THE FEBRUARY 6, 2023, KAHRAMANMARAS-TURKIYE EARTHQUAKES: SEISMO-TECTONIC EVALUATIONS AND EFFECTS ON RC BUILDINGS

Asst. Prof. Dr. Adnan Kiral
Recep Tayyip Erdogan University, The Faculty of Engineering and Architecture
Correspondence: - ORCID ID: https://orcid.org/0000-0002-4534-3686

Asst. Prof. Dr. Zeliha Tonyali
Recep Tayyip Erdogan University, The Faculty of Engineering and Architecture
- ORCID ID: https://orcid.org/0000-0002-6637-7949

ABSTRACT

The Eastern Anatolian Fault Zone (EAFZ), which is one of Turkiye's two main active fault systems, experienced two of the largest and most destructive earthquakes last century on Feb. 6th, 2023. The epicentres were close to Kahramanmaras, in the districts of Pazarcik and Elbistan, at local times of 04:17 and 13:24, and the corresponding magnitudes were Mw7.7 and Mw7.6, respectively. The earthquakes' depths were 8.6km and 7.0km, respectively. Many buildings were damaged but did not collapse in the Pazarcik earthquake. However, nine hours later some of heavy damaged buildings collapsed in the Elbistan earthquake. This study (i) briefly presents seismotectonic features of the earthquake region, and (ii) presents damages on reinforced concrete buildings with on-site investigations due to the following subsequent earthquakes in the EAFZ. The use of plain round rebar, a lack of stirrup tightening in the column-beam joint, poor construction quality, the presence of a soft/weak ground story, low concrete strength, pounding effects, underestimating the requirements for earthquakes, and the building's foundation flipping over were the general causes of collapses.

Keywords: 2023 Kahramanmaras-Turkey Earthquakes; Damages on RC structures; The Eastern Anatolian Fault Zone

1. INTRODUCTION

Turkiye is one of the most seismically active regions of the world and the Middle East, having two active fault zones: The North Anatolian Fault Zone (NAFZ) and the East Anatolian Fault Zone (EAFZ). Two of the most destructive earthquakes occurred on the EAFZ on February 6th, 2023. The epicenter of first major earthquake was Pazarcik district of Kahramanmaras province, with a magnitude Mw7.7 at a local time of 4:17. Following this major earthquake, 9 hours later at 13:24 local time, a second major earthquake with a magnitude of Mw7.6 occurred in Elbistan district of Kahramanmaras province on the same fault zone as **Figure 1**. The closest distance between Pazarcık and Elbistan districts is about 80km, and the magnitudes and locations of the earthquakes were observed to be quite close to each other. A seismic sequence of hundreds of

aftershocks of magnitude greater than four and more than 50 aftershocks with a magnitude of Mw>5.0 have occurred in the earthquake region on the EAFZ as of March 14 **[1]**. These devastating sequential mainshocks occurred on the EAFZ having a strike-slip fault mechanism, and these are two of the strongest earthquakes ever recorded in the country's southeast (SE) region in the last century. **Table 1** shows the five largest magnitudes and the local coordinates of the epicenter of these main earthquakes. They felt in a very large area, including Syria, Egypt, Cyprus, Lebanon, and the Black Sea east coast of Turkiye. Also, the events produced the largest ground motions and caused major impacts to life and infrastructure throughout SE Turkiye and NW Syria. As a result of the damage assessment studies carried out in 11 provinces on the EAFZ line, 1895348 buildings were identified, of which 303455 were to be destroyed, heavily damaged (to be demolished immediately) or moderately damaged (to be repaired)**[1]**.

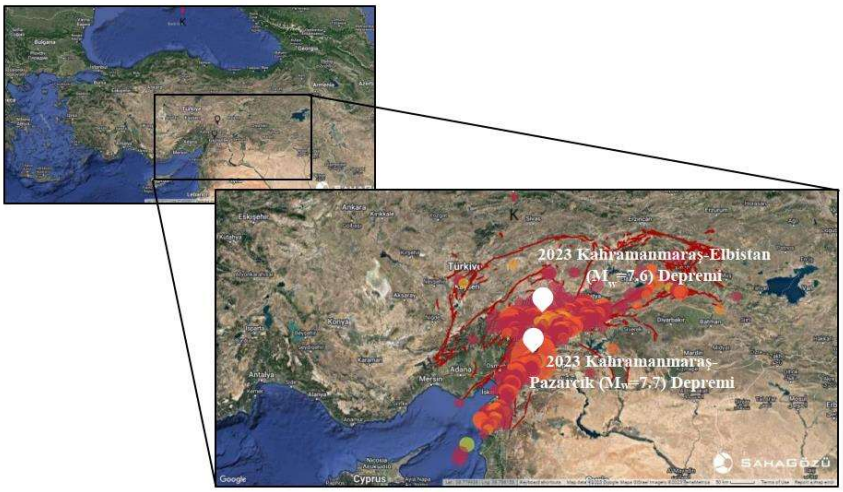


Figure 1. Kahramanmaras-Pazarcik (Mw7.7) and Kahramanmaras-Elbistan (Mw7.6) earthquakes occurred on February 6, 2023, and aftershocks in the region.

