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Engineering implications of the RC building damages after 2011 Van Earthquakes

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Abstract. Two destructive earthquakes occurred on October 23 and November 9, 2011 in Van province of Turkey. The damage in residential units shows significant deviation from the expectation of decreasing damage with increasing distance to epicenter. The most damaged settlement Ercis has the same distance to the epicenter with Muradiye, where no damage occurred while relatively less damage observed in Van having half distance. These three cities seem to have resembling soil conditions. If the damages are evaluated: joint failures and insufficient lap splice lengths are observed to be the main causes of the total collapses in RC buildings. Additionally, low concrete strength, reinforcement detailing mistakes, soft story, heavy overhang, pounding and short columns are among other damage reasons. Examples of damages due to non-structural elements are also given. Remarkable points about seismic damages are: collapsed buildings with shear-walls, heavily damaged buildings despite adequate concrete strength due to detailing mistakes, undamaged two-story adobe buildings close to totally collapsed RC ones and undamaged structural system in buildings with heavily damaged non-structural elements. On the contrary of the common belief that buildings with shear-walls are immune to total collapse among civil engineers, collapse of Gedikbulak primary school is a noteworthy example.

Keywords: Ercis; distance to epicenter; irregularity; reinforced concrete; seismic damage; shear wall; Van

1. Introduction

A destructive earthquake (M_w = 7.1) was occurred on October 23, 2011 with an epicenter near city of Van, in Turkey. The epicentral coordinates are 38.68°N, 43.47°E and the focus of the earthquake has a depth of 19 km (DEMP, 2011a). The location of the epicenter was 21.5 km to the city center of Van, 39 km to Ercis, 42 km to Muradiye and 57 km to Edremit. The earthquake was felt especially in Van and surrounding towns and villages along with the largest destruction in Ercis. According to the data supplied by Disaster and Emergency Management Presidency of Turkey (DEMP), the death toll was 604 (DEMP 2011a).

Following the October 23, 2011 earthquake, the second one (M_w = 5.6) occurred on November 9, 2011 in the same region. This earthquake can be evaluated as a moderate seismic activity in

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terms of Richter scale. In the city center of Van, it was felt more intensely compared to the first one. 40 people died according to the data given by DEMP (DEMP 2011a).

This paper aims to evaluate and report the damages after these earthquakes. Especially the damage distribution in neighboring residential units being significantly different from the expectation of decreasing damage with increasing distance to the epicenter is a noteworthy point. The gathered damage and acceleration data is compared with the assessments made by different attenuation relations. The reasons of the damages in RC (reinforced concrete) buildings are discussed and some remarkable observations are given in the paper.

2. Evaluation of the damage distribution

For the first earthquake, structural damages were observed especially in the center of Ercis and its surroundings. However, it is not possible to analyze the level of devastation separately from the second one, since it occurred soon after the first earthquake without the completion of data collection. Table 1 shows the number of collapsed or damaged structures in Van, Ercis and Edremit for both earthquakes. In the obtained data, there is no information about the total number of buildings for the earthquake region. Therefore, damage ratios of structures were found by dividing the number by population accommodating in the cities as an indicator of the total building number.

Table 1 Total number of damaged buildings in Van, Ercis and Edremit after the earthquakes of October 23, 2011 and November 9, 2011 (DEMP, 2011b)

	Collapsed-Heavy Damaged	Moderate	Population	Collapsed-Heavy Damage/Population
Van City Center	13520	9308	353419	0.0383
Ercis City Center	5158	1428	76463	0.0674
Edremit City Center	241	51	12629	0.0190

The damage data presented in Table 2 was obtained by a team from Middle East Technical University (METU), Turkey, who performed damage assessment studies in Van region after October 23, 2011 earthquake (METU 2011). Even if it is limited in terms of investigation range, the data reflect the view of devastation in Van and Ercis after only the first earthquake and hence are important. When the proportionality between the level of damage and population given in the last row of Table 2 is considered, it is clearly seen that Ercis experienced 2.5 to 25 times higher damage ratios compared to Van. This shows that Ercis was affected from the first earthquake more than Van.

Field observations and evaluation of the data given in Tables 1 and 2, show that earthquake damages was mainly concentrated in Ercis. According to the data normalized by the population, the damage in Ercis is nearly twice of Van while, it was the lowest for Edremit (Table 1). This is not an expected case when the distances to the epicenter of the earthquakes are considered. The first and second earthquakes centered about 22 and 12 km away from Van. Although Edremit is 57 km away from the first earthquake, it is just 2 km away from the second one. Even if Muradiye and Ercis are situated at a same distance (around 40 km) to the first epicenter, no reported damage occurred in Muradiye.

Table 2 Damage distributions after the field observations of the October 23, and November 9, 2011 Van earthquakes by METU team (METU, 2011a)

	Collapsed	Heavy	Moderate	Light	None	Total
Van City Center	6	9	10	38	72	135
Van City Center Ratio(%)	4.4	6.7	7.4	28.1	53.3	100.0
Ercis City Center	52	23	29	48	61	213
Ercis City Center Ratio (%)	24.4	10.8	13.6	22.5	28.6	100.0
Ercis/Van Damage Ratio (per Population)	25.63	7.45	8.49	3.70	2.48	

According to the evaluation of data given in Table 2, it is obvious that first earthquake largely affected Ercis instead of Van and Muradiye which are located at a half and the same distance to the center, respectively. The second one was very effective in Van, 12 km away from the center, instead of Edremit, 2 km away from the center. In earthquakes of October 23 and November 9, 2011, results seem to be opposite of what was anticipated, when the general expectation of "the effects of an earthquake decrease with distance to the epicenter" is considered. Therefore, presence of such seismic activities should be reported in literature.

Building damage data for the whole region are tabulated in Table 3. In general, it is expected that the ratio of the damage decreases with increasing level of the damage. Hence, the ratio of the heavily damaged buildings may be less than moderately damaged ones. Such a situation was observed after 1999 Kocaeli and Duzce earthquakes. However, Table 3 shows that the ratio of severely damaged or collapsed buildings is 3 times higher than that of moderately damaged buildings after 2011 Van Earthquakes. Meanwhile, slightly damaged buildings are high in number, 4.71 times more, compared to moderately damaged buildings. This means that the buildings were either slightly damaged or severely damaged/collapsed. This condition indicates the presence of a building profile with low ductility and potential to get heavy damage readily after being affected from an earthquake. Many examples of insufficient rebar development length and high number of joint damages in the region can be considered in compliance with this condition. Detailed information about the damages occurred in the region is given in later sections.

