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DESIGN DEFICIENCIES AND FAILURE MODES IN REINFORCED CONCRETE STRUCTURES: THE CASE OF KAHRAMANMARAS EARTHQUAKE

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Abstract. In Turkey, after two big earthquakes centered on Kahramanmaraş on February 6, 2023, a catastrophic damage occurred and more than fifty thousand people passed away, and a lot of people lost their comfort of life even though they were rescued from the rubble. It has been emphasized by scientists that this great destruction, in almost all types of structures such as concrete, steel, stacking and prefabricated, is usually caused by design errors, poor material quality and workmanship. In this study, design errors and damage modes of reinforced concrete structures in Malatya were examined with a field study. During the fieldwork, it was determined that reinforced concrete structures were generally damaged or collapsed due to inadequate longitudinal reinforcement and stirrup, poor reinforcement and concrete quality, design errors in the column-beam joint region (strong beam-weak column and lack of stirrup spacing), torsional irregularity, ignoring the soil-structure interaction and soft storey.
Keywords: RC structures, earthquake, failure modes, design deficiency

Introduction. Earthquakes turn into a disaster due to structures that have not received engineering services and cause economic, social and psychological negativity on society as well as loss of life. In Turkey, which is located on the seismic belt, the loss of life and property in the great earthquakes that have occurred in recent years has brought many questions about the condition of the existing structures. The closest example of this was experienced with two major earthquakes in Kahramanmarash on February 6, 2023. At 04:17 Turkey time, Pazarcık (Kahramanmaraş) Mw 7.7 and Elbistan (Kahramanmaraş) Mw 7.6 earthquakes occurred. Oludeniz Fault with a line that includes parts of the Eastern Anatolian Fault System between Çelikhan Pötürge in the northeast of the epicenter earthquake (65 km between Çelikhan-Gölbaşı), Gölbaşı (90 km between Gölbaşı-Türkoğlu), Amanos (110 km between Tür-koğlu-Kırıkhan). He broke the Pomegranate Piece at the North end of the System; The second Elbistan eccentric earthquake was thought to be related to the Çardak Fault and the Doğanşehir Fault Zone (Fig.1).

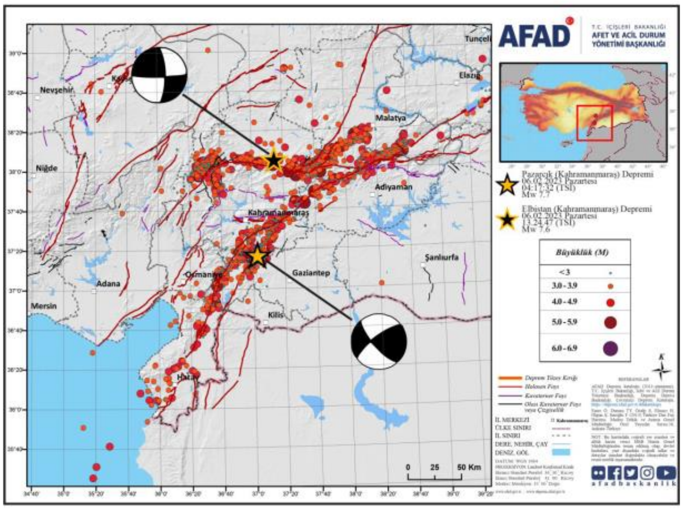

Figure 1. Map showing aftershocks activity of 06.02.2023 earthquakes [3]

Although some stations did not work after the Mw 7.7 earthquake, which is one of the 6 February 2023 earthquakes, data were recorded in many stations in our country during the Mw 7.7 and 7.6 earthquakes. Pictures of the nearest accelerometers recording both earthquakes are given in Figure-2 and Figure 3.

