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Original Article

Materials and Structural Failures Observed after the February 6, 2023 Kahramanmaraş Earthquake in Turkey

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Abstract *- Turkey is located on a very active tectonic plate, causing strong seismic earthquakes. On February 6, 2023, two major earthquakes struck Turkey with a magnitude of Mw 7.8 and 7.5. This study presents the different types of common structural damage observed in the buildings after the earthquake. The damage status of a bridge, a railway, and roads are also reported. The main conclusions are that seismic codes must be revised and adjusted, and structures must be strictly monitored by civil engineers as they are designed and constructed to avoid the listed deficiencies.*

Keywords *- Earthquake, Damage, Buildings, Infrastructure, Turkey.*

1. Introduction

Turkey is located in an area of high seismic activities, where the collision of the Eurasian and African tectonic plates causes frequent earthquakes, as illustrated in Fig. 1 (Aktug et al. 2009). The history of earthquakes in Turkey goes back centuries, and the region has experienced numerous devastating earthquakes throughout history. In the 20th century, several major earthquakes have occurred in Turkey. In 1939, a magnitude 7.9 earthquake struck the eastern city of Erzincan, killing over 30,000 people. In 1999, a magnitude 7.6 earthquake struck the Marmara region, which includes Istanbul, killing over 18,000 people and causing significant damage to infrastructure (Dikbaş et al. 2018).

In addition, Turkey has experienced several significant earthquakes in recent years. In 2011, a magnitude 7.1 earthquake struck the eastern city of Van, killing over 500 people. In 2020, a magnitude 7.0 earthquake struck the Aegean Sea off the coast of Izmir, causing significant damage and loss of life (Caglar et al., 2020).

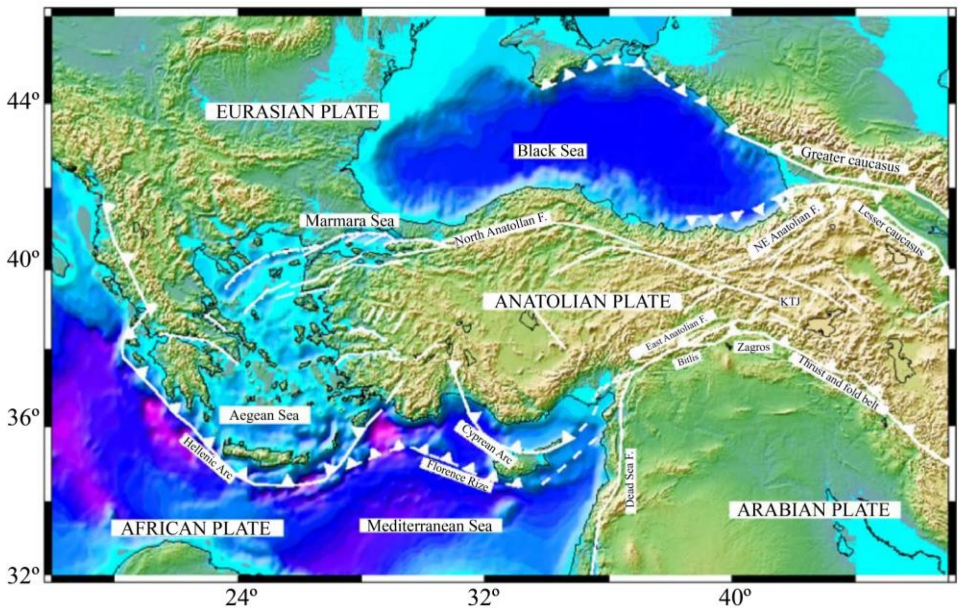


Fig. 1 Tectonic structure of anatolia and surrounding regions (Aktug et. al. 2009)

On February 6, 2023, at 04:17 local time (01:17 UTC), a magnitude of Mw 7.8 earthquake was recorded in southern central Turkey and northern western Syria. The epicenter was 37 km northwest of Gaziantep City. The earthquake's epicenter was 37.17 N–37.08 E, with a depth of 18 km. The earthquake was felt by approximately 10 Turkish provinces: Adana, Adiyaman, Diyarbakir, Gaziantep, Hatay, Kahramanmaras, Kilis, Malatya, Osmaniye and Sanliurfa, causing huge destruction and damage to the structures in the area. On the same day, after about nine hours, at 13:24 local time (10:24 UTC), another earthquake struck about 50 km northeast of kahramanmaraş city with a magnitude of Mw 7.5. The earthquake's epicenter was 38.11 N–37.24 E, with a depth of about 10 km. The locations of the two earthquakes are illustrated in Fig. 2. The earthquakes caused severe damage to the struck places, as will be shown later.

As the building construction industry expands around the world, it is expected that earthquakes will cause widespread damage if codes and correct practices are not followed. In the next paragraphs, several misconducts will be surveyed and highlighted to make recommendations that can be implemented in the related codes in the future. In addition, this will help engineers and contractors to avoid such practices that lead to such severe damages.

Fig. 2 Locations of February 6, 2023, major two earthquakes

2. Literature Review

Earthquakes usually cause different levels of damage to structures, depending on many variables. Many researchers have reported damage due to different earthquakes around the world. These reports always help engineers and institutions to understand the behavior of the structures better and eventually make them more resilient and seismic resistant. Sucuoğlu et al. (1997) presented the damage in Dinar City in Turkey due to 1995 earthquakes. The earthquake was of medium scale and caused moderate shaking across the city, although the damage it inflicted was greater than anticipated. The fault rupture mechanism and the soil characteristics may have influenced the magnitude of the damage.

Kawashima et al. (2011) investigated bridge damages in Chile after the 2010 Maule earthquake. They stated that low precast girder strength, inadequate bridge integrity caused by not implementing appropriate diaphragms, and the absence of an effective stopper mechanism all contributed to significant damage. These defects were especially significant in skewed bridges, which were severely damaged as a result of an entire bridge trial to rotate in the plane.

Bhagat et al. (2018) studied the 2015 Nepal Gorkha earthquake and its effects on cultural heritage structures through a field survey of the severely affected areas of the Kathmandu Valley. They covered damage in both engineered and non-engineered buildings.

Gurbuz et al. (2023) described the effects of the Aegean Sea Earthquake in October 2020 on structures in the vicinity of Izmir in Turkey, as seen during the site examination. The seismic sensitivities of structures are discussed. They discussed the damage mechanisms of the deficiencies and flaws that contributed to the collapse of the structures. They also investigated the non-structural damage that could affect building usage. Recommendations are then suggested for avoiding fatalities and casualties in the future.

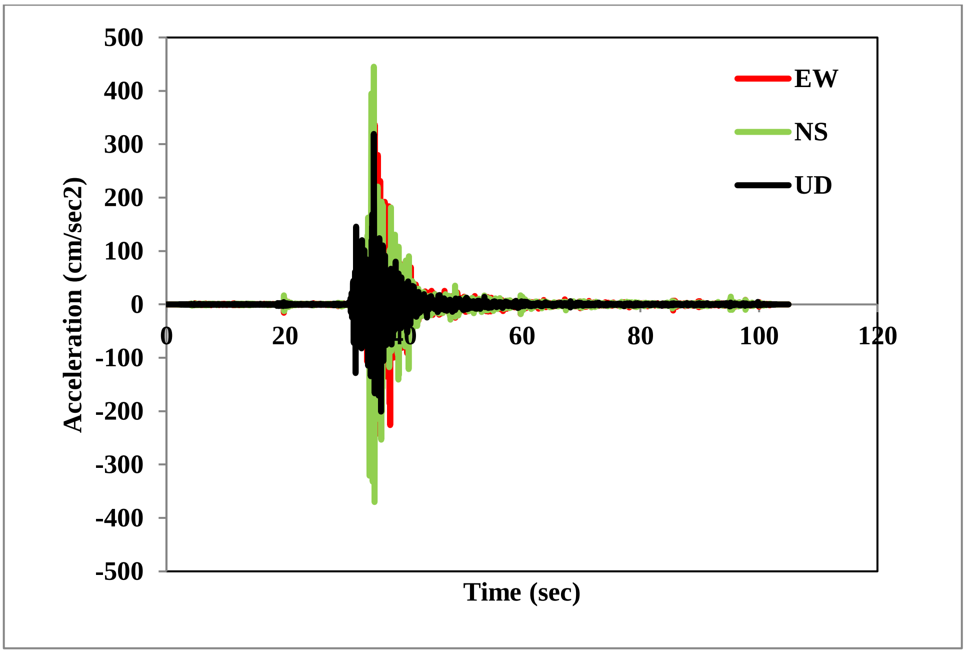
Moradi and Shah-Hosseini (2021) assessed earthquake damage by using deep learning techniques on satellite images. Mimura et al. (2011) highlighted the damages caused by a very strong earthquake near the east coast of Japan in 2011.

From this survey, it can be seen that only a few research is found in the literature discussing severe earthquake damages. The objective of this paper is to investigate the failures that occurred and the reasons behind them after the major earthquakes that struck Turkey on February 6, 2023. In addition, recommendations will be made to improve design and construction practices.

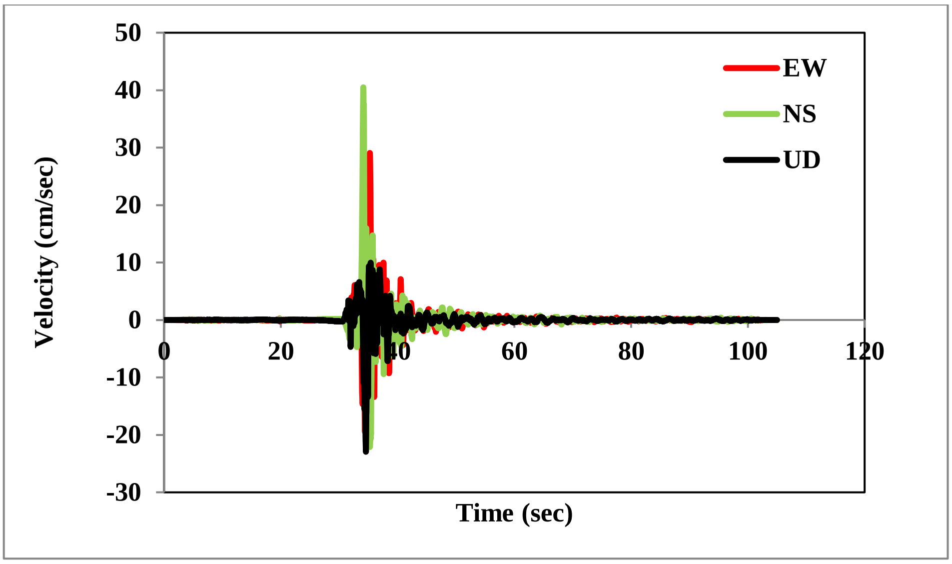
3. Earthquake Records

The first earthquake's processed acceleration, velocity, and displacement records are extracted from the Turkish Accelerometric Archive - Disaster and Emergency Management Presidency (2020), Earthquake Department, station number 2712, in Nurdagi City. These records are shown in Fig. 3. In addition, the same records for the second earthquake are extracted from station number 4612, which is located in Ekinozu town in Kahramanmaraş Province. These records are illustrated in Fig. 4. Figures 3 and 4 provide curves that present the records in three directions: East-West (EW), North-South (NS), and Up-Down (UD). These data were extracted from stations showing each earthquake's highest peak ground acceleration.

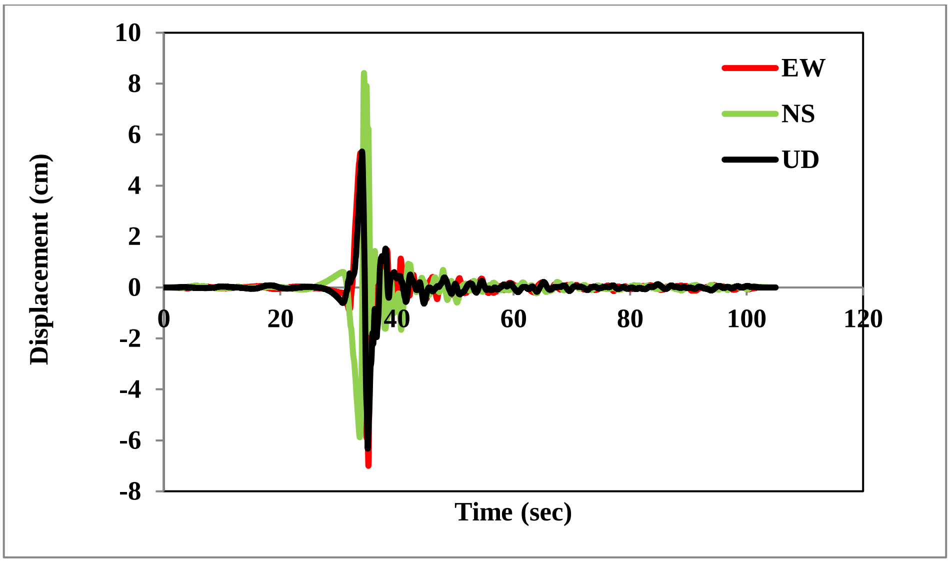
The first earthquake's records show intensive ground acceleration that reached about 445cm/sec2 or 0.454 g. It lasted for about 20 seconds before it started fading. On the other hand, the second earthquake's records show peak acceleration reaching about 76 cm/sec2 that lasted for about 60 seconds, divided into two major periods. Velocity records are also significantly lower in the second earthquake compared to the first one. The peak velocity was 4.18 cm/sec in the second earthquake compared to 40.49 cm/sec in the first one. Displacement peaked at about 8.38 cm in the first earthquake and about 0.69 cm in the second one. These records would indicate that most of the structural damages and failures that happened were mainly due to the first earthquake more than the second one.



(a)

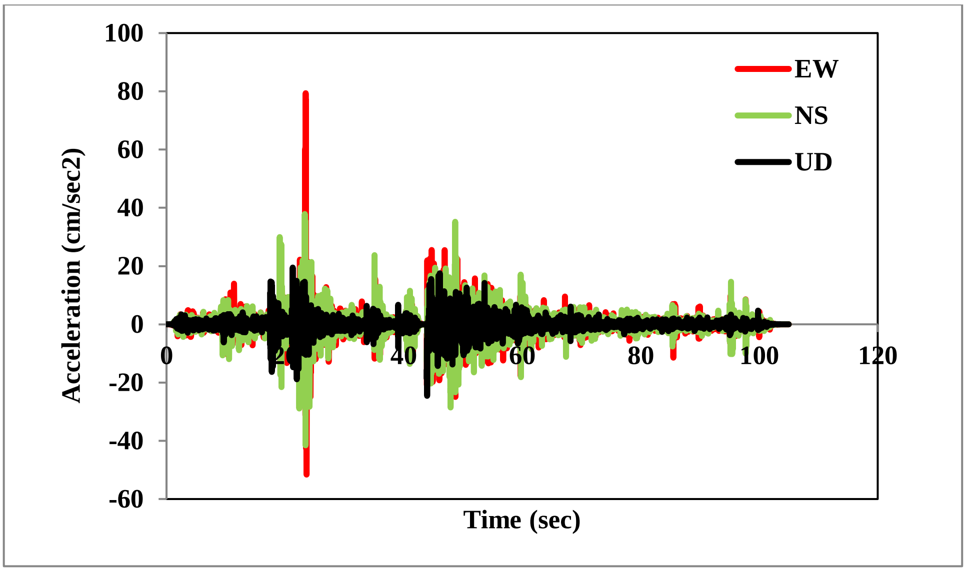


(b)