3. Properties of ground motions and soil conditions

October 23, 2011 Van Earthquake (M_w 7.1) was recorded by 22 stations of National Strong Motion Monitoring/Measuring Network. The maximum ground accelerations belonging to the first and second earthquakes were measured to be 178.50 cm/s^2 in north-south direction in Muradiye

Table 3 Results and comparison of damage assessment studies after 2011 Van Earthquakes and 1999 Kocaeli and Duzce Earthquakes (DEMP 2011b, TGNA 2010, Sahin and Tari 2000)

	Collapsed/ Heavy	Moderate	Light	Total
October 23 and November 9, 2011 Van Earthquakes Damage Data	50599	15334	72257	138190
October 23 and November 9, 2011 Van Earthquakes Damage Ratios (%)	36.64	11.10	52.29	100.00
August17, 1999 Kocaeli Earthquake Damage Data	112735	124131	128039	364905
August17, 1999 Kocaeli Earthquake Damage Ratios (%)	30.89	34.01	35.09	100.00
November 12, 1999 Duzce Earthquake	66403	66863	79630	212896
November 12, 1999 Duzce Earthquake Damage Ratios (%)	31.20	31.40	37.40	100.00

Table 4 Peak ground acceleration values of October 23, and November 9, 2011 Van Earthquakes obtained from stations (DEMP 2011c)

		October 23, 2011 Van Earthquake			November 9, 2011 Van Earthquake		
Province	Town	N-S (gal)	E-W (gal)	Distance (km)	N-S (gal)	E-W (gal)	Distance (km)
Van	Muradiye	178.50	168.50	42	13.00	9.50	74
Van	Center	-	-	22	148.10	245.90	12
Van	Edremit	-	-	57	65.70	102.60	2
Mus	Malazgirt	44.50	56.00	95	3.00	4.00	101
Bitlis	Center	89.66	102.24	116	3.90	5.80	97
Agri	Center	18.45	15.08	121	-	-	-
Siirt	Center	9.90	9.16	158	-	-	-
Mus	Center	10.30	6.86	170	-	-	-
Bingol	Solhan	4.58	4.19	211	-	-	-
Bingol	Karlıova	7.52	11.08	222	-	-	-
Batman	Center	8.29	8.58	223	-		-
Mardin	Center	2.00	1.90	284	-	-	-

and 245 cm/s^2 in Van, respectively (DEMP 2011c). Since, there is no information record of Van during the first earthquake; comparison with the second one is not possible. It should be remembered that no damage was reported in Muradiye where the acceleration information for the first earthquake is given. Much higher values were probably experienced in Ercis, where the damages concentrated. Table 4 gives information about the recorded peak ground accelerations at the stations for both earthquakes.

The damage observed in Van, Ercis and Muradiye being unrelated with distance was also discussed in public opinion. The idea that ground properties of Ercis increases the effects of earthquake was verbalized frequently (CAT 2011, CGET 2011, Ozden *et al*. 2011). Although Muradiye and Ercis, which are at the same distance to the epicenter, have similar soil properties, as seen from Fig. 1, the earthquake was felt slightly in Muradiye. Similarly, Fig. 1 (GDMRE 2002) and previous studies (Uner *et al*. 2010) show that Van and Ercis also have resembling soil properties.

Some of the published documents also mention about the unfavorable soil conditions in Van in terms of seismic actions (CGE 2011, METU 2011b). The damage in Van city being less than the damage in Ercis for the first earthquake, even though Van has half distance to the epicenter, gives rise to the thought that not only the soil conditions in Ercis is effective for the devastation. The second earthquake had led to destruction mainly in Van. If it had not occurred, the negative effects of the soil conditions in Van may not be discussed at this extent, like the less/none emphasize of the soil conditions in Muradiye, where no damages reported.

The geometric pattern of the surface deformations and micro-morphology obtained, point out that the mechanism of the faulting for the first earthquake, was reverse (thrust) faulting mechanism and the plane of the fault inclined to the North (GDMRE 2011) (see Fig. 2). The length of the main surface rupture was found to be approximately 8 km and the northern block (hanging wall) overlapped the southern block (foot wall) along the main surface rupture (Dogan and Karakas 2012). The maximum thrust offset and the maximum left lateral offset were defined 0.15 m and 0.09 m respectively during the field observations (Dogan and Karakas 2012). Another source, with the measurements performed along 10 km west side fault line, showed that north (hanging wall) block found to be risen nearly 0.10 m (GDMRE 2011).

Authors consider that such damage distribution could be related with the properties of the ground motion and the geological structure of the region. The city center of Ercis and Gedikbulak

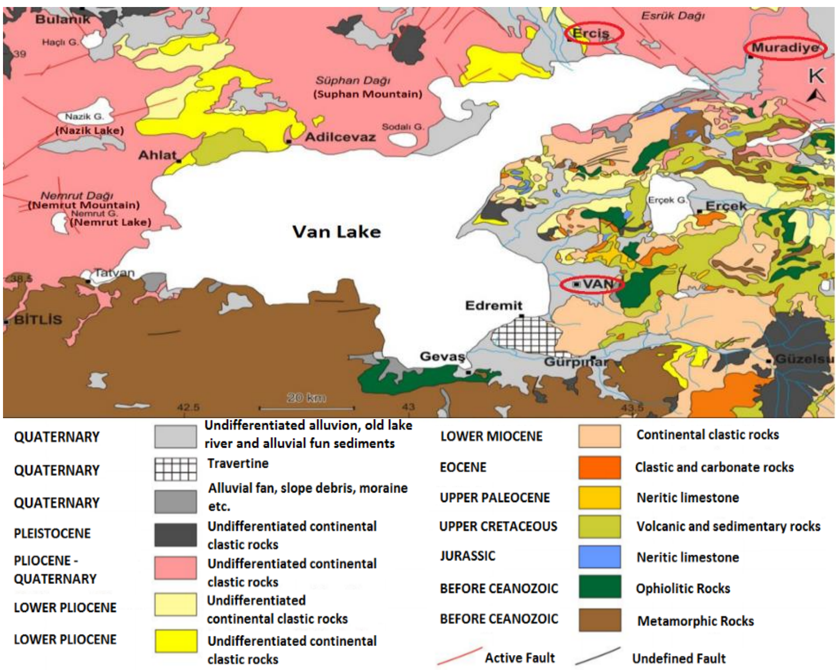


Fig. 1 Soil properties of Van area (GDMRE 2002)

District, where the damage is mainly concentrated, are located in the direction of the hanging wall of the fault. In fact, the observed damages are mainly concentrated around the hanging wall of the fault. The locations of the faults yielding the earthquakes in question are given in Fig. 2.

