component of ground accelerations recorded at the Muradiye and Van stations (Figs. 5-6). According to Turkish Seismic Code (TSC), design damping ratio has been taken as 5% for R/C buildings (TSC 2007). In case damping ratio of 5%, according to these figures, the spectral amplification ratios are 3.64, 2.73 and 3.0 for the N-S, the E-W and the U-D components, respectively, for October 23, 2011 Van earthquake. For November 9, 2011 Edremit earthquake, these values change as 2.96, 3.18 and 3.71, respectively.

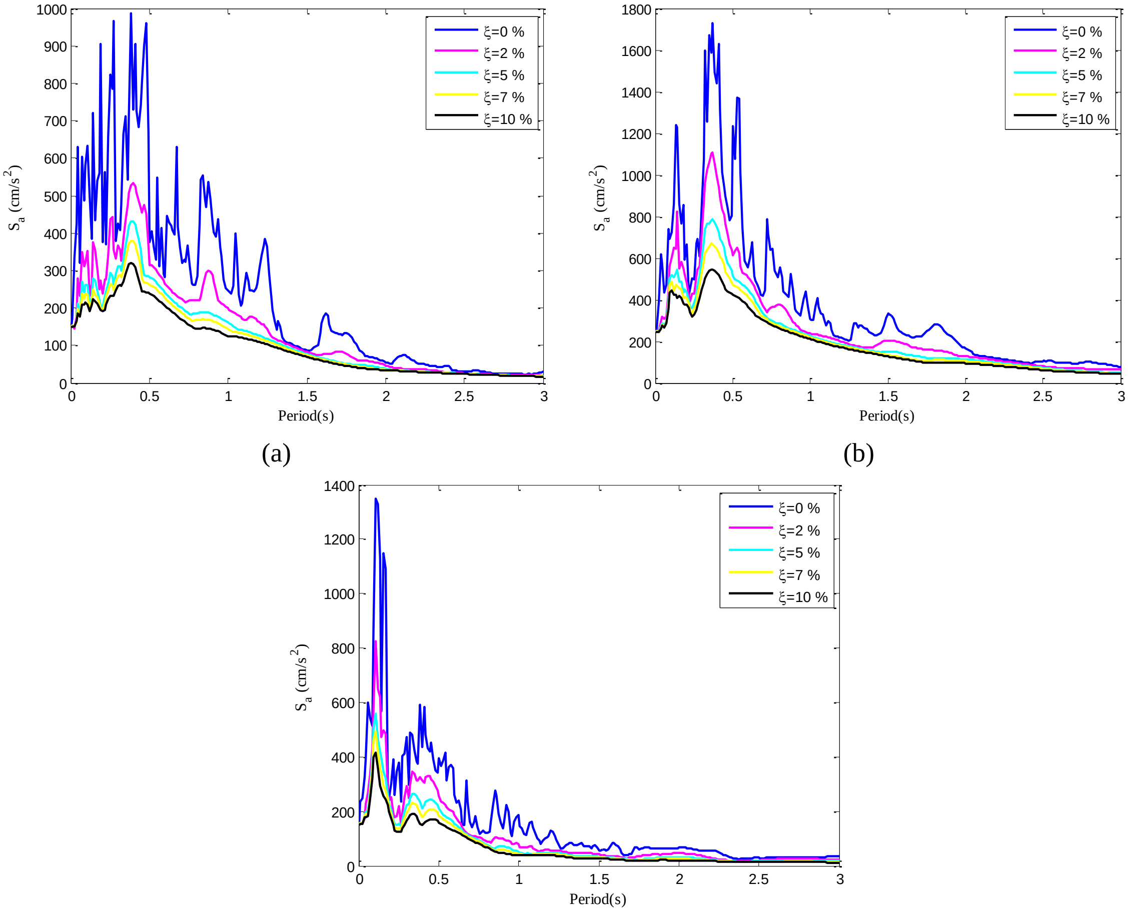
Figs. 7, 9 show the acceleration response spectra of N-S and E-W components for two earthquakes in case damping ratio of 5% and the design spectra of the TSC for all soil classes. Also, normalized spectral curves according to the maximum acceleration are illustrated in Figs. 8, 10 where peak ground acceleration shown as PGA. In these Figures, local soil classes are represented with Z1, Z2, Z3 and Z4. In these soil classes, stiffness of the soil decrease from Z1 to Z4. For the first seismic zone, design spectra which determined in the TSC are larger than the response spectra of earthquake records as seen in Figs. 7, 9. However, the amplification factors in the two normalized spectrum curves of the earthquake records exceed 2.5 which is design code limit (Figs. 8, 10).



