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24 January 2020 Sivrice-Elazığ Earthquake: Assessment of Seismic Characteristics of Earthquake, Earthquake Territory and Structural Performance of Reinforced Concrete Structures

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Abstract

An earthquake with a magnitude of 6.8 (M_w) has occurred in Sivrice district of Elazığ province in Eastern Turkey, on January 24, 2020. The main shock and long-term aftershocks felt fairly by near vicinities. Many structures have been damaged severely or demolished at this moderate earthquake that occurred on East Anatolia Fault (EAF) zone. Also resulted in sum 41 casualties, including 37 people in Elazığ and 4 people in Malatya. The purpose of this paper is to give information of the tectonic characteristics of the EAF zone, the seismic characteristics of the earthquake territory, the general characteristics of the main shock and after-shocks. In addition, another purpose of this article is to reveal the damages caused by the earthquake in the reinforced concrete (RC) buildings in Elazığ, with the post-earthquake field observations. The main reasons of damages have presented and discussed. The most important reason for damages of structures is the lack of engineering services, in other words, not being constructed properly with respect to the available building codes.

Keywords: 2020 Sivrice-Elazığ earthquake, reinforced concrete structures, earthquake damage survey, East Anatolia Fault zone, damage assessment

1. INTRODUCTION

On January 24, 2020, an earthquake with a magnitude of 6.8 (M_w) of according to Turkey Disaster Emergency and Management Agency (DEMA) [1] occurred in Sivrice district within the borders of Elazığ province in the Eastern Province of the Eastern Anatolian Region in Turkey. The earthquake was felt in 42 provincial centers and 26184 settlements, 750 km from the epicenter. The EAF zone is located between the Arabian Plate moving northward and the Anatolian Block moving westward. It has an average width of 30 km and a length of approximately 600 km and forms a left-lateral strike-slip transform boundary trending North-East. The EAF zone consists of

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segments ranging in length from 50 km to 145 km (Figure 1) [1].

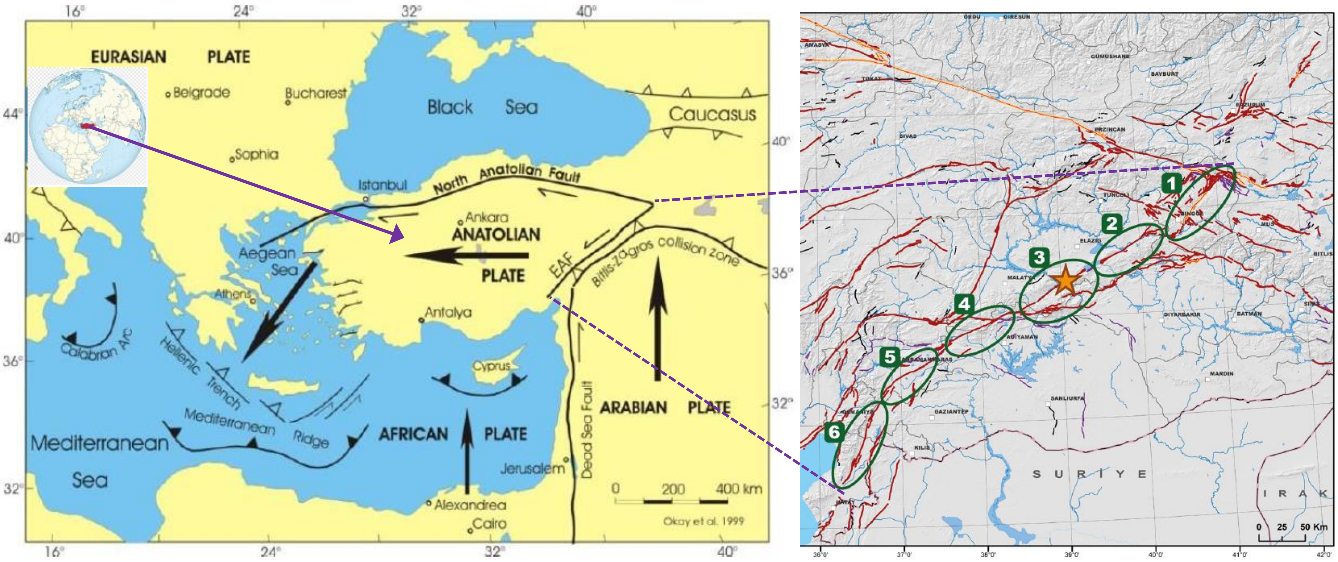

Figure 1 EAF zone (1:Karlıova-Bingöl, 2:Palu-Hazar Lake, 3:Hazar Lake-Sincik, 4:Çelikhan-Gölbaşı, 5:Gölbaşı-Türkoğlu, 6:Türkoğlu-Antakya) [1, 2]