One important point to be emphasized is that parameters like geological structure, fracture of the fault, distance of the residential units to the epicenter and the characteristics of the over ground structures are strongly effective on the level of the damages of an earthquake.

It is considered that the reason why the second earthquake (November 9, 2011, M_w 5.6) was felt more intensely than the first one may be related with the fault mechanism and the location of the Van city center. In contrast to the first earthquake, the second earthquake was the result of an oblique type normal fault with N-S direction, inclined towards Lake Van, and known to be a part of the Van Fault Zone passing through Van City Center (Kocyigit *et al.* 2011).

The record of the first earthquake obtained from Muradiye on October 23, 2011 and that obtained from Van on November 9, 2011 are given in Fig. 3 and Fig. 4, respectively. Although it is concluded that the effects of earthquake do not fit the assumption of the acceleration attenuation with the distance from the epicenter of the earthquake, it may be interesting to see the correspondence between recorded accelerations and attenuation relations. Fig. 5 and Fig. 6 demonstrate the variation of the acceleration data and predictions on acceleration-distance relations made by attenuation relations of two local (Kalkan and Gulkan 2004, Ulusay *et al.* 2004) and two global (Boore *et al.* 1993, Campbell 1997) for both earthquakes. As there is not sufficient data recorded from the close stations to the epicenter, it is not possible to decide which attenuation relation best fits the acceleration values. Based on the average values of the attenuation relations applied for the first earthquake, it is expected to have a ground acceleration value of 0.17 g for Muradiye, 0.18 g for Ercis and value of 0.25 g for Van.

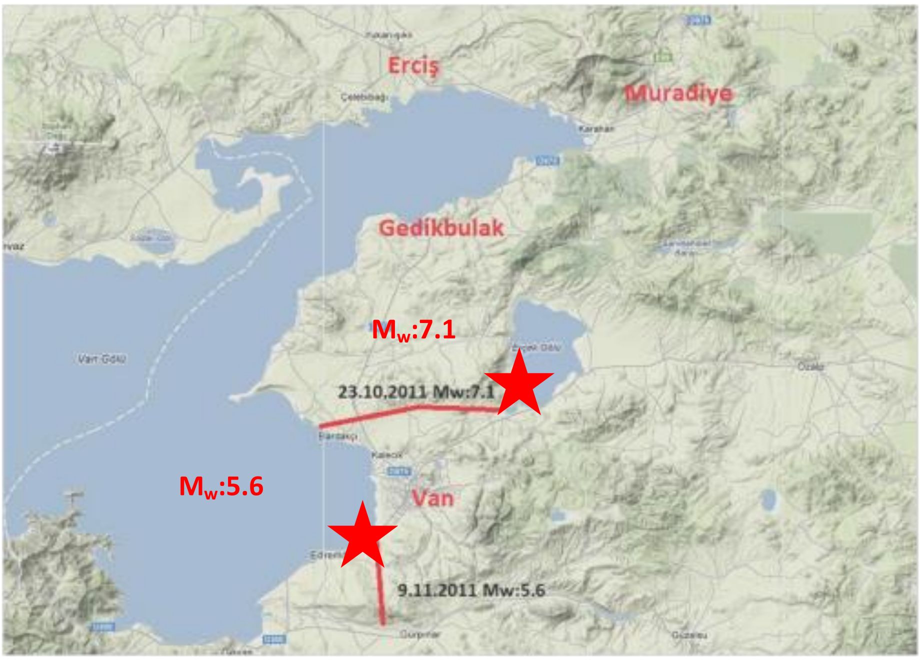


Fig. 2 The fault and epicenters yielding October 23 and November 9, 2011 Van Earthquakes (GDMRE 2011)

For the second earthquake, the values were predicted as 0.39g for Edremit, which is located very close to the epicenter and 0.18g for Van. Since there is not sufficient number of stations close to the epicenter of the earthquakes, the accelerations could not be evaluated clearly. On the other hand, the damages during both earthquakes and the recorded acceleration values in the Edremit (103 *gal*) and Van (246 *gal*) stations for the second one give significantly different results.

It is notable that Ercis (far from epicenter but heavily damaged in the first earthquake) and Van (close to the epicenter but slightly damaged in the first earthquake) are located at the different sides of the fault segment. Similarly, Edremit (very close to the epicenter but slightly damaged in the second earthquake) and Van (far from epicenter but heavily damaged in the second earthquake) are also located at the different sides of the fault segment. Even though, the stiff soil conditions in Edremit may be attributable as a factor for the lower damage, the case is different for the first earthquake (see Fig. 1).