Table 1. Significant data about the five events with the greatest magnitudes [1]

Earthquake ID	*Date (m/d/y hour (UCT))*	*City*	*District*	*Lat. [°]*	*Long. [°]*	*Mw*	*Depth [km]*	*Mechanism*
543428	02.06.2023 01:17	Kahramanmaras	Pazarcik	37.288	37.043	7.7	8.60	Strike-slip
543431	02.06.2023 01:28	Gaziantep	Nurdagi	37.304	36.920	6.6	6.20	Strike-slip
543430	02.06.2023 01:36	Gaziantep	Islahiye	37.128	36.639	5.7	11.19	Strike-slip
543593	02.06.2023 10:24	Kahramanmaras	Elbistan	38.089	37.239	7.6	7.00	Strike-slip
551067	02.20.2023 17:04	Hatay	Yayladagi	36.037	36.021	6.4	21.73	Strike-slip

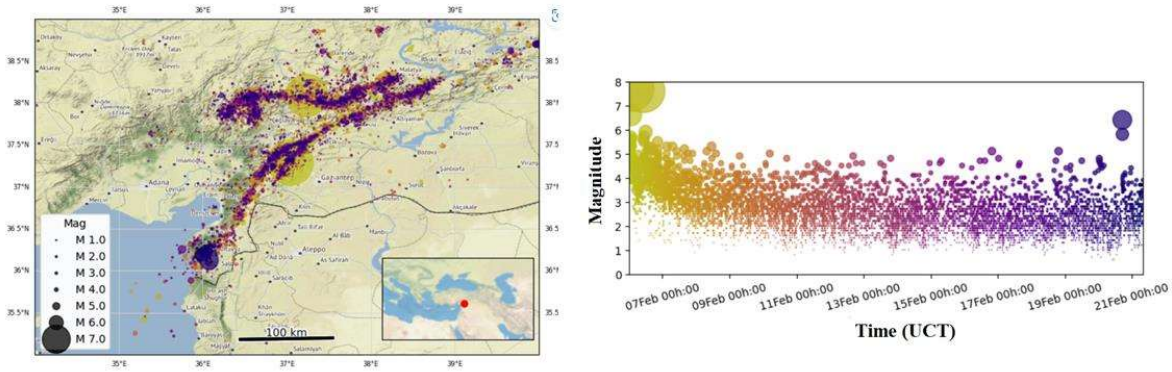
The aim of this study is to briefly presents seismotectonic features of the earthquake region, and to discuss observed damages on reinforced concrete buildings with on-site investigations due to the following subsequent earthquakes in the EAFZ. In the damage assessment studies conducted in the earthquake region, it was observed that numerous buildings in the earthquake-affected region were destroyed or suffered heavy damage. Besides that, to understand the

behaviour of collapsed or damaged buildings and to observe their performance during earthquakes, some evaluations based on field observations are presented in this study.

2. EVOLUTION OF THE SEISMIC SEQUENCE SO FAR

The EAFZ has complicated tectonics, and more research is still needed to comprehend the region's geologic history. The Arabian and Anatolian plates can move tectonically together through to the EAFZ, which is a large fault zone that extends through eastern Turkiye **[2]**. The whole length of the EAFZ, which begins in Karliova-Bingol and ends at the DSFZ (Dead Sea Fault Zone) and, creates triple connection with the NAFZ and DSFZ, is 550km **[3]**. By Emre et al **[4]**, the major branch of the EAFZ was divided into 7 segments: Karliova, Ilca, Palu, Poturge, Erkenek, Pazarcik, and Amanos portions.

On Feb. 6th, 2023, two earthquakes hit Turkey's Kahramanmaraş province at local times of 4:14 and 13:24, with magnitudes of Mw7.7 and Mw7.6. The epicenters of the earthquakes within the sequence are shown in **Figure 1**. 970 aftershock recorded three days after the mainshock with a magnitude greater than 2.5, including two major events of Mw7.7 and Mw 7.6 by EMSC**[5]**. As shown in **Figure 2a**, it's noteworthy to notice that their spatial distribution can be split into two lines and explained by the rupture of two adjacent faults. According to AFAD, 7915 aftershocks have been recorded between the 6th and 21th of February and locations of the earthquake sequence are shown in **Figure 2**.



(a) (b)

Figure 2. a) Locational evolution of the recorded earthquake sequence up to Feb. 21th; b) The variation of recorded earthquakes' magnitudes over time up to Feb. 21th**[5]**.