Many devastating earthquakes have occurred on the EAF zone throughout history. Some of these earthquakes have been recorded historically and some instrumentally (Figure 2) [1]. The earthquakes of 1789-Palu, 1866-Elazığ, 1874-Elazığ, 1875-Bingöl-Elazığ and 1893-Malatya are some of the most important earthquakes recorded historically in the region (Table 1) [3- 11].

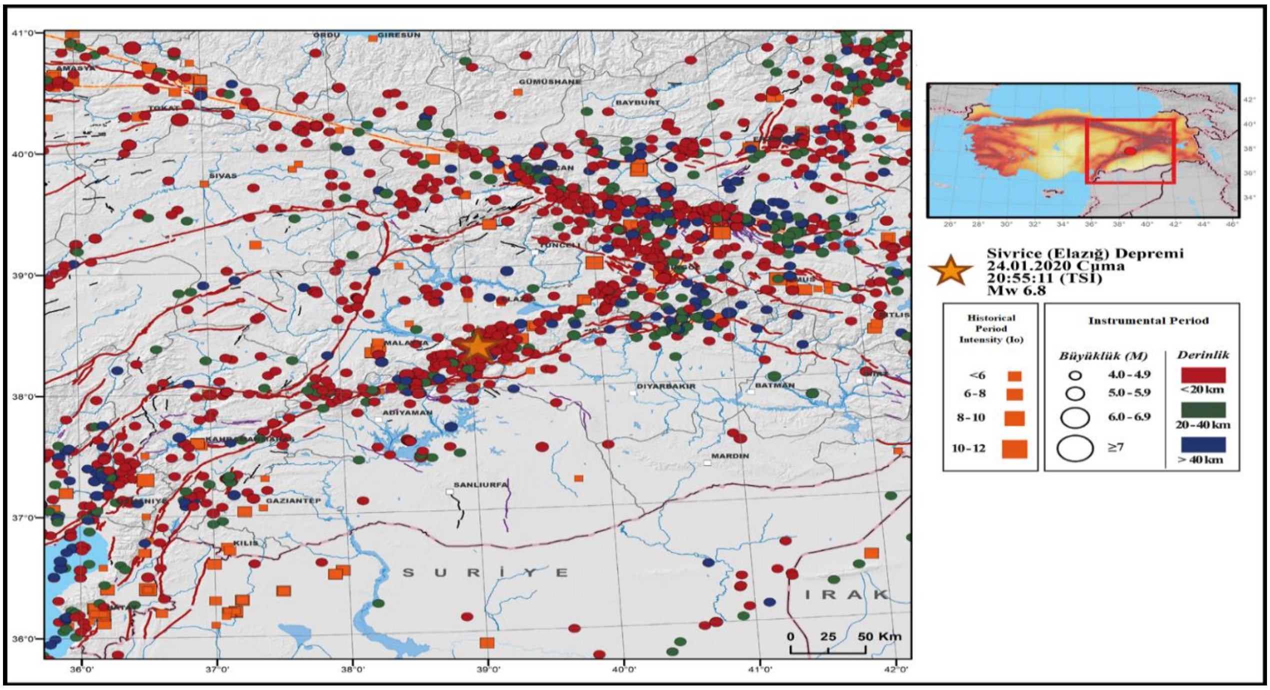

Figure 2 Earthquake activity in the historical and instrumental period along the EAF zone [1]