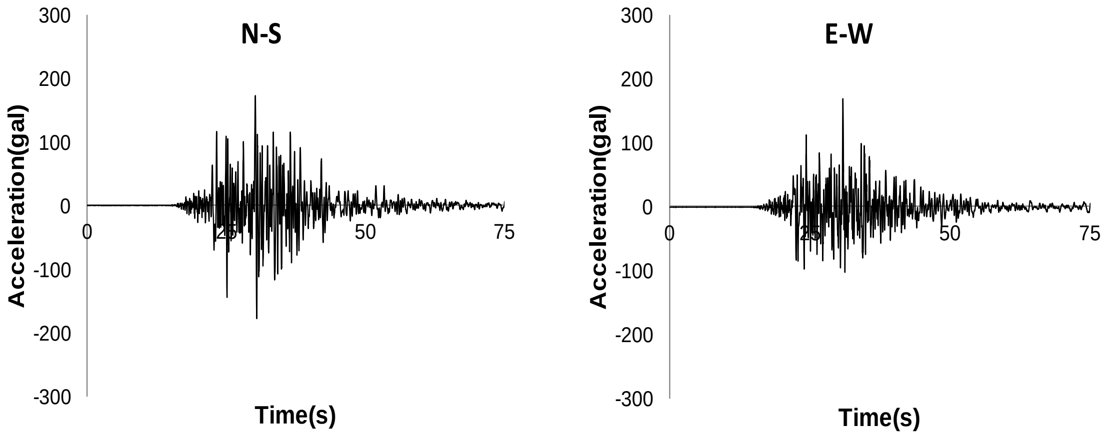


Fig. 3 October 23, 2011 Van Earthquake Muradiye station records

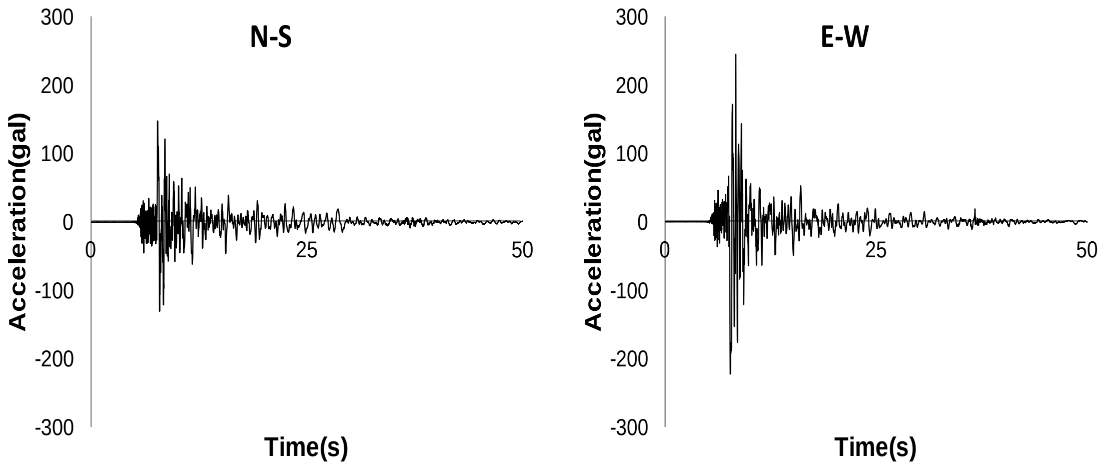


Fig. 4 November 9, 2011 Van Earthquake Van station records

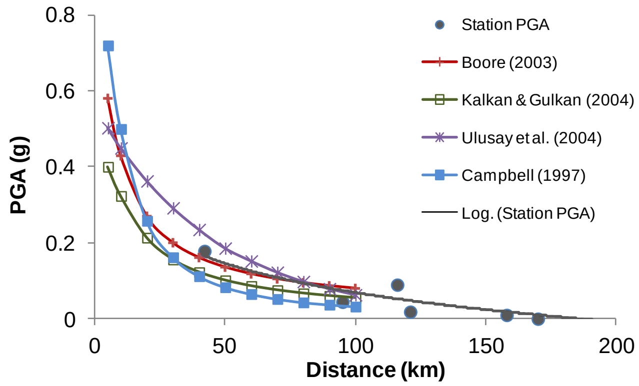


Fig. 5 Variation of the acceleration data and predictions on acceleration-distance relations, made by attenuation relations for October 23, 2011 Van earthquake

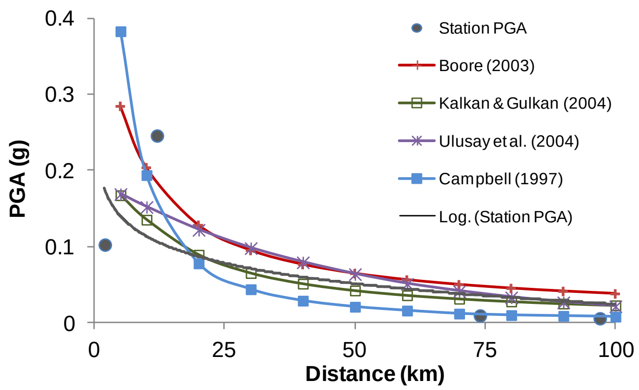


Fig. 6 Variation of the acceleration data and predictions on acceleration-distance relations, made by attenuation relations for November 9, 2011 Van earthquake

Earthquakes occur as a result of the motion of the two sides of the fault relative to each other. The damages after especially the firs earthquake suggest the probability of one of the two plates displacing much more than the other and/or presence of a discontinuity in geological structure that prevents the transmission of seismic waves, such that acceleration values differ significantly. One of the aims of this paper is to draw attention of researchers so that the subject is examined in more detail. By investigating Van Earthquakes, some progresses may be achieved about the dynamics of the ground motion.

The comparison of the design spectrums for the region and 5% damped spectral acceleration spectrums for 23th October and 9th November earthquakes are given in Fig. 7 for Muradiye and Van stations, where the highest values recorded. As Muradiye is in the highest seismic zone of Turkey with 0.4g as ground acceleration, and Van city is in the second zone with 0.3g as ground acceleration; the design spectrums are given correspondingly. Please note that the Muradiye record is not taken where the most damages occurred. The spectral accelerations for Van E-W record exceeds the values given in design spectrum for a small period range of 0.34-0.44s. Except this region, the experienced accelerations are significantly below the design values for corresponding locations.

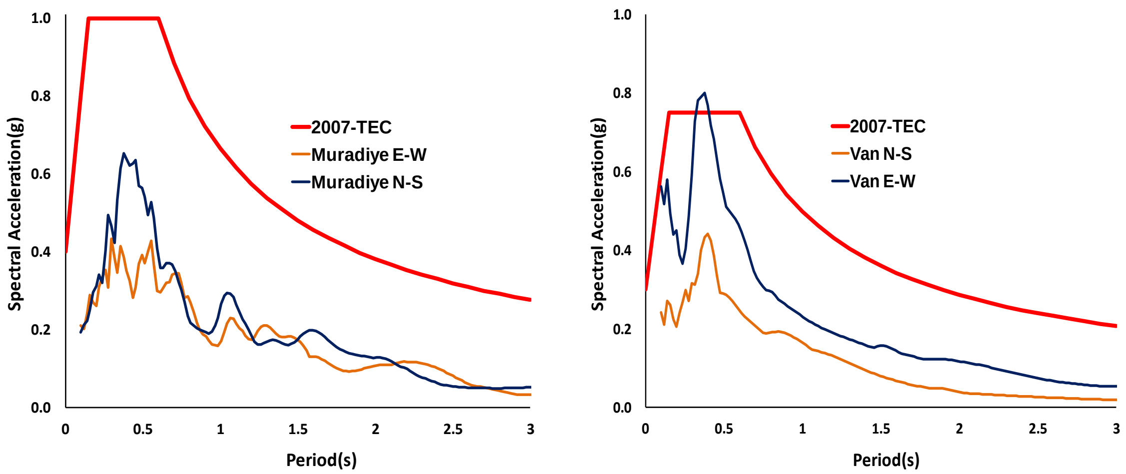


Fig. 7 Acceleration spectrums for %5 damping for the October 23, and November 9, 2011 Van Earthquakes and design spectrums for the region

4. The reasons of the damages

In this section, examples on the building damages are given and the reasons behind those damages are discussed. The area where the damages of the earthquake were focused was Ercis and its neighborhood. In Ercis, many buildings were totally collapsed resulting increase in the death toll. Based on the examinations and field surveys performed in Van-City Center, Ercis-City Center and Gedikbulak Village, the following evaluations about the types and reasons of the damages were made.