3. THE GROUND MOTION PROPERTIES OF THE EARTHQUAKE

The EAFZ in southeast Turkiye experienced two very significant earthquakes (Mw7.7 and Mw7.6). The events produced significant ground motions and caused major impacts on superstructures and infrastructure in the relevant region. Strong ground motions were observed for both occurrences, with intensities reaching the Modified Mercalli Intensity (MMI) 8 or 9

according to data gathered by a large network of strong motion stations and estimated from the ShakeMap product **[6]**. The two earthquakes produced the biggest ground motions in instrumental time and are the largest in the EAFZ system. This means that they are disastrous for the entire area **[7]**. Several stations operated by AFAD recorded the ground motions of the primary and aftershocks of the Kahramanmaraş earthquakes. These data are accessible in the official AFAD **[8]** database. The acceleration, velocity and displacement -time histories for all components of the earthquake at selected stations are given in **Figure 3**.

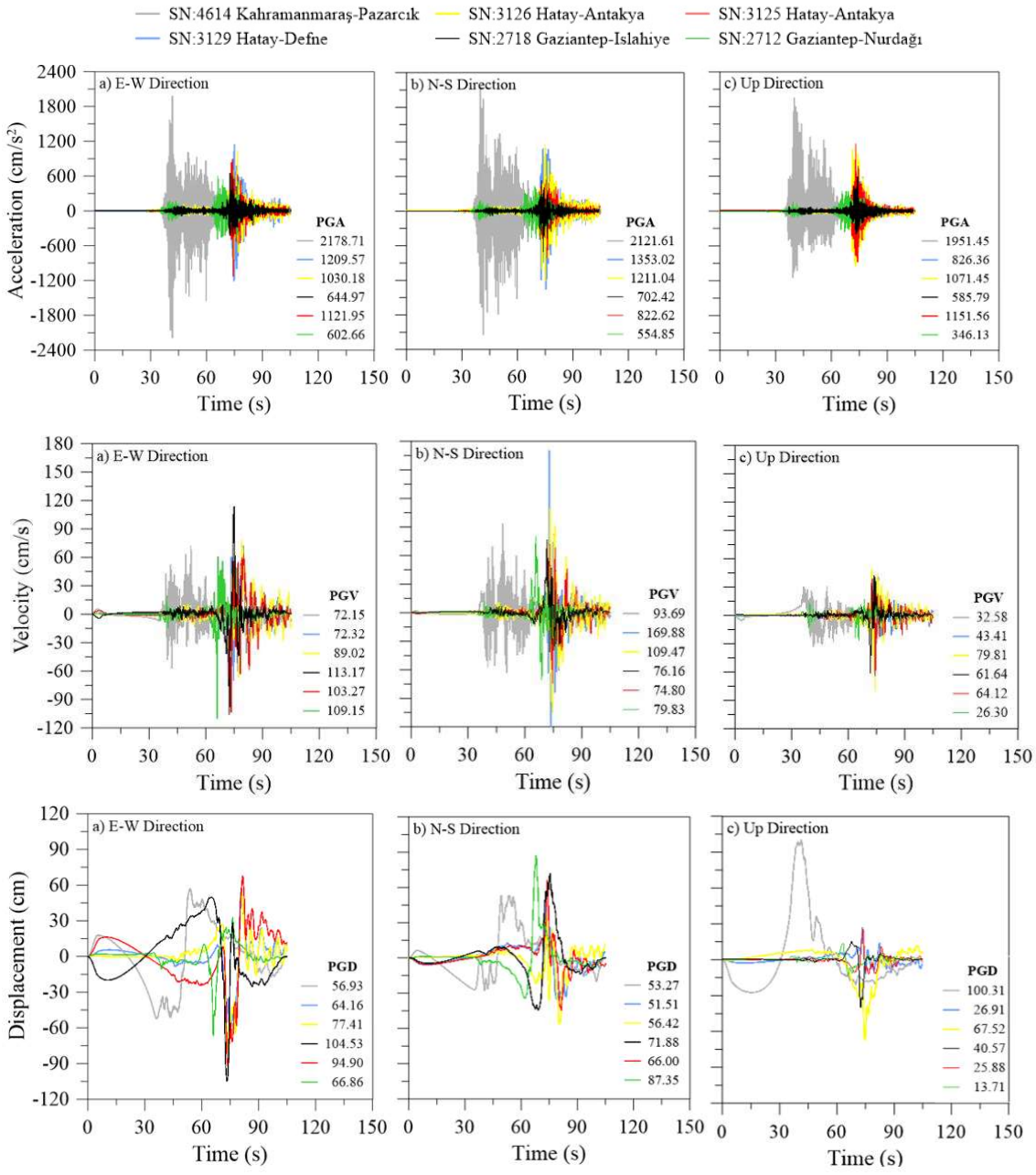


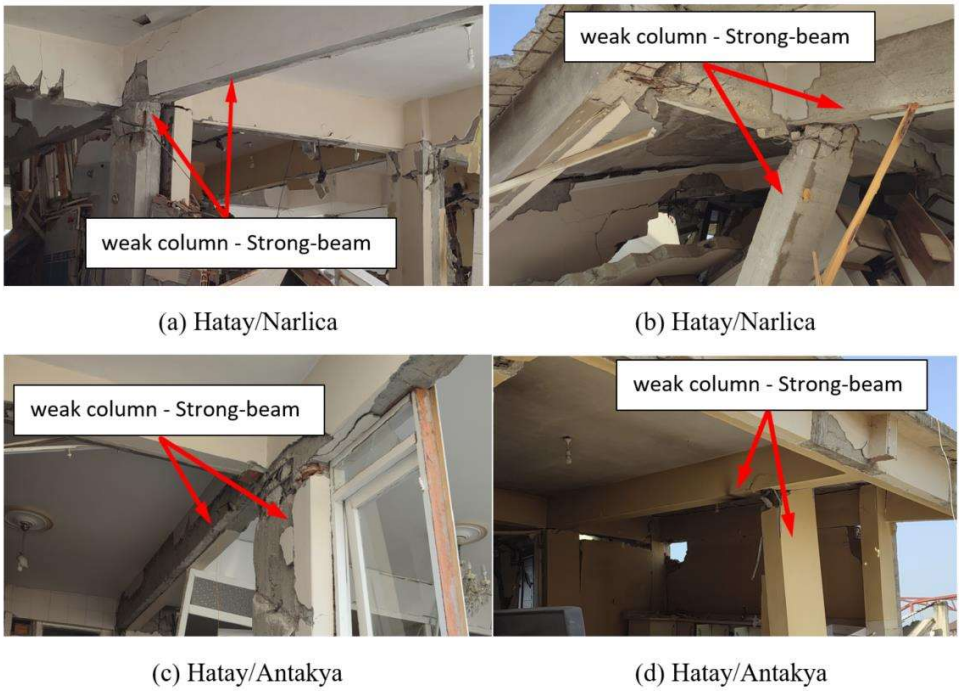
Figure 3. The largest acceleration, velocity and displacement time-histories recorded at selected stations on the Kahramanmaras-Pazarcik earthquake (Mw7.7)

According to the AFAD database on March 31th, the largest ground acceleration value was recorded at Pazarcik station located in the Pazarcik district of Kahramanmaras province on February 6th 2023 Kahramanmaras-Pazarcik earthquake (Mw7.7) and these are around 2g in all directions as shown in **Figure 3**. Also, the acceleration of ground motion exceeds the acceleration of gravity at many stations operated by AFAD. This means that these acceleration values are quite serious. While earthquake engineers frequently concentrate on acceleration, velocity more accurately depicts damage that can be seen **[9], [10]**. The Shakemap Intensity Map Worden et al. **[11]**, which includes 10 levels linked to ground velocity and acceleration, indicates that very substantial damage to structures and lifelines is associated with ground accelerations