(a) (b)

(c)

Fig. 5 Acceleration response spectra for N-S, E-W and U-D components obtained from Muradiye station (a) N-S component, (b) E-W component and (c) U-D component



(a) (b)

(c)

Fig. 6 Acceleration response spectra for N-S, E-W and U-D components obtained from Van station. (a) N-S component, (b) E-W component and (c) U-D component

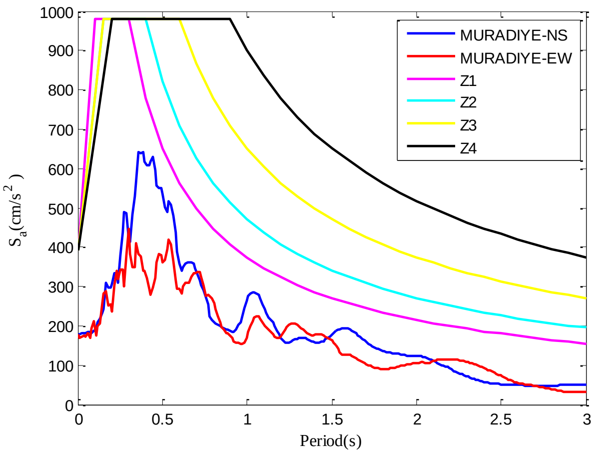


Fig. 7 Comparison of design and response (October 23, 2011 earthquake) spectrums

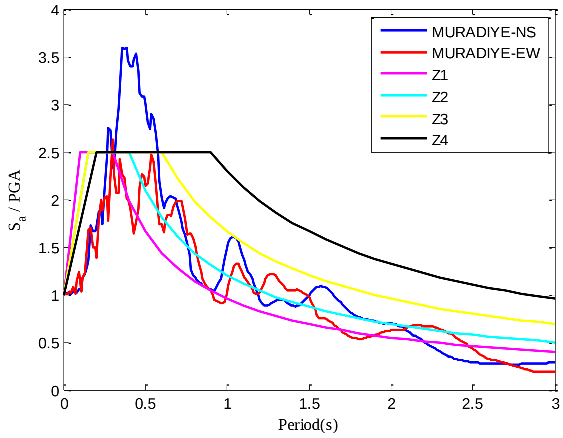


Fig. 8 Comparison of the normalized design and response (October 23, 2011 earthquake) spectrums

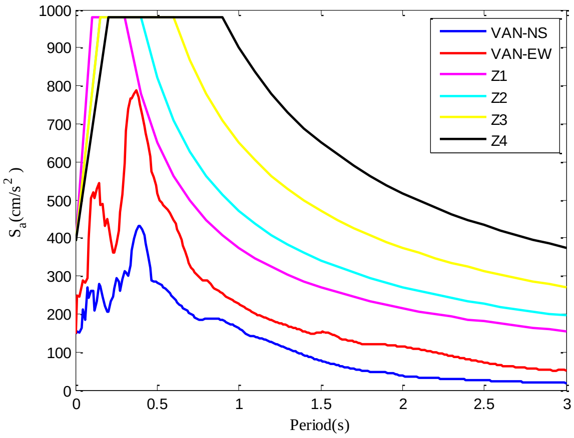


Fig. 9 Comparison of design and response (November 9, 2011 earthquake) spectrums

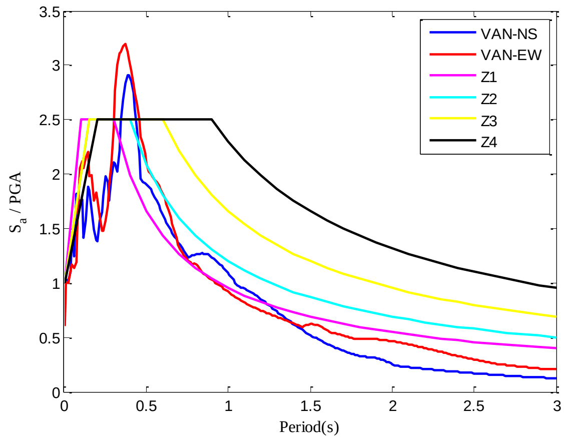


Fig. 10 Comparison of the normalized design and response (November 9, 2011 earthquake) spectrums

Although the response spectra of the earthquakes are under the design spectra, life loses and the structural damages and collapses are larger than expected result. This situation is the evidence of deficiencies of structural stock in the region.