4.1 Damages related to improper detailing

Failures in the joint regions are one of the most frequently observed types of damages. These types of damages are considered as one of the main reasons causing collapses in the structures. Structures with damaged joint regions become unstable quickly and collapse without significant resistance to the earthquake forces. According to design principles, joint regions are the points which should not be damaged. In a properly designed building, beams are the location of initial damages consuming significant amount of energy by ductile behavior. Unfortunately, in Turkey, joint regions are one of the parts where mistakes related to lateral reinforcement detailing are often made (Celebi *et al.* 2012). In the region, common application faults are discontinuity of lateral column reinforcements in the column-beam joint regions, insufficient lap splice length of the longitudinal reinforcements and improper termination of the longitudinal reinforcements in the beams at the joints (Erdik *et al.* 2012) (see Fig. 8(a)).

The investigation conducted in the region showed that in the buildings with heavily damaged joint regions, the columns and beams separated from the system without resisting the forces imposed by the earthquake. This rapid destabilization of buildings ended up sudden collapse of the structure (see Fig. 8(b)).

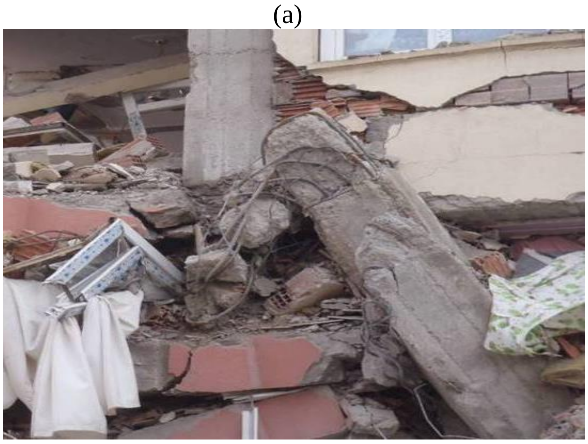
Debonding in many longitudinal reinforcements of the structural elements was observed as a result of the insufficient lap splice length (see Fig.8(c), (d) and Fig. 9(a)). In Fig. 8(d), the damage on the shear wall clearly demonstrates the poor quality of the detailing. In cases, where shear walls are damaged in this manner, it is difficult to consider that the building could survive from an earthquake (Celebi *et al.* 2012).

As stated above, improper detailing of the joint regions may cause serious problems (see Fig. 8 (b), 9(b)). It should be noted that the cost of the proper reinforcement detailing is not much compared to the overall construction cost. For that reason, it is assumed that, these defects are not results of economic considerations but instead lack of proper engineering service.

Short column formation, formed by ribbon window, was observed in many buildings (see Fig. 9(c)). In fact, short column damage does not form only due to ribbon windows, which decreases the clear length. In some cases, short column behavior can be seen as a result of the infill wall behavior. Deformation of the RC system under seismic effects may end up partial collapses of the infill walls. Similar to ribbon window, partial collapse of infill wall occurring at the edges of the column decreases the overall length of the column and may result in severe short column damages (see Fig. 9(d)). Such types of damages were also encountered in the other earthquakes in Turkey (Inel *et al.* 2013).

(a)

(b)



(c)

(d)

Fig. 8 (a) Joint damage, (b) totally collapsed building with heavily damaged joints, (c) joint damage and (d) disintegrated shear wall with debonded longitudinal reinforcement

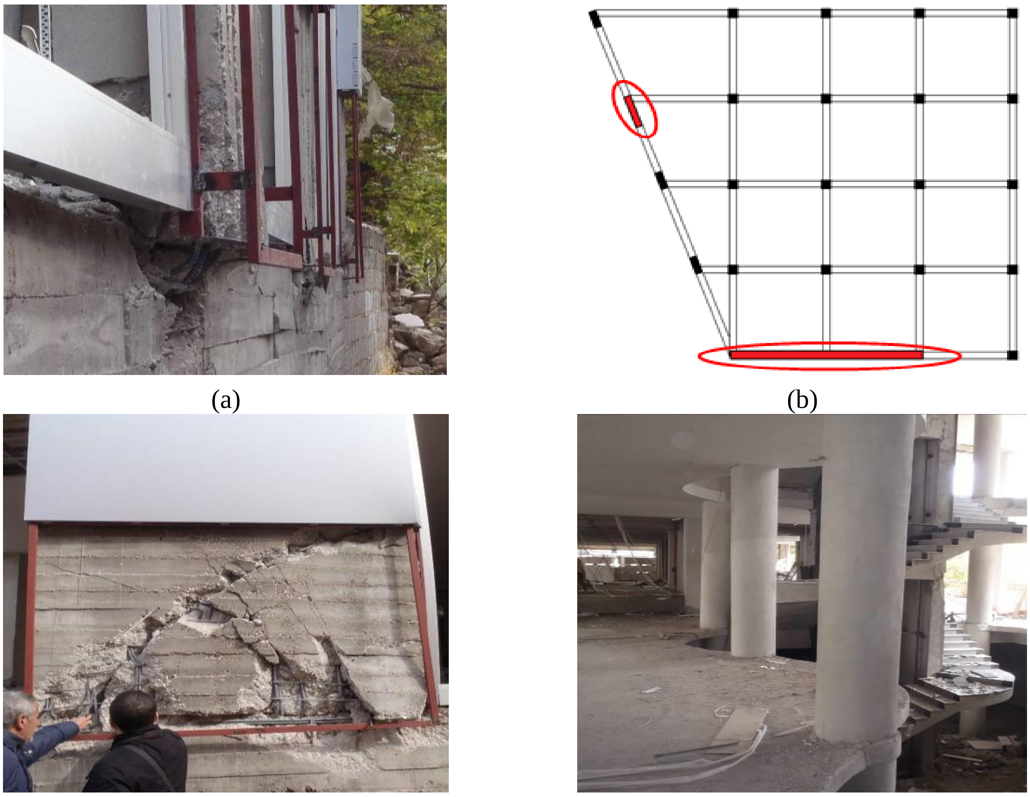
(a) (b)