greater than approximately 1.4g or ground velocities exceeding around 180cm/s. It is also observed that the largest velocity records in the N-S direction occurred at Defne station in Hatay as shown in **Figure 3**, which is 169.88cm/s. A ground velocity greater than 80-90 cm/s in this earthquake implies considerable damage to structures.

4. RC BUILDING SEISMIC PERFORMANCE DURING THE 2023 TURKIYE EARTHQUAKE

4.1 Weak column-strong beam

The older RC structures in Turkiye were built using a strong beam and weak column design before the current seismic codes were introduced. The strong beams in this form of construction respond elastically to earthquakes, but the weak columns have brittle failures due to compression crushing or shear failure. When the Kahramanmaraş-Turkiye earthquake struck on February 6, 2023, the strong beam-weak column design was mostly to blame for the complete and partial collapse of buildings. **Figure 4** depicts the collapse of many structures damaged by this kind of design.



(a) Hatay/Narlica (b) Hatay/Narlica

(c) Hatay/Antakya (d) Hatay/Antakya

Figure 4. Damages related to weak column-strong beam

4.2. Damages due to poor concrete quality, corrosion and inadequate concrete cover

In order for RC buildings to perform as expected during earthquakes, concrete compressive strength is one of the crucial components. Field investigations revealed that many badly damaged or collapsed structures lacked appropriate concrete quality. Corrosion of reinforcing bars and inadequate concrete cover were other structural material issues observed in the earthquake regions. The lack of concrete cover resulted in reinforcement corrosion, which reduced the reinforcing bars' diameter. Turkiye began using ready-mix concrete after the 1999 Kocaeli earthquake. Prior to this earthquake, hand-prepared concrete without the use of a vibrator was often used. Because of this defect in the application, the concrete did not mix uniformly and did not produce the desired compressive strength. Damages to buildings caused by poor-quality concrete and corroded reinforcement bars are shown in **Figure 5**.