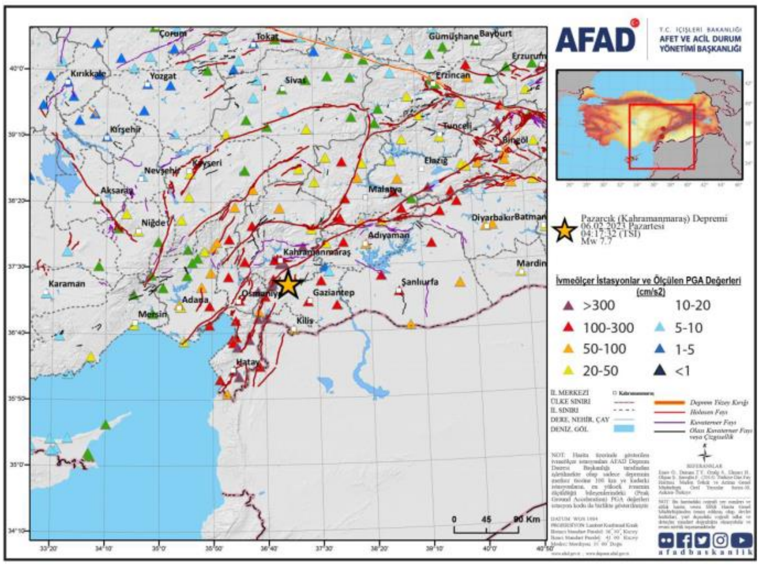

Figure 2. Distribution of nearest accelerometer stations recording the Mw 7.7 earthquake [5]

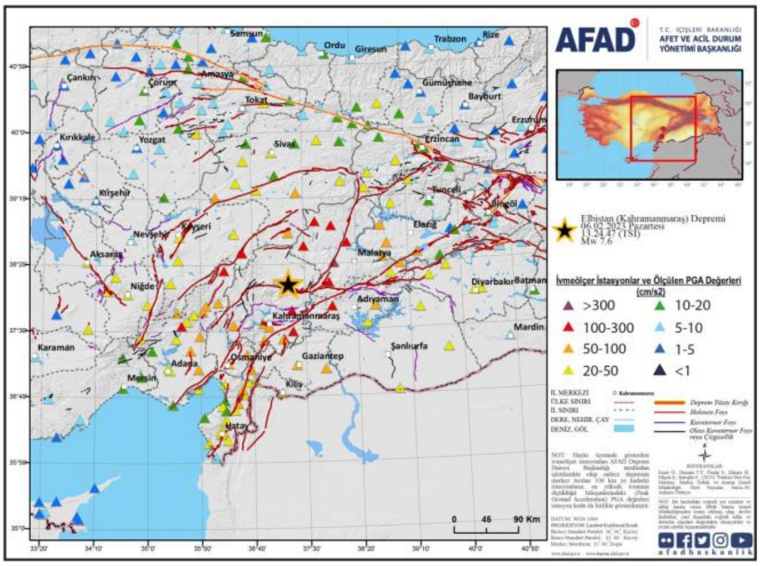

Figure 3. Distribution of nearest accelerometer stations recording the Mw 7.6 earthquake [5]

In Malatya, which is one of the provinces most affected by the Mw 7.7 and 7.6 earthquakes, data were recorded at many stations during these earthquakes. The stations closest to Malatya Center are given in Fig.4.