(c) (d)

Fig. 9 (a) debonding of beam longitudinal reinforcement due to insufficient lap splice length, (b) deficient joint construction, (c) column damaged due to ribbon window and (d) short column damage due to disintegration of infill wall

(a) (b)

Fig. 10 (a) Building with collapsed ground floor due to soft story and (b) pan cake collapse toward the weak axis of RC building having overhang without beams connecting columns



(a) (b)

(c) (d)

Fig. 11 (a) RC columns damaged and displaced out of the building due to unsymmetrical shear walls, b) building plan with unsymmetrical shear walls, (c) RC shear wall with heavy shear damage due to deficient changes of the design project and (d) undamaged circular columns after earthquake

4.2 Damages due to deficient design of the load bearing system

Soft storey is a common problem in many buildings where the basement is used for commercial purposes (Erdik *et al.* 2012, Rajeev and Tesfamariam 2012). A typical example is given in Fig. 10(a). It is considered that the reason for the collapse of the floor story in this building, which was used as a shop, was the formation of the soft storey mechanism.

Heavy overhangs, at which columns are not connected with beams, decrease the column rigidities in the direction of the missing beams. Thereby the overall resistance of the building against earthquake decreases. Considering that the ductility of the many buildings constructed in Turkey is much lower than the required values, increasing displacement demands due to decreased rigidity cause heavy damages or even total collapses (Inel *et al.* 2008a).

In Fig. 10 (b), a completely collapsed building can be seen. It is significant that the building in Fig. 10 (b) was collapsed in the weak direction where the columns were not connected by beams.

RC shear walls increase the resistance of the buildings to the earthquakes significantly (Inel *et al.* 2008b). For this reason, it is frequently considered that the buildings with shear walls are not heavily damaged in earthquakes. However, it should not be forgotten that the shear walls could be heavily damaged, unless they are designed or detailed properly.

An important design deficiency is the placement of the shear walls asymmetrically in plan view. This result in additional torsional moments and heavy damages may occur in the building, especially in the places where shear walls do not exist. In Fig. 11(a), displaced columns can be seen which occurred as a result of the asymmetrical placement of the shear walls. In Fig. 11(b), the plan view of the building in question is given. Asymmetrical placement of the shear walls can be seen, clearly.

In the same building, heavy shear damage occurred in an improperly designed shear wall element (see Fig. 11(c)). In fact, in the design drawings of the structure, it was shown that this shear wall was designed as a column. The dimensions of the RC member were increased and additional longitudinal reinforcement was utilized in the construction stage. The wall became insufficient against shear force effects, as it did not contain sufficient amount of lateral reinforcement. Since the amount of the longitudinal reinforcement increased unconsciously, shear forces increased as a result of the increased bending moment capacity. Such improper changes in the construction stage, may affect the seismic performance of the structure significantly. The concrete quality in this building is believed to be sufficient as the building is recently constructed and ready-mixed concrete is used.

(a) (b)

(c) (d)

Fig. 12 (a)an example of strong beam-weak column; (b) a view of common flat slab beam system in the region; (c) slightly damaged RC building after earthquake; (d) an undamaged adobe building after earthquake

The amount and the detailing of the lateral reinforcements are also important for the sufficient deformation capacity of the members. There are many square shaped columns with high dimensions such as 700 x 700 mm in the building in question. The examination of these columns showed that the concrete in the lower ends of all of these columns were crashed. It was seen that, no lateral reinforcement other than peripheral stirrup was used in the columns, which is probably the reason of the damage. As a result of this mistake, rectangular stirrup lost its effectiveness along the long stirrup arms. Due to the lack of confinement, concrete core in the column fell into pieces under increased compressive loads by the seismic loading.

In this building, damage in columns with circular cross-section was not observed (see Fig. 11(d)). As the stirrup was subjected to axial tension in the columns with spiral lateral reinforcement, hooks are not vital for the proper confinement. This may be taken as an example of the higher seismic performance of columns with circular lateral reinforcement.

One of the main reasons of the heavy damages observed in the region is ignoring the fundamental design parameters. In Fig. 12(a) a heavily damaged column which had insufficient lateral reinforcement is seen. Apparently, the column was constructed without considering the strong column-weak beam principle. The cases of the broken concrete pieces give a clue for the quality of the materials used.

Many buildings with hollow-tile floor slab were detected during the investigation in the region (see Fig. 12(b)). Hollow-tile floor slab is frequently used for architectural purpose of having a flat ceiling. When the negative effects of hollow-tile floor slab on seismic performance of the buildings are considered, this can be thought as one of the reasons for heavy damages.

It should be remembered that properly designed and constructed structural unit of any kind could have sufficiently high performance under seismic effects. In Fig. 12(c), a RC building without significant damage, but surrounded by many collapsed buildings, is seen. In Fig. 12(d), an adobe building in the region without any sign of seismic damage after the earthquake is given.

4.3 Gedikbulak primary school

In Van Earthquakes, one important point is the high amount of damages occurred in shear wall-frame systems. Many of the RC shear walls did not behave properly under seismic effects. The most striking example was RC Gedikbulak Primary School (Gedikbulak P.S.) building (Fig 13(a), (b), (c)). The structure has the same template design with many of the buildings examined and strengthened by the authors within the scope of the 10370 type school projects in Denizli and Kutahya (Inel *et al.* 2008b). With its symmetrical structure, few number of stories and presence of shear walls with high amount (more than 0.8% and 1.14% of floor area in two principal directions), the building was expected to survive with no or limited damage after such an earthquake (see Fig. 13 (d)). It may be expected that there are more than one reason for the collapse of such a RC building.

The examination of the Gedikbulak P.S. demonstrated that RC shear walls were separated at the base and storey levels (see Fig. 13(c)). It is highly probable that insufficient lap splice lengths of the longitudinal reinforcement were the main reason for this separation. It can be suggested that total collapse of the building occurred due to the members of the RC system which did not behave monolithically. The building was collapsed towards the region where shear walls did not exist (see Fig. 13(b) and (d)). As the load-bearing system did not behave monolithically, shear walls did not contribute the strength and rigidity of the building at the required level.