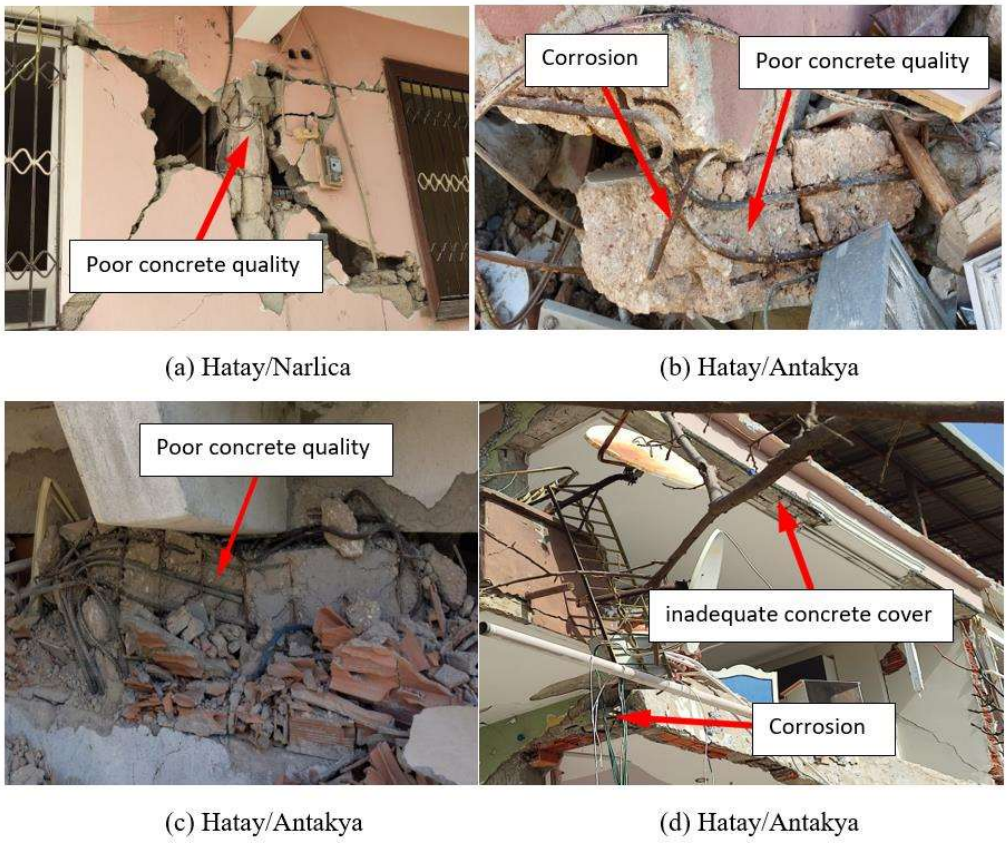
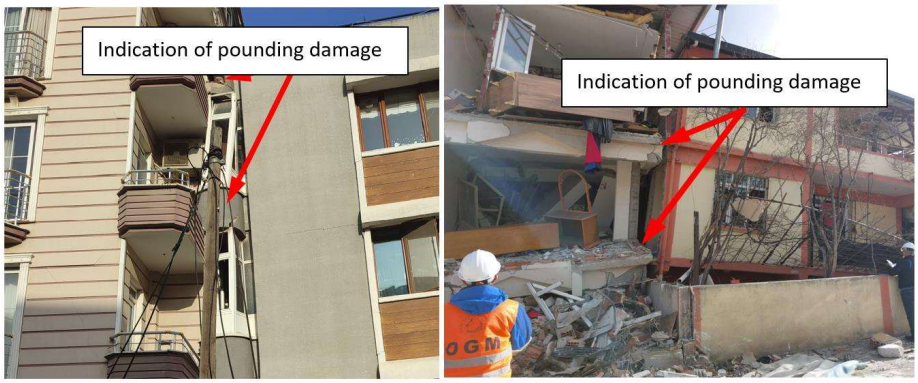


Figure 5. Poor concrete quality, corrosion and inadequate concrete cover related damages

4.3. Damages due to inadequate distances between neighbouring structures

In the city centres, adjacent structures are constructed due to a lack of available land. This allows one or two building facades to be in contact with one another or to have a little gap between them. Insufficient space between the two buildings causes them to collide during an earthquake. The scenario becomes especially dangerous when neighbouring structures' floor levels are out of alignment. These kinds of situations might result in brittle fractures if the floor of one structure crashes into the columns of the other. To avoid this damage, there must be enough space between neighbouring structures. **Figure 6** presents building damages in the region, which are related to inadequate distances between neighbouring structures.