Table 1 Earthquake intensity in the historical period along the EAF zone

Year	Location	Intensity (I_o)
995	Elazığ (Palu, Sivrice)	VI
1513	Malatya	IX
1789	Elazığ (Palu)	VII
1866	Elazığ	IX
1874	Elazığ, Diyarbakır	X
1875	Elazığ, Bingöl	VII
1889	Elazığ (Palu)	VI
1890	Malatya	VI
1893	Malatya	X

When the earthquakes recorded instrumentally were examined, it was seen that 564 earthquakes over 4.0 occurred on the EAF zone. If we examine the earthquakes with magnitude 6 or more occurring on the main line and close segments of the EAF zone; the earthquakes of Pütürge (1905), Malatya (1908), Sincik-Adıyaman (1964), Varto-Muş (1966), Karlıova-Bingöl (1966), Bingöl (1971), Lice-Diyarbakır (1975) and Doğanşehir-Malatya (1986) earthquakes can be given as examples. During these earthquakes many people lost their lives and many houses were destroyed and heavily damaged [1].

When we entered the 21st century, earthquakes continued to occur in the EAF zone. Pülümür-Tunceli (2003) and Bingöl (2003) earthquakes are the first earthquakes to occur. After these earthquakes, there was a serious dynamism in the EAF system and there were always earthquakes at certain time intervals until 24 January 2020 Sivrice earthquake. In this time period, Sivrice-Elazığ (2004), Pütürge-Malatya (2005), Sivrice-Elazığ (Feb 9, 2007), Sivrice-Elazığ (Feb 21, 2007), Kovancılar-Elazığ (2010), Elazığ (2011), Sivrice-Elazığ (April 4, 2019) and Sivrice-Elazığ (December 27, 2019) earthquakes occurred (Figure 2). For the EAF zone, in the 17-year period since 2003, it is seen that there has been an increase in earthquake activity incomparable with previous periods. In addition, the Sivrice-Elazığ (2019) earthquakes occurred both on the same fault and in a very close location with the January 24, 2020 earthquake. Therefore, it is possible to interpret the 2019 Sivrice earthquakes as the foreshock of the January 24, 2020 earthquake [12].

Structural damages occurred with the past earthquakes in various regions had been investigated by many researchers according to the structure types. The earthquake performance of the RC structures is evaluated by Sezen et al. [13] for 1999 Kocaeli earthquake and by Doğangün [14] for 2003 Bingöl earthquake. Celep et al. [15] investigated failures of masonry and concrete buildings during the March 8, 2010 Kovancılar and Palu Earthquakes in Elazığ, Turkey. Calayır et al. [16] assessed damages of various structures (adobe, masonry, hımış, and RC structures, and minarets) in the rural area during the March 8, 2010 Kovancılar Earthquakes in Elazığ, Turkey. Sayın et al. [17] presented a comprehensive study on the 24 January 2020 Sivrice-Elazığ, Turkey. They summarized past and present seismic characteristics of the earthquake region. In addition, they also summarized the seismotectonic of the region, the general characteristics of the earthquake and more specifically to report on the structural damage, and structural damage caused by the earthquake, observed during the site investigation. Günaydın [18] et al. examined the case studies of damaged masonry buildings and as well as failure or collapse mechanisms. Yetkin et al. [19] investigated the damages occurred at the minarets in Elazig after the M_w = 6.8 magnitude earthquake that took place in Sivrice district of Elazig on January 24, 2020. In the examined minarets, the parts which the damages occurred in were determined and also the causes of these damages were evaluated. At the end of the study, some recommendations were made for the repair and strengthening of damaged minarets and the construction of new minarets.

The aim of this paper is to give information of the past and present seism tectonic characteristics of the EAF zone, the seismic characteristics of the earthquake territory, the general characteristics of the main shock and after-shocks. Also, the damages of RC buildings in Elazığ province were examined by the post-earthquake field observations. The observed damages was classified and discussed for RC structures.

2. ON JANUARY 24, 2020 SIVRICE-ELAZIĞ EARTHQUAKE

The closest settlement to the focal point of the earthquake that occurred on January 24, 2020 is Çevrimtaş village in Sivrice district. Çevrimtaş village is located 0.81 km from Sivrice (Figure 3).