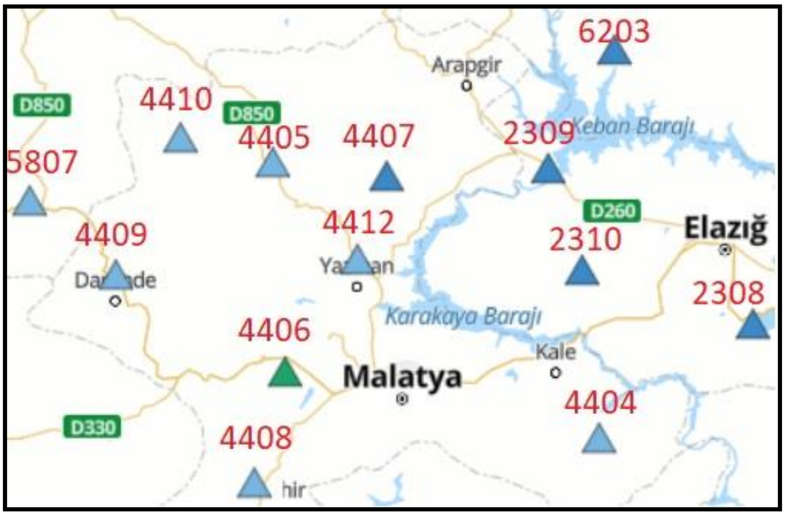

Figure 4. Distribution of accelerometer stations closest to Malatya Center [6]

The reaction spectra created according to the acceleration values received from the stations closest to the center of Malatya, the coordinates of the stations and the graphs created according to the ground are given in Fig.5. As can be seen from these graphs, the reaction spectrum of the earthquake is more than DD2 at most moments and has reached DD1 level at some moments. This is one of the reasons why the destruction of earthquakes is so great.