(a) Hatay/ Antakya (b) Hatay/Antakya

Figure 6. Damages related to inadequate distances between neighbouring structures

4.4. Damages due to short column

An outside band window used for lighting the basement facilitates the formation of a short column. It reduces the effective length of a column, makes it stiffer, and causes considerable shear forces for the column, resulting in shear cracking and brittle failure. In **Figure 7**, this kind of critical failure is depicted.



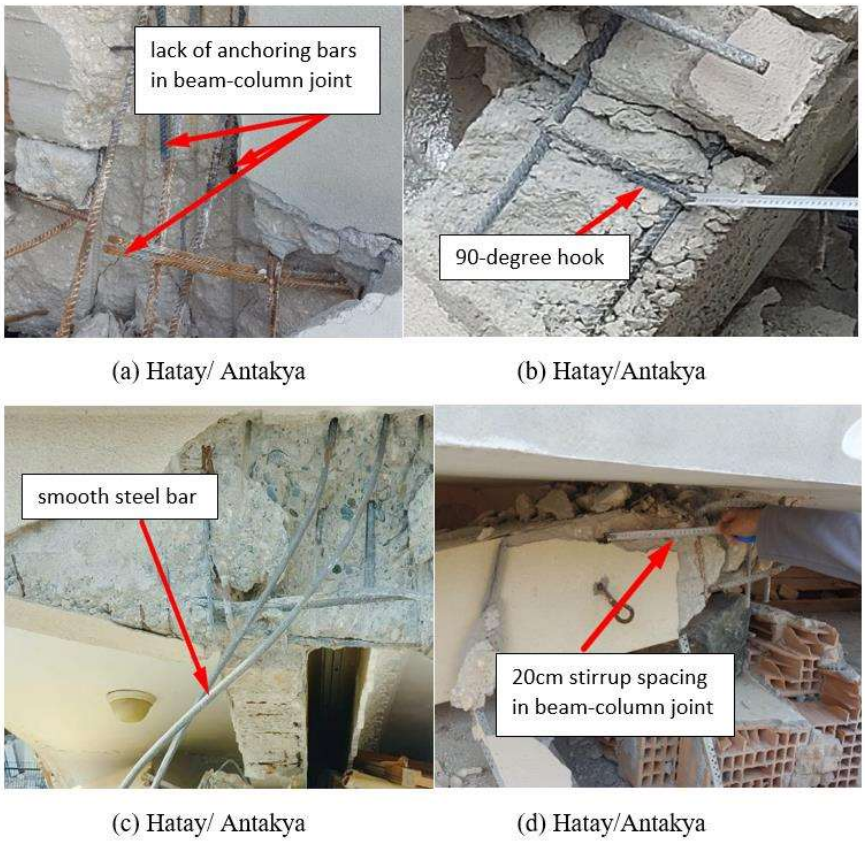
(a) Hatay/Antakya (b) Hatay/Narlica (c)Hatay/ Narlica

Figure 7. Short column related damages

4.5. Damages due to transverse and longitudinal reinforcing

To achieve the expected structural response to earthquakes, all structural components must be sufficiently ductile. The flexural ductility and shear resistance of columns and beams are both critically dependent on transverse reinforcement. Due to improper construction, reinforced bars can easily bend under compression during an earthquake. Investigations at the site revealed that

more than 90% of seriously damaged structures did not comply with regulations regarding transverse reinforcement spacing. The spaces between structural members were particularly large in the plastic hinge regions, where they ranged from 20cm to 35cm. Bond failure, which may potentially result in brittle failures, was another problem that was noted. The design guidelines strongly advise against smooth reinforcement and insist that bars be tightly anchored. When bending seismic hooks and ties, the reinforcing bar must not be damaged and the bending angle must not be less than 135°. However, a site inspection revealed smooth transverse reinforcement, which reduces concrete adhesion (bond-slip), and 90-degree bent seismic tie hooks. **Figure 8** shows the observed building damages in the region due to transverse and longitudinal reinforcing .