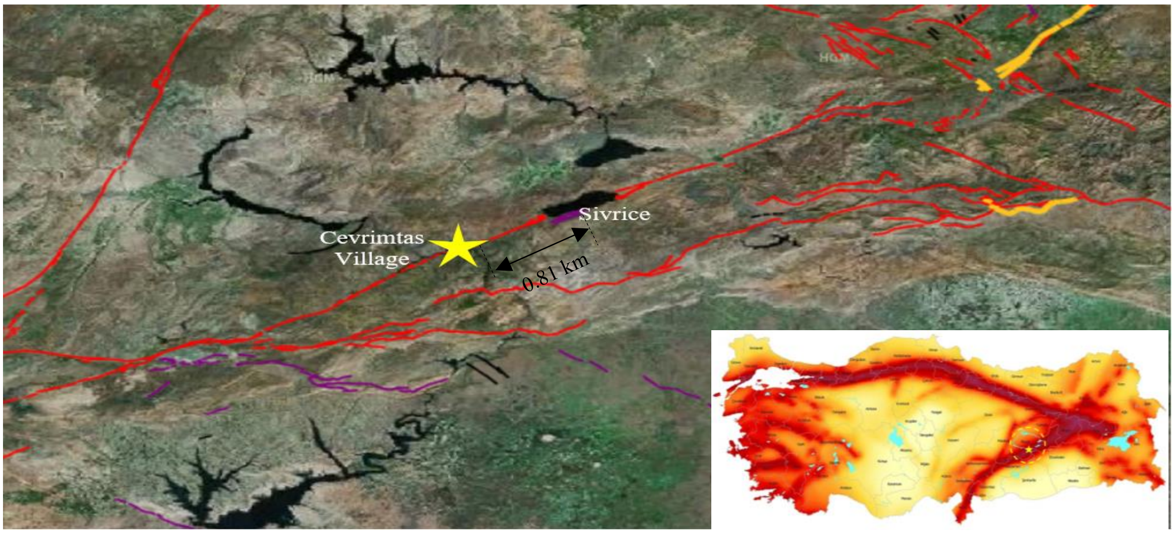

Figure 3 Location of the January 24, 2020 earthquake [11, 20]

This earthquake was felt in Elazığ and all its districts, and also in many other provinces, starting from the Çevrimtaş village. The magnitude of the earthquake has been announced by DEMA as 6.8 (M_w). Magnitude and source characteristics of the earthquake are defined by various institutions as given in Table 2. The depth at which the main shock occurred has been explained as different values by these institutions, and these values are in the range of 8.06-15.0 km. It is seen that aftershocks intensity in the depth range of 5 ~ 20 km (Figure 4). Therefore, earthquakes that occur are shallow earthquake.

Table 2 January 24, 2020 Sivrice-Elazığ earthquake characteristics for various institutions.

Institutions	Magnitude (M_w)	Depth (km)	Longitudinal	Latitude
Turkish Ministry of Interior Disaster and Emergency Management Agency (DEMA)	6.8	8.06	39.06	38.36
Kandilli Observatory and Earthquake Research Institute (KOERI)	6.5	5.0	39.24	38.37
European-Mediterranean Seismological Centre (France)	6.8	15.0	39.22	38.37
German Research Center for Geosciences	6.8	10.0	39.20	38.36
Instituto Nazionale di Geofisica e Vulcanologia (Roma)	6.8	11.0	39.12	38.39
United States Geological Survey	6.7	11.9	39.08	38.39

After the main shock, the aftershocks continued for days. The number of daily aftershocks for one month in the region is given in Figure 4. The aftershocks have gradually decreased. When 1-month data are evaluated in the region; it was observed that a total of 3080 earthquakes occurred, including the main shock, and 26 of these aftershocks were 4.0 (M_w) and above [1]. The distribution of earthquake aftershocks shows that the rupture started in the southwest of Sivrice. In addition, aftershocks are mostly concentrated in the northwest block very close to the Pütürge Segment. This data shows that the earthquake source fault is inclined to the northwest [12].