In Fig.13 (e) and (f), damaged RC shear walls can be seen. As can be revealed from the figure,

Fig. 13 (a) Collapsed Gedikbulak Primary school, (b) totally collapsed portion of the building without shear walls, (c) shear wall decomposed at story and foundation levels, (d) building floor plan and collapse direction and (e-f) shear walls with heavy joint damage and decomposition at story levels

any damage was not observed on the shear walls indicating resistance to the seismic forces. The shear wall bended in the collapse direction as it was pulled by the floor during the failure of the building (see Fig. 13(c)). The lower side of the shear wall moved independently from the base, as there was no sufficient interlocking of longitudinal reinforcements to the foundation. It is probable

(a) (b)

Fig. 14 (a) neighboring damage due to collide of the series of the buildings; (b) damaged beam element and walls due to the collapse of neighboring building)

(a) (b)

Fig. 15 Out of plane collapse of unframed gable walls

that the concrete strength of the building was much lower than what it should be. High axial load ratio in the columns, insufficient confinement and lap splice lengths are the main reasons of the inductile and non-monolithic behavior. It is highly probable that the collapse initiated from the region with columns experiencing high level of axial loads, where the shear walls are not present (see Fig. 13(d)).

4.4 Damages due to pounding

One of the most frequently observed deficiency in the structural design and construction is insufficient distance between adjacent buildings. As the adjacent buildings did not behave in identical way, the pounding was also observed after Van Earthquakes. Apart from pounding, the collapsed buildings may collide to the neighborhood ones yielding severe damages, see Fig. 14(a)

(a) (b)

Fig. 16 Infill wall damage at overhang portion

(a) (b)

Fig. 17 (a) Partially collapsed wall constructed without mortar and (b) near collapse infill wall

and (b). One of the attached buildings given in Fig. 14(a) collapsed and collided the two other buildings, causing permanently shifted vertical axeses.

4.5 Damages of the non-structural elements

Non-structural damages were among important reasons of the casualties and economic losses (Boduroglu, 2011). Especially, improperly manufactured gable walls introduce significant damage. Due to the heavy snow in the region, the slope of the roof is increased by constructing one of the walls much higher than the other. However, construction is not performed properly in these walls. During the earthquakes, this ended up destruction of many walls which was not surrounded with a RC frame as forced by earthquake code (TEC-2007) (see Fig. 15).

The wall damages in overhang regions increase as a result of two problems: walls are not

(a)

(b)

Fig. 18 (a) building with partially collapsed infill walls due to deficient insulation applications and (b) heavy cladding partially separated from the wall

(a)

(b)

Fig. 19 Building with undamaged structural system but damaged architectural elements

enclosed by columns at the end of overhangs and significant movement occurs in the cantilever like overhang portion due to vertical acceleration of the earthquake. In fact, overhangs are improper architectural applications for seismic actions, as they also cause problems in connecting columns by beam elements. Encouraging people to construct such overhangs by current architectural codes is a significant problem in elimination of such earthquake damages. In Fig. 16, it can be seen that the walls of the overhang were damaged so heavily that they can fall off from the building.

Improper construction of the gable walls are frequently observed in the region. In Fig. 17(a), a gable wall constructed in a mall without using mortar is shown. During the earthquake, some parts of this wall fell off. In Fig.17 (b), an exterior infill wall, which was almost collapsed, can be seen.

It is apparent that the connection between bricks and column-beam system was insufficient

As a result of the cold climate of the Van region, isolation is frequently applied to the buildings while unconsciously made applications could be dangerous. In Fig. 18(a), a typical example to this is given. Although such walls were constructed as a double-layer wall with isolation material in between, the connection of interior and exterior wall layers are commonly insufficient. For this reason, in many buildings parts of exterior wall, which were loosely attached, were partially collapsed. In such a case, the wall pieces falling off from a height could be very dangerous for people and property as experienced in 2011 Simav Earthquake (Inel *et al.* 2013, Tama 2012).

Additionally, as a result of the movement of the building during an earthquake, different types of coatings on the interior walls could also fall off. For example, heavy marble coatings can be dangerous if they are utilized up to the ceiling and/or in primary schools where pupils present. Fig.18 (b) gives an example where the coating separated from an interior wall and close to falling off. It should be noted that in the same building, coatings fell off in many places.

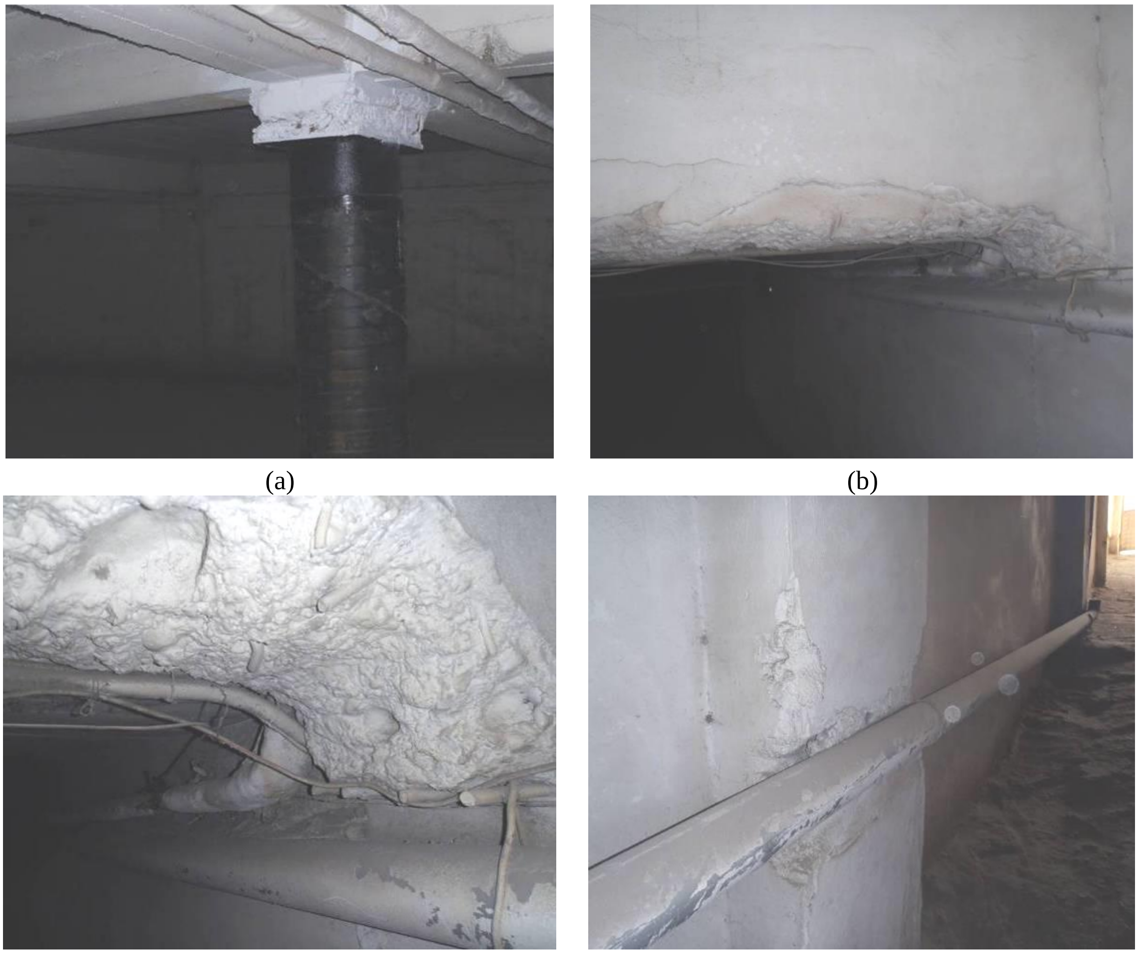
After the earthquake, it was also observed that there were buildings with slightly damaged or un-damaged load-bearing system while their infill walls were heavily damaged. In Fig. 19, an example to this case is given. The building was constructed in accordance to the 2007 Earthquake Code (TEC-2007) and serious level of damage was not observed in load-bearing elements by visual inspection. However, the walls of the building were heavily damaged during the earthquakes as the structural system was flexible. While such structures with insufficient rigidity, do not pose a risk as a load-bearing system since they are ductile, they cause heavy infill wall and other property damages. This is problematic for the following reasons; firstly heavily damaged/collapsed infill walls may cause injuries and even causalities, and secondly, depending on the properties of the building, repairing architectural damages may have a significant cost even if there is no damage in load-bearing system. In this building, a well-preserved load-bearing system and a high-cost architectural damage coexist. While it can be stated that the target performance for load-bearing system was reached, it is highly questionable if the structure attained the required seismic performance when the overall cost of the repairing is considered.