3. Failures of R/C buildings

Van and vicinity have been located depression area and enclosed with volcanic mountains. Elevation of the city is 1720 m above on the eastern coast of Lake Van and it is located on lake deposits of sand and organic soil layers (Gülkan *et al.* 1978). Van city centre and around is generally consists of R/C buildings with brick infill walls. These buildings which generally have 4-7 stories are concentrated in these settlements. Many R/C buildings damaged seriously due to various engineering mistakes and structural deficiencies such as, soft story, short columns, low workmanship and quality of materials, structural irregularities and strong beams-weak columns. In order to prevent possible earthquake damages for future engineering applications, reasons of damages were investigated in reinforced concrete buildings at Van and Erciş settlements and are presented below.

3.1 Soft and weak storey mechanism

In some R/C buildings, especially at the ground floor, walls may not be continuous along to height of building for architectural, functional and commercial reasons. While ground floor generally encloses with glass window instead of brick infill walls, partition walls are constructed above from this storey for separating rooms for the residential usage. If partition walls are not constructed at the ground floor, more heavy and stiff upper floors forced large inelastic displacement at ground floor level. Also in these buildings, the storey height of the ground floor which has not separating walls is approximately 40-50 % more than the upper stories. This situation causes brittle failures at end of the columns. In mid-rise reinforced concrete buildings, the most common failure mode is soft-storey mechanism, particularly at the first storey, in Turkey. Fig. 11 shows total and partial collapses which arisen from soft storey mechanism at various reinforced concrete buildings. In these buildings, soft-storey mechanism occurred at the ground floor due to no special attention is paid to the code requirements. These wrong applications caused brittle collapse at columns in which no plastic hinges developed at the end of columns. In order to prevent this kind of failures, amount of structural walls which limit lateral displacement and/or cross section of columns should be increased.

Also, some soft storey buildings includes mezzanine. These mezzanines, depending on earthquake motion, cause damages at columns especially if there is no inadequate gap between column and mezzanine. Such a damage type is seen in Fig. 12.

Failures can be concentrated at any story as called weak storey in which the lateral strength changes suddenly between adjacent stories due to lack of or remove of partition walls or decreasing of cross section of columns. Thus, during an earthquake partial and total collapses occur in these storeys. To prevent this kind of collapse and failures TSC requires that, in R/C buildings, the case where in each of the orthogonal earthquake directions, the ratio of the effective shear area of any storey to the effective shear area of the storey immediately above, should not be less than 0.80. But it was seen that these requires had not been considered in some buildings. Fig. 13 shows the effect of weak-storey at various R/C buildings.

Fig. 11 Soft storey mechanism at various reinforced concrete buildings

Fig. 12 Damage at a column due to mezzanine

Fig. 13 Weak storey mechanism at various R/C buildings

Fig. 14 Inadequate transverse reinforcement, improper hooks and smooth bars

3.2 Inadequate transverse reinforcement in columns and beams

Shear forces increase during an earthquake especially at columns and beam-column joints.

Consequently, special attention should be paid to construction and design of beam-column joints and columns. Seismic design requires increasing of ductility of structures for performance-based design approach. But it had not been paid necessary attention to this approach when old R/C buildings constructed in Turkey. In these earthquakes, our observations showed that, especially columns of buildings had insufficient transverse reinforcement in the plastic hinge region. Therefore, structural elements which have such details shown low performance against to dynamic loads and lost their shear and axial load carrying capacity. It was seen that, spacing ties in the columns were approximately 20-40 cm. The wide spacing of the between transverse reinforcement caused buckling of longitudinal rebar, spalling off concrete cover and shear failures. But, according to TSC the maximum tie spacing should not be exceed 10 cm in plastic hinge region for columns of R/C buildings in all seismic zones. Also, special seismic cross ties and hooks should be bended 135^o in all seismic zones. But, transverse and longitudinal bars of columns and beams at damaged buildings were smooth and hooks of ties had been bended 90^o. In the observed buildings, it was seen that, necessary care was not given to designing of longitudinal reinforcement bars and sufficient amount of transverse bars were not used in the columns and beams. Fig. 14 shows damaged structural elements of buildings due to inadequate transverse reinforcement, improper hooks and smooth bars.