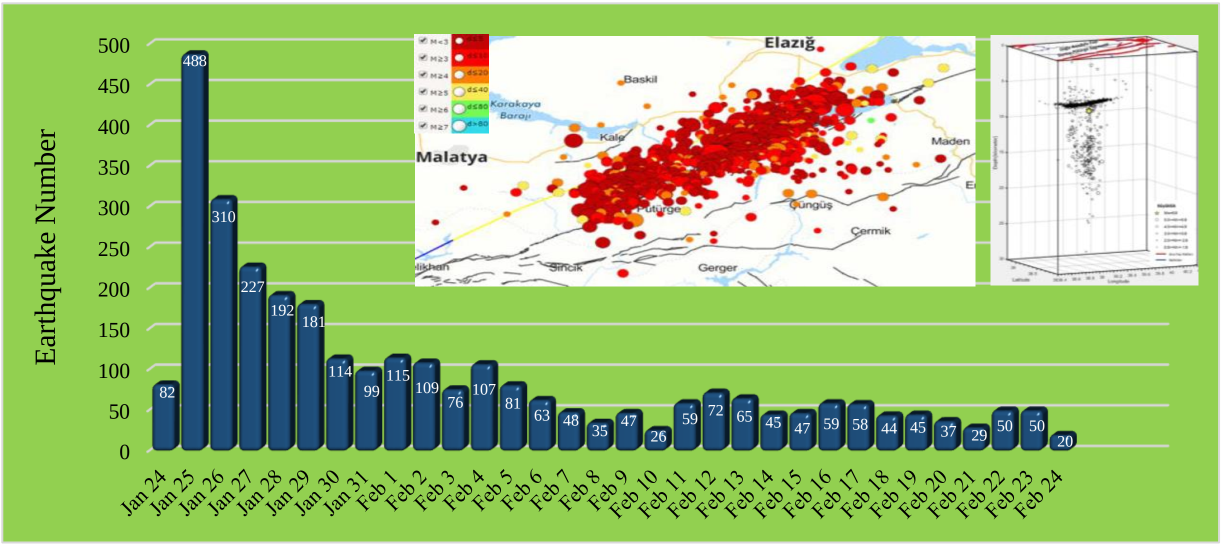

Figure 4 The number and location of daily aftershocks for one month [1, 21]

The main shock caused significant damage and resulted in sum of 41 which are 37 people in Elazığ and 4 in Malatya casualties. In addition, many buildings such as houses, workplaces, places of worship, animal shelters were damaged and some of these structures were demolished. As a result of the investigations made by the damage determination committees, the building damage states for Elazığ province are given in Figure 5.

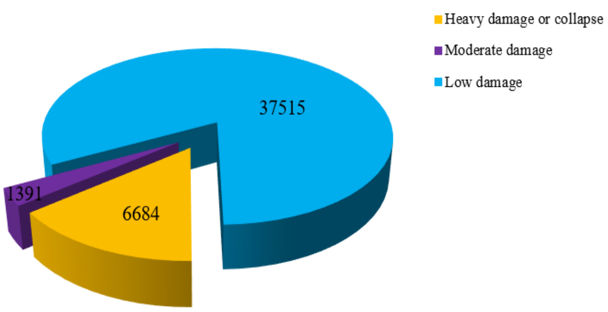

Figure 5 The building damage states for Elazığ province [22]

When the damage assessment results are examined, it is noteworthy that the number of damaged buildings is quite high. For some of these buildings, urgent demolition decision has been taken and some of them are determined as severely damaged and will be demolished. When the PGA data for the region on the Turkey Earthquake Hazard Map (DEMA) were evaluated, it was determined that the PGA-475 value (Design Earthquake) was 0.622 g, but the maximum acceleration values measured for the earthquake that occurred were 0.298 g [1]. Thus, it has been revealed that the maximum acceleration of the occurring earthquake has a smaller value than the Design Earthquake.

The spectral acceleration values of the records of Elazığ-Sivrice station were compared with the former Turkish Earthquake Code (TEC-2007) [23] and the current Turkish Building Earthquake Code (TBEC-2018) [24] design acceleration spectra in Figure 6. While calculating the design spectrum, the ground class of the region was accepted as Z3 according to TEC-2007 and ZC according to TBEC-2018. Elastic design spectrum was calculated for DD-2 earthquake ground motion level (design level, i.e., 10% probability of exceedance in 50 years-475 years return period) [20].