4.6 Changes in structural members after construction

In the region, there are structures with unconsciously made changes performed in the load bearing system. These changes, generally applied to increase the architectural functionality of the structures, may cause significant problems under seismic effects. There is a common sense in the community that the load-bearing systems do not lose their capacities whatever change is made on them. Thus, it is not a rare practice to cut the column and longitudinal rebar and to break the beams, if thought necessary for architectural purposes (see Fig. 20). However, there is not any direct sentence in the criminal code to punish these actions and there is no tradition to punish them by indirect sentences. Commonly, punishment is applied when it is too late, e.g., in case of an event with causalities. In order to prevent those types of damages, it is important to make necessary arrangements and corrections in the code.

5. Conclusions

On 23th of October and 9th of November, 2011, two earthquakes occurred in Van Province,



(a) (b) (c) (d)

Fig. 20 (a) vertical element placed after the destruction of column, (b) partially destructed beam for easy passage of the cars, (c) cut reinforcement and (d) partially destructed column for placement of the pipe

resulting in significant damages. The damages and their reasons observed in these earthquakes were evaluated and summarized below.

- The observations and damage evaluations point out that the first earthquake caused more damage in Ercis rather than Van and Muradiye, which has the half and same distance to the epicenter, respectively. The second earthquake, on the other hand, caused significant damages in Van, 12 km away from the epicenter, rather than in Edremit, 2 km away from the epicenter. From these points of view; Van Earthquakes, occurred on October 23, 2011 and November 9, 2011 yielded contradictory results to the expectation that the effects of an earthquake decrease with the distance to the epicenter which is the main assumption of the attenuation relations.
- It has been frequently suggested that the properties of the soil in Ercis region increased the effects of the earthquakes. However, Van and Ercis have resembling geological properties and

Van has half distance to the epicenter when compared to Ercis for the first earthquake.

- The field examinations performed after the earthquake demonstrated that the most important reasons of the collapses were improper joint regions and insufficient development lengths. Under seismic effects, joint regions, which were expected to behave rigidly, were the weakest links damaged initially. Thus, in many buildings, the load bearing system collapsed even before beams and columns were damaged.
- When the building damage ratios are examined for different damage levels, it was detected that slightly and heavily damaged or completely collapsed building ratios are higher compared to the moderately damaged ones. This means that the buildings were either slightly damaged or severely damaged/collapsed. This condition indicates the presence of a building profile with low ductility and potential to be heavily damaged readily after being affected from an earthquake. Many examples of insufficient rebar development length and considerable number of joint damages in the region can be considered in compliance with this condition.
- Insufficient lateral reinforcement amount, improper detailing and low concrete strength can be shown as the main reasons of the damages occurring in the structural members.
- If designed or detailed with heavy deficiencies, even buildings with shear walls may collapse. The Gedikbulak Primary School building is a striking example for this case with its symmetrical structural system, few numbers of stories and presence of shear walls with high amount.
- In many damaged buildings, capacity design rules were not obeyed. Many buildings in which weak column-strong beam condition formed were heavily damaged, even collapsed.
- In some adjacent buildings, damages related to pounding caused by insufficient gaps and rigidity weaknesses explained above were observed.
- Not only unconsciously constructed ribbon windows, but also partially collapsed infill walls caused the formation of short column yielding severe shear damages.
- The limited use of ready-mixed concrete and thus low quality of concrete in the region caused important insufficiencies. However, the use of low quality concrete cannot be the sole reason of all damages as many buildings in which ready-mixed concrete was used were also heavily damaged and even collapsed.
- In some ductile structures, having load carrying systems with high flexibility and low rigidity, important damages in architectural elements occurred. In these buildings, structural system demonstrated sufficient load bearing behavior, while it is questionable if the overall behavior of the building is satisfactory when the cost of the architectural element repair is considered.
- There are many buildings in the region with overhangs, some of which constructed improperly and thus severely damaged in the earthquakes. Depending on the condition of these extensions, there were damages in the slabs, columns and beams. The important reason of the extensive utilization of overhang is the encouragement by the architectural codes. In these codes, it should be ceased to allow construction of lower and upper storey with different areas.
- Defects were detected in the design of the gable wall at the roofs. In many buildings the wall damages, even wall collapses, occurred as these walls were not surrounded by beams and columns as enforced by earthquake codes (TEC-2007). Such types of damages were observed in different regions of Turkey. Thus, it can be defined as a common fault.

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