(a) Hatay/ Antakya (b) Hatay/Antakya

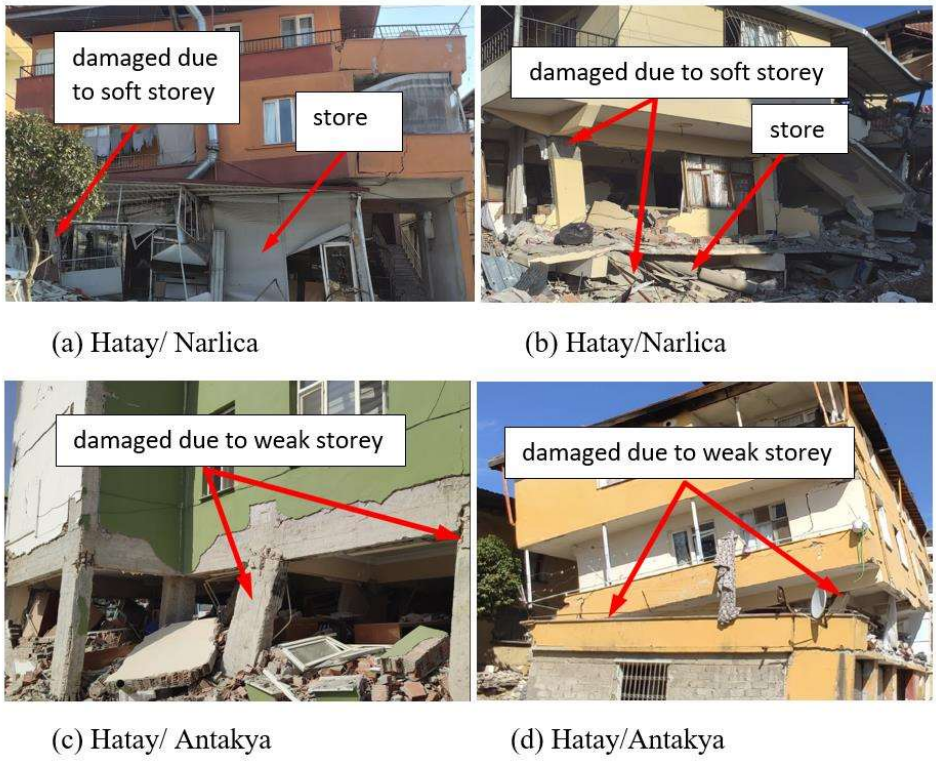
(c) Hatay/ Antakya (d) Hatay/Antakya

Figure 8. Damages related to transverse and longitudinal reinforcing

4.6. Soft/ weak storey formations

In Turkiye, the ground level of buildings is frequently used for commercial purposes like stores. When transforming ground floors into commercial spaces, business owners usually remove portions of the ground floor's infill walls. The base level, where the partition walls are removed, deforms more than the upper floors. This led to a soft-storey mechanism. Another aspect contributing to soft-story mechanisms development is the rise in ground floor height. Heightening the floor reduces floor rigidity. This floor experiences massive displacements and thus extremely big second-order moments during an earthquake, which causes the building to

completely collapse on this floor's top. Buildings should use RC shear walls or larger columns to restrict ground floor drift to avoid soft/weak-storey damage. **Figure 9** shows the collapses connected to a soft/weak-storey mechanism during the 2023 earthquakes.