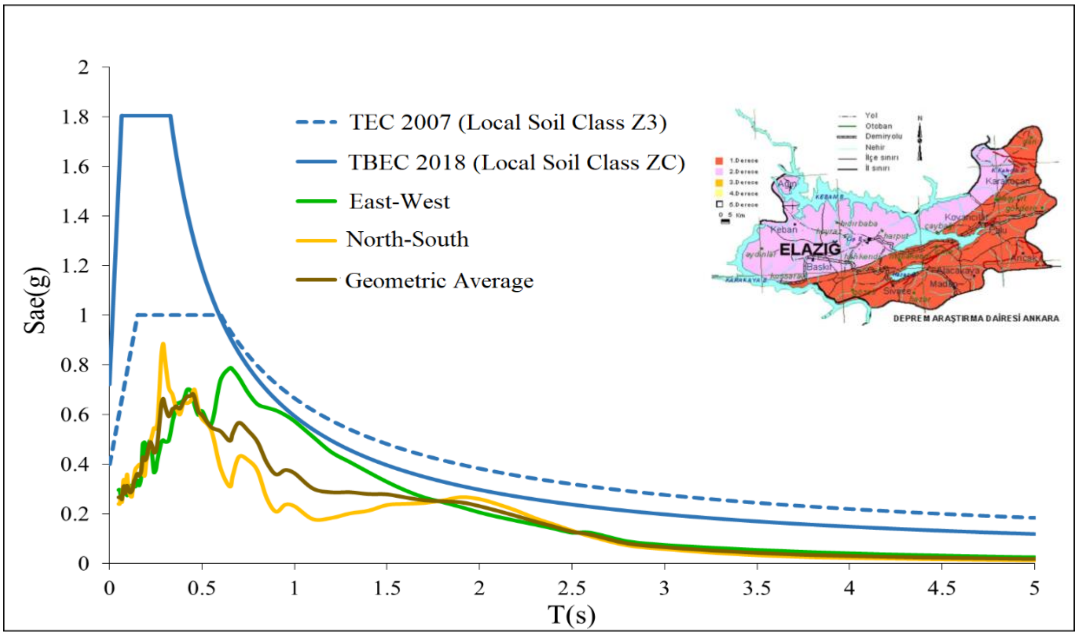

Figure 6 Comparison of the acceleration spectra of the Sivrice-Elazığ (2308) station horizontal acceleration records with the TEC-2007 and TBEC-2018 design spectra [1]

According to seismic codes, limiting permanent structural damage in order to ensure life safety in severe earthquakes is the basic principle of earthquake-resistant building design. Accordingly, it is desired that the structural elements consume the energy of a severe earthquake with plastic deformations (permanent displacement and damage), in other words, to act ductile. However, when the damage caused by the earthquake and the acceleration values recorded in the earthquake are examined, it is obvious that the level of damage to the buildings is higher than expected. This situation have shown that heavily damaged or collapsed structures weren't construct in accordance with seismic codes.

3. PERFORMANCE OF REINFORCED CONCRETE (RC) BUILDINGS

Many RC buildings were affected by the 6.8 (M_w) earthquake that occurred in the Sivrice district of Elazığ Province in Eastern Turkey on January 24, 2020. The damages were generally caused due to various engineering and structural deficiencies. Causes of damages of various types of RC buildings in the earthquake area are presented below.

3.1. Column Damage

The transverse reinforcement is of primary importance to ensure the adequate ductility capacity of the system in earthquake resistant building design. During the earthquake, shear forces is increased significantly, especially at end of column and beam, and beam-column joints. For this reason, we, as engineers, should pay special attention to the transverse reinforcement details during the project and construction of the building. However, in the field observations made after the earthquake, it was observed that the columns were damaged due to insufficient transverse reinforcement in the plastic hinge regions. Besides, it was seen that longitudinal reinforcement bar were also buckled owing to inadequate transverse reinforcement. This important deficiency caused the columns to display low performance against the shear forces of earthquake. In Figure 7-8, some of columns damaged in the earthquake due to insufficient transverse reinforcement have presented.