3.3 Beam-column joints

The structural performance of buildings completely changes due to improper design of beam-column joints during an earthquake. The joints must be remained in elastic region and there are not to be serious failures after an earthquake. These joints are very important distribution of force and moment. Shear and bond mechanisms are common failure of these joints. In Van earthquakes many R/C buildings heavily damaged or collapsed since failures of these joints. It was seen that poor detailing at joints of beam-column and poor quality of materials with low workmanship were the main reasons of these failures. Also lack of transverse and seismic cross ties, and inadequate anchorage bars of beam and column in reinforced concrete elements lead to joint failure. Fig. 15 shows various beam-column joints failures. In this figure, it is seen that beam-column joint have insufficient confinement and shear reinforcement at the joint.

Fig. 15 Joint failures at various reinforced concrete buildings

Fig. 15 Continued

To prevent failure of the joints, sufficient confinement and shear reinforcement must be used and paid special care designing of these joints.

3.4 Short columns

Due to structural adjustments and/or to continuous openings at the top of infill walls between columns, short columns may be developed. Lateral forces which occurred by an earthquake are received by columns and shear walls. Length of column is an important factor at dissipation of these loads. When the length of column decreases, the column becomes stiffer and brittle than the other columns and this column attracts more shear forces. Thus, shear failure which is a critical type of concrete column damage occurs at these columns. However, TSC requires certain requirements for confinement of longitudinal reinforcement for short columns. According to the code, transverse reinforcement requirements, used in column confinement zones (wide spacing should not exceed 10 cm), should be applied at these columns. It was seen that any requirement which determined in TSC was not applied and thus, many R/C buildings damaged due to the short column effect during the earthquakes. Fig. 16 shows short column failures at various buildings.

Fig.16 Short column damages at various buildings

3.5 Inadequate gaps between adjacent buildings

Buildings are generally constructed adjacent in city centre in Turkey because of the lack of building lots. In this layout plan, two faces of two buildings are contact to each other. Consequently, the buildings which have not adequate gaps pound to each other during the earthquake. If the floors of the buildings are not at the same level, hitting of the buildings becomes more dangerous because floor of the building hit the other building's column. To prevent this damage, TSC requires gap between the adjacent buildings. According to the code, minimum size of gaps should be 30 mm up to 6 m height and from thereon a minimum 10 mm should be added for each 3 m height increment. Unless a more unfavourable value is obtained in accordance with requirement defined in previous statement, sizes of gaps should not be less than the sum of the absolute values of average storey displacements multiplied by the coefficient α. If adjacent buildings' floor levels at all stories are same then $\alpha=R/4$ else then $\alpha=R/2$. In these equations, factor of the structural behaviour is shown by R. Damaged buildings due to inadequate gap are given in Fig. 17.

Fig. 17 Inadequate gap between adjacent buildings and damages

3.6 Strong beam-weak column

In Turkey especially many old R/C buildings were constructed with strong beam and weak column before the development of current seismic codes. In these buildings, deep and rigid beams were used with flexible columns. Therefore, these beams resist more moments, occurred by dynamic loads, than weak columns. In such a design during an earthquake while deep and rigid beams show elastic behaviour, shear failure or compression crushing cause plastic hinges at flexible columns. Design of strong beam-weak column was the main reason of the partial and total collapse during the Van earthquakes. Fig. 18 shows collapsed buildings in one direction where column’s depths are considerably small according to depth of beams. To prevent this kind of damages or collapses which arisen from strong beam-weak column, TSC requires that sum of ultimate moment of columns framing into a beam-column joint should be at least 20% more than the sum of ultimate moment of beams framing into the same joint. Thus, plastic hinges occur ends of the beam and brittle failure prevents. But this situation had not been seen at observed buildings which collapsed totally. Also, it was determined that, these buildings had not shear wall, thus all of lateral forces had been provided weak columns.

Fig. 18 Total collapses at various buildings due to strong beam-weak column

Fig. 19 Out-of-plane failures of gable walls at various buildings

3.7 Failures of gable walls

The most common failure mode at gable walls is out-of-plane collapse in the earthquakes.

Although failures of gable walls are not structural damages, these damages may be cause loss of lives and properties. Stability problems and large unsupported wall lengths cause damages at these walls. It was determined that poor wall to wall and wall to floor connections, and absence of lateral supporting walls were main reasons of these damages. To prevent these kinds of damages, TSC requires that if height of masonry gable walls exceeds 2 m reinforced concrete vertical and inclined tie beams should be used. Gable walls of investigated buildings were not built according to the current seismic codes. In these walls had not got any vertical or inclined reinforced concrete tie beams. Out-of-plane failures of gable walls of various reinforced concrete buildings in the region are illustrated in Fig. 19.

3.8 Poor concrete quality and corrosion

Our field observation showed that the other main reasons of damages were low concrete strength and workmanship. Concrete quality is an important factor for building performance against to earthquake. In Turkey, using of ready mix concrete became common after 1999 Kocaeli earthquake. Before this earthquake handmade concrete was generally used without using

Fig. 20 Poor quality concrete at various buildings

vibrator. Due to this wrong application, homogeny mixing was not obtained and expected compressive strength was not provided. The TSC requires that compressive strength of concrete should be minimum 20 Mpa in all buildings to be constructed in all seismic zones. But it was seen that, strength of concrete was very low at observed buildings. Fig. 20 shows poor quality of concrete in various buildings that existed earthquake area.

Using of aggregates which have improper granulometry, corrosion which decreases reinforcement bar area and using of smooth steel reinforcement effected strength of concrete. Also it was seen that at many buildings concrete cover was very thin for preventing reinforcement to corrosion. Fig. 21 illustrates these mistakes at columns of different buildings.

Fig. 21 Corrosion, smooth reinforcement and improper granulometry at columns of different buildings

3.9 Damages of infill walls

In Turkey, infill walls of R/C buildings have been constructed by using unreinforced brick masonry and cement mortar. In the earthquake area brick masonry exterior infill walls had been generally constructed two layers due to sound and heat isolation while interior infill walls had been built with one layer. But, it was seen that the layers of the exterior walls behave separately from each other since layers are poorly connected to each other and frames. Thus, these exterior walls suffered from out of failure mechanism. However, damage levels of these walls increased due to heavy and large overhangs in which the cantilever length may be reach generally 1-1.5 m. Fig. 22 shows these type damages in the earthquake region. To prevent this kind of failures it must be avoided from this wrong application in seismic regions.

Shear damages are seen as common failure mechanism in infill walls which are constructed between frames. These walls contribute to lateral resistance of buildings significantly. During an earthquake diagonal cracks (X-shape) which originate at the corners of openings occur in plane of infill walls since unreinforced brick masonry walls have lower deformation capacities than the R/C structural elements. Fig. 23 shows in plane failures at various buildings.

Fig. 22 Damages of exterior walls

Fig. 23 In plane failure mechanism in infill walls at some R/C buildings

4. Conclusions

Van earthquake which struck on October 23, 2011 is the one of the largest earthquakes in last century in Turkey. After 17 days later from this devastating natural hazard, second earthquake hit Van and vicinity again. 644 people lost their lives, more than 2000 people were injured and 17005 dwelling houses collapsed or heavily damaged after these earthquakes. In this study, reinforced concrete buildings which damaged due to Oct 23, 2011 and Now 9, 2011 Van-Turkey earthquakes were evaluated and main reasons of damages presented. According to information which obtained from field observations, seismic performances of the R/C buildings generally were poor. The main factors of damages attained from this case study are given below.

- Soft and weak storey application (large openings at the ground or intermediate floor of buildings)
- Inadequate transverse reinforcement and not bending of hooks of ties in structural elements
- Insufficient confinement and inadequate shear resistance of beam-column joints
- Short column problems
- Inadequate gaps between buildings and pounding

- Design of strong beam and weak column
- Poor connection of gable walls and high gable walls which have no tie beams
- The poor material quality (handmade concrete, insufficient concrete cover and using of improper aggregate etc.)
- Application of heavy overhangs and large cantilevers
- Insufficient connection between layers of multilayer exterior infill walls.

However, it was seen that the many R/C buildings were not built according to the main requirements of the current TSC even if very simple engineering procedures had not been applied in the earthquake region. Thus, loss of lives and heavy damages in buildings occurred in these earthquakes. In order to decrease damages of reinforced concrete buildings and to prevent human casualties, R/C buildings should be designed and constructed by take care of the requirements of the current seismic codes and provided adequate control engineering services.

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