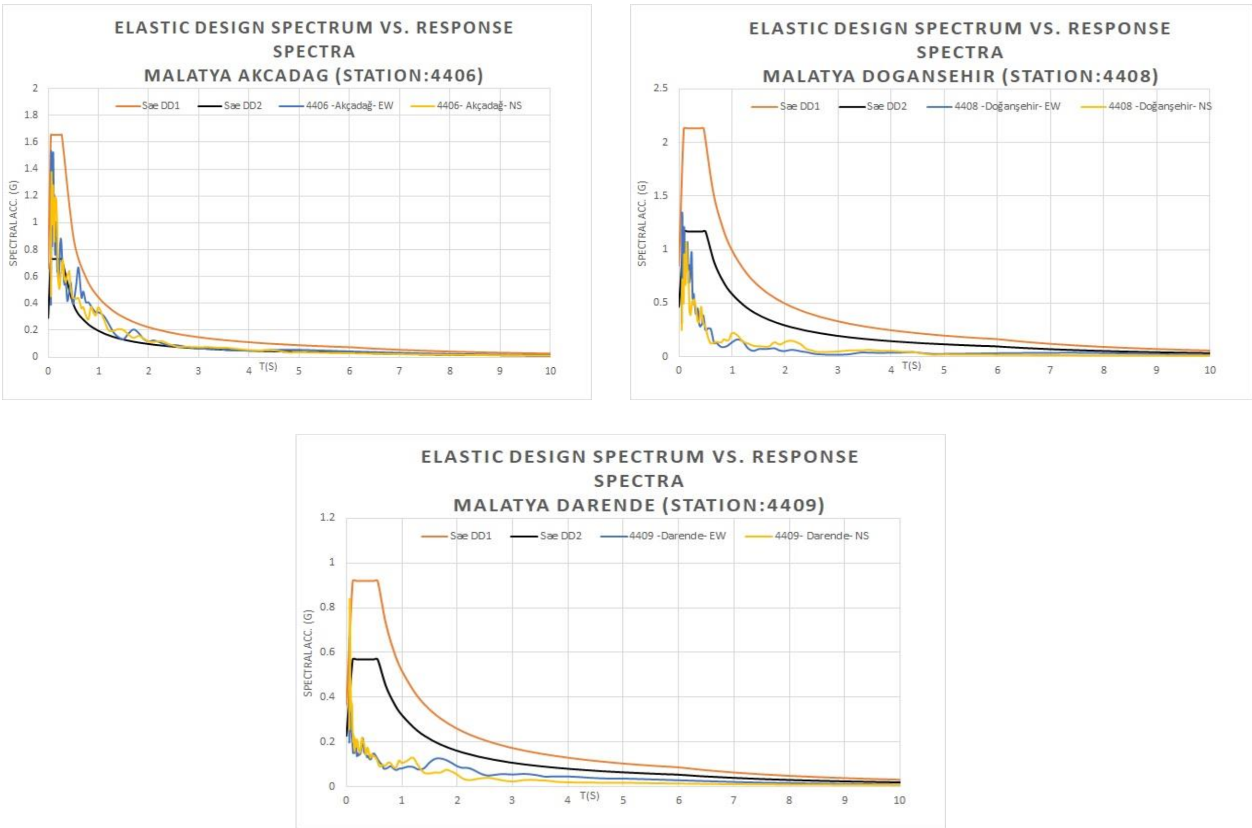

Figure 5. Comparison of the response spectrum and design spectra based on the acceleration values [7]

Many technical and scientific reports have been written for the structures that have been destroyed or severely damaged after the earthquakes in the past and it has been tried to shed light on the status of the existing structure stock. For example, in the report published by the Chamber of Civil Engineers after Izmir Earthquake that occured October 30, 2020, it was stated that collapses occurred at early levels due to inadequate confinemennt bar detail, inadequate clamping lengths and low concrete compressive strength in the structures built before the 1998 Earthquake Code [1]. Damage distributions in reinforced concrete structures after the earthquake attracted the attention of the researchers and many field studies were performed. Many research for 1999 Kocaeli earthquake [2], 2003 Bingöl earthquake [3], 2011 Van earthquakes [4], 2011 Simav earthquake [5], 2011 Van earthquakes [6-7] and 2020 Sivrice earthquake [8-9] presented in the literature. The causes of damage caused after the earthquake in the reinforced concrete structures listed below have been reported and discussed in detail [10].

– Inadequate transverse reinforcement of structural members
– The short column
– Insufficient space between adjacent buildings
– Strong beam – weak column
– Poor concrete quality and corrosion
– Collapse of the walls on the roof
– Damage in the infill walls

Within the scope of this study, the design errors and damage modes of reinforced concrete structures in Malatya were investigated with the field study. During the field work it has been determined that, structures are generally damaged or collapsed due to insufficient longitudinal reinforcement and stirrup reinforcement, low reinforcement and concrete quality, design errors in the column-beam junction region (strong beam-weak column and lack of stirrup tightening), torsional irregularity, ignoring soil-structure interaction and soft storey.

Field study to examine reinforced concrete structures in Malatya. In order to investigation the conditions presented in the introduction section, concrete structures in the locations shown in Figure 6 were examined one week after the 6 February 2023 Kahramanmaraş earthquakes.

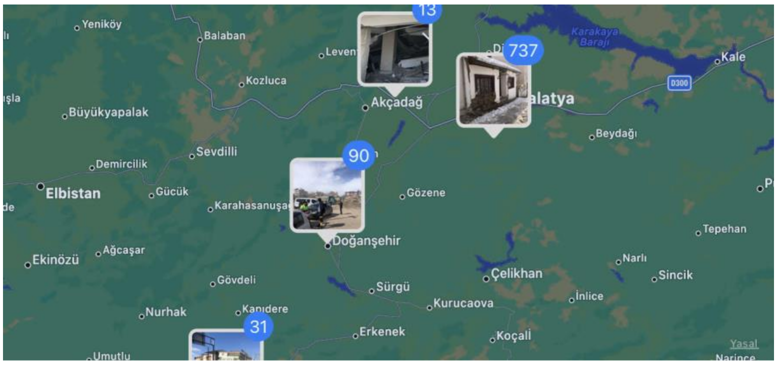

Figure 6. Locations where investigations took place [7]

Soft storey. The difference in rigidity between the floors of the building creates a soft storey irregularity. It is desirable that the total displacement of the building be divided by the total floor height. However, if there is a floor with less rigidity, this floor displaces more and this floor is called soft storey. After the earthquake, the examinations in Malatya indicated that, one of the most common causes of collapse was the soft storey. Examples of structures damaged due to soft storey are shown in Figure 7.

Figure 7. Examples of damage due to soft storey [9]

Failures of gable walls. Existing gable walls were weak against the out-of-plane mechanism during the earthquake because these walls were constructed without bond beams. This type of failure is not a structural damage but falling parts of wall can be cause loss of lives and properties. The main reason of damages to such walls is the large unsupported wall lengths. It was determined that poor wall-to-wall, wall-to-floor connections, and absence of lateral supporting walls were the other reasons of these damages [10]. The photos taken during the investigations after the earthquake in Malatya and the damage caused to the gable walls are shown in Fig.8.

Figure 8. Failures of gable walls in Malatya [10]

*Strong beam–weak column***.** In reinforced concrete structures, the stronger design of the columns than the rafters is a very important design principle. Because the parts that are exposed to the most earthquake force with the moments that will occur during the earthquake will be at the column-beam junction points and the formation of plastic hinge will occur. The formation of these plastic hinges on the beams will prevent the structure from being heavy damaged and will allow it to consume more energy However, during the field work, many strong beams and weak column combinations were observed by the researchers in the buildings that were heavily damaged and collapsed, and some of them were shown in the Fig.9.

Figure 9. Failures due to strong beam- weak column combination [10]

Inadequate reinforcement. Another design error determined in reinforced concrete structures in Malatya during the fieldwork is inadequate reinforcement. Examples of damages caused by this design error are shown in Fig.10.

Figure 10. Damages caused by inadequate reinforcement [10]

Adjacent Buildings. Adjacent buildings are frequently preferred in Turkey, especially in old settlements. If a building with insufficient seismic performance is located somewhere between adjacent structures, it can perform better than expected by getting support from other structures. Although this situation was encountered in Malatya, the opposite scenarios were also observed. That is, buildings that are individually modeled and resistant to earthquakes, without considering the effects of adjacent systems, are usually heavily damaged or collapsed if they are located at the outermost of the structures built as adjacent structures. A situation related to this is shown in Figure 11 with the buildings in the same adjacent order.

Figure 11. Examples of damage and collapse in adjacent structures [10]

Torsional irregularity. Torsional irregularity occurs because the rigidity center and center of gravity of the structures do not overlap, or the limits given in the regulations are exceeded. This irregularity can often cause structures to collapse with heavy damage. Examples of torsional irregularities observed in center of Malatya and Doğanşehir (district of Malatya) are shown in Fig.12.

Figure 12. Examples of damages in structures with torsional irregularity [10]

Poor quality of materials. During the fieldwork approximate compressive strengths were tried to be measured with schmidt hammer from the concrete in the reinforced concrete structures that were demolished. Generally, it has been determined that the compressive strength of concretes are below 10 MPa. As reinforcement, unribbed flat reinforcement is used and its tensile strength is 220 MPa. In addition, a decrease in cross-section due to corrosion was also detected in the reinforcements. Studies on material quality are shown in Fig.13.

Figure 13. Poor quality of materials [10]

Conclusion. Within the scope of this study, one week after the earthquake in Kahramanmaraş on February 6, 2023, Malatya was visited and design errors in reinforced concrete structures in the field and damage modes caused by the earthquake were investigated. As a result of the observations made in the field; it was determined that the longitudinal reinforcements in the structural members were insufficient, and the stirrup reinforcements were missing. In addition, the measurements made with the Schmidt hammer showed that the concrete quality was lower than expected. Likewise, it has been clearly observed that the reinforcements used in most of the collapsed buildings are unribbed and of poor quality. Neglecting of tighten stirrups at the junction of columns-beams, which is one of the critical areas in buildings, and preference of weak column-strong beam instead of strong column-weak beam reveals the design errors. Also, it is thought that important parameters such as torsional irregularity, soil-structure interaction and soft storey, which should be considered during the design phase, have been ignored and increased the destructive effect of the earthquake.

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