Figure 7 Column damage due to insufficient transverse reinforcement

Figure 8 Buckling longitudinal reinforcement bars of damaged column due to insufficient transverse reinforcement

3.2. Beam Damage

The beams are usually exposed to shear and bending damage because of the aforementioned structural deficiencies. In field observations for the Elazığ earthquake, shear and bending cracks were observed in the beams. In addition, damages were observed in the connected point the secondary beams to the supporting beams were as well. Some of the beams damaged in the earthquake have shown in Figure 9.

Figure 9 Beam damages

3.3. Strong Beam–Weak Column

In Turkey, especially available old RC structures stock was constructed with strong beam and weak column design. Accordingly, the beams are deep and rigid while the columns weak and flexible. Therefore, damage of these RC building in the event of an earthquake start at the ends of the columns. The design of strong beam-weak column was the main reason of the partial and total collapse of some buildings during the Sivrice-Elazığ earthquake. In Figure 10, columns of structures damaged due to strong beam-weak column design are presented.

Figure 10 Strong beam–weak column

To prevent this kind of damages or collapses arising from the strong beam-weak column design, current and former seismic codes require 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 [23, 24]. Thus, plastic hinges occur at the ends of the beam in case of the earthquake and brittle failure prevents.

3.4. Damages of Infill Walls

In Turkey, the infill walls in the RC buildings are generally constructed by using brick and cement mortar. During an earthquake, the in-plane and out-of-plane behaviour of these infill walls is extremely complex and depends entirely on the interaction mechanism of the infill wall and RC frames. During the field observations, different type of infill damages were encountered as shown in Figure 11-14. During the earthquake, the diagonal cracks were observed in the infill walls due to the interaction with the RC frame. (Figure 11). Also partial or total out-of-plane mechanism was observed in the infill wall damages (Figure 12). The other type of observed damage in the infill wall is the separation of the infill wall from the frame (Figure 13). In addition, numerous overhang infill wall damages have been also observed in the earthquake-affected region with the aforementioned damages (Figure 14).

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Figure 11 In-plane damage

Figure 12 Partial out-of-plane damage

Figure 13 Disconnection of infill wall from the frame

Figure 14 Damages of overhang infill walls

Infill walls are especially very sensitive to the inter-story drift ratio demand of the structural system. Therefore, TBEC (2018) limits these ratios. In order to prevent such damages, rules of earthquake code must strictly comply both during the project and the construction stage.

3.5. Inadequate Gaps between Adjacent Buildings

Today, due to the increase in the human population and the insufficiency of construction areas in city centers, adjacent buildings are often built. As a result of this, one or both facades of the buildings touch each other or there is little space between the buildings. Therefore, during an earthquake, these structures is collided because they do not have sufficient displacement space. A more dangerous situation is emerged when the story levels of adjacent structures are not same aligned. The slabs of the building can hit the columns of neighbor building, causing severely damage. Such damages were detected in the field observations made after the Elazığ earthquake (Figure 15).

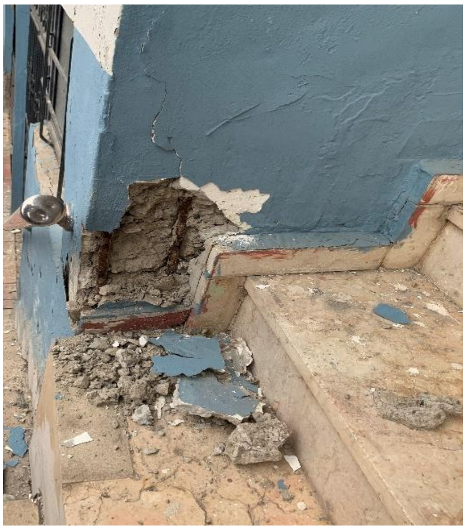
Figure 15 Damages of adjacent buildings

To prevent such damages, there must be sufficient gaps between adjacent buildings. TBEC (2018) is required the construction of seismic joints that will maintain certain spacing between adjacent buildings. In this way, in the event of an earthquake, neighboring buildings can move independently without interfering with each other. According to the code, the minimum joint gap to be left will be at least 30 mm up to a height of 6 m and at least 10 mm will be added to this value for every 3 m of height after 6 m. Unless a more unfavorable 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 story displacements multiplied by the coefficient α. If adjacent floor levels of buildings at all stories are same, then the amount of gap is $\alpha = 0.25\ (R/\mathrm{I})$, $\alpha = 0.50\ (R/\mathrm{I})$ if not. In these equations, R is the structural behavior factor and I building importance factor.

3.6. Poor Concrete Quality, Corrosion and Erroneous Applications

In Turkey, ready-mixed concrete has started to be used widely especially after 2000s. That's why, the majority of existing RC buildings were built with cast in-place concrete without any official control. As a result of this, many such buildings have low strength concrete due to high water-cement ratio, improper aggregate size and gradation, and reinforcement subjected to corrosion. In the field study, poor concrete quality, corroded reinforcement bars and erroneous applications which shown in Figure 16 were encountered in the structural members of the buildings.

(a)



(b)

(c)

Figure 16 a) Poor concrete quality b) corrosion c) erroneous application

In order to prevent these erroneous applications that negatively affect the behavior of structural members;

- Appropriate gradation concrete should be used.
- A vibrator should be used in order for the concrete to settle into the mold homogeneously.
- It should be ensured that the structural elements have sufficient concrete cover.
- Wrong applications that will weaken the RC system should be avoided.

4. CONCLUSIONS AND SUGGESTIONS

On January 24, 2020 an earthquake with a magnitude (M_w) of 6.8 hit the Elazığ Province, Turkey. Many structures have been damaged severely or demolished at this moderate earthquake that occurred on East Anatolia Fault zone. A total of 41 people died, including 37 people in Elazığ and 4 people in Malatya. The purpose of this paper is to summarize tectonic characteristics of the EAF zone, the seismic characteristics of the earthquake territory, the general characteristics of the main shock and after-shocks. In addition, another purpose of this article is to reveal the damages caused by the earthquake in the RC buildings in Elazığ, by the post-earthquake field observations. The main reasons of damages have assessed. The main factors of damages attained from this case study are given below.

- Using plain bar, large spacing transverse reinforcement, absence of crossties has caused significant damage to structural elements. In addition, the ends of the stirrups, which is an important detail, had not bent 135 degrees. Because of all of these, the wrapping effect of the stirrups in the concrete block has considerably reduced and the section integrity has been sufficiently not ensured. To avoid damage of structural members, attention should be paid to detailing of transverse reinforcement, and close-spaced stirrups should be used.
- During the earthquake, the diagonal cracks were observed in the infill walls due to the interaction with the RC frame. In addition, heavy overhangs in the building has increased the degree of damage. In order to prevent such damages, the infill wall should work independently from the frame. Also heavy overhangs should be avoided especially.
- Each building has different natural vibration periods due to their structural and material properties. During an earthquake, a hammering effect occurs between adjacent buildings or buildings with insufficient gap between them. This situation is devastating for buildings, especially when the neighbor buildings have different floor levels. To avoid this kind of damage, proper gaps should be left between the attached buildings.
- Material quality, proper workmanship and appropriate detailing are the main factors that positively affect the earthquake performance of structural systems. The information obtained the field observation shows that poor concrete quality, corrosion of reinforcement bars and wrong interventions reduce the structural performance of buildings. Hence, expected performance against earthquake cannot be provided. To prevent damage arising from this situation, selection and application of materials, workmanship and subsequent interventions should be paid attention.

RC buildings should be designed and built in accordance with the requirements of current seismic codes in order to reduce the damage of RC buildings and to prevent loss of property and life. In addition, construction workers should be taught that workmanship has an important role in the earthquake performance of the building. Building construction must be strictly controlled by engineers at every stage.

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Authors' Contribution
The authors contributed equally to the study. All authors participated in discussions of results and manuscript preparation.

The Declaration of Ethics Committee Approval
This study does not require ethics committee permission or any special permission.

The Declaration of Research and Publication Ethics
The authors of the paper declare that they comply with the scientific, ethical and quotation rules of SAUJS in all processes of the paper and that they do not make any falsification on the data collected. In addition, they declare that Sakarya University Journal of Science and its editorial board have no responsibility for any ethical violations that may be encountered, and that this study has not been evaluated in any academic publication environment other than Sakarya University Journal of Science.

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