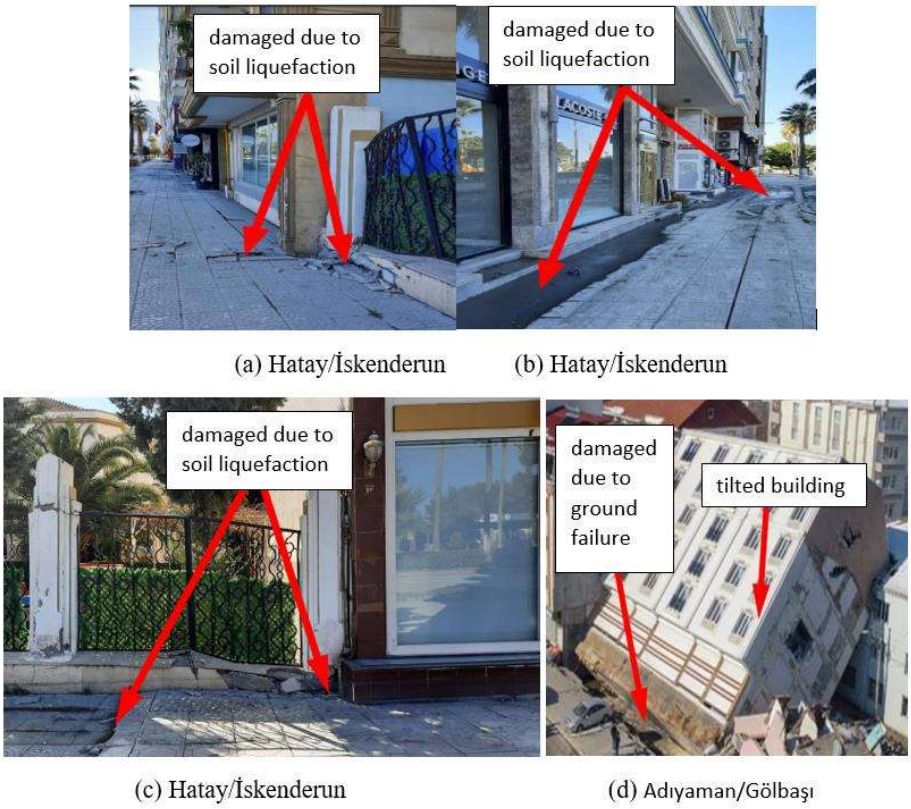
(a) Hatay/ Narlica (b) Hatay/Narlica

(c) Hatay/ Antakya (d) Hatay/Antakya

Figure 9. Damages related to weak and soft storey mechanism

4.7. Foundation damage

The excessive settlements and bearing capacity failures in the foundation of several residential structures in Hatay-Iskenderun (**Figure 10**a, b and c) and Adiyaman/Gölbaşi were observed due to seismic soil liquefaction. A few centimetres and as much as 100 centimetres were the sizes of these foundation settlements **[12]**. **Figure 10**d depicts a severe instance of liquefaction-induced bearing capacity failure in Adiyaman-Gölbaşi **[13]**.



(a) Hatay/İskenderun (b) Hatay/İskenderun

(c) Hatay/İskenderun (d) Adıyaman/Gölbaşı

Figure 10. Damages related to soil liquefaction

5. CONCLUSION

Powerful earthquakes shook Syria and Turkey. On February 6, 2023, a number of earthquakes occurred in Turkiye's EAFZ, with the strongest and most devastating having its epicentre in Kahramanmaraş. The outcomes of this paper is as follows:

- Buildings significantly damaged due to insufficient anchoring bars, inadequate transverse reinforcement spacing, smooth bars usage, 90-degree hook in stirrup end, corrosion, poor concrete quality, inadequate concrete cover and having weak/soft storey mechanism.
- Damage to ground floors caused by short-column formation was one of the frequent causes seen in the area. This area can be prevented from significant structural damage by building a wall around it.
- Because there was not enough space between the buildings, they felt the pounding of an earthquake. Damages can be avoided by leaving enough space between them.
- Nearly 90% of structural damage observed in the area's old structures was caused by strong beam-weak column mechanism. To avoid this sort of damage, columns should be stronger than beams.
- One of the causes of building damage in the area, particularly in Hatay and Adiyaman, was due to soil liquefaction. This issue could be resolved by restricting the number of storeys or by applying advanced foundation retrofitting methods.

Acknowledgment:

We would like to express our thanks to AFAD (Disaster and Emergency Management Presidency of Turkey) for providing the required data.

REFERENCES

[**1**] AFAD, "Disaster and Emergency Management Presidency of Turkey, Available From:https://www.afad.gov.tr," 2023.
[**2**] N. N. Ambraseys, "Temporary seismic quiescence: SE Turkey," *Geophys. J. Int.*, vol. 96, no. 2, pp. 311–331, 1989,
[**3**] A. M. C. Şengör, N. Görür, and F. Şaroğlu, "Strike-slip faulting and related basin formation in zones of tectonic escape: Turkey as a case study," 1985.
[**4**] Ö. Emre *et al.*, "Active fault database of Turkey," *Bull. Earthq. Eng.*, vol. 16, no. 8, pp. 3229–3275, 2018,
[**5**] EMSC, "European-Mediterranean Seismological Centre," 2023. https://www.emsc-csem.org/Earthquake/271/Earthquake-sequence-in-Turkey-February-6th-2023
[**6**] USGS, "United States Geological Survey," 2023. https://earthquake.usgs.gov/earthquakes/eventpage/us6000jlqa/finite-fault
[**7**] D. Melgar *et al.*, "Sub- and super-shear ruptures during the 2023 Mw 7.8 and Mw 7.6 earthquake doublet in SE Türkiye," 2023.
[**8**] AFAD, "Disaster and Emergency Management Presidency of Turkey. 'Kahramanmaraş'ta Meydana Gelen Depremler Hk. – Basın Bülteni 36', Available From:https://www.afad.gov.tr/kahramanmarasta-meydana-gelen-depremler-hk-36," 2023.
[**9**] O. O. Erteleva, "Velocity response spectra: Estimates of parameters and shapes," *Seism. Instruments*, vol. 52, no. 4, pp. 301–307, 2016,
[**10**] N. Makris and C. J. Black, "Evaluation of Peak Ground Velocity as a 'Good' Intensity Measure for Near-Source Ground Motions," *J. Eng. Mech.*, vol. 130, no. 9, pp. 1032–1044, 2004,
[**11**] C. B. Worden, E. M. Thompson, M. G. Hearne, and D. J. Wald, "Shakemap 4.0 Manual. United States Geological Survey," 2020.
[**12**] TMMOB, "6 Şubat 2023 Depremleri Tespit Ve Değerlendirme Raporu," 2023.
[**13**] K. . Cetin, M. Ilgac, G. Can, and E. Cakar, "Preliminary Reconnaissance Report on February 6, 2023, Pazarcık Mw=7.7 and Elbistan Mw=7.6, Kahramanmaraş-Türkiye Earthquakes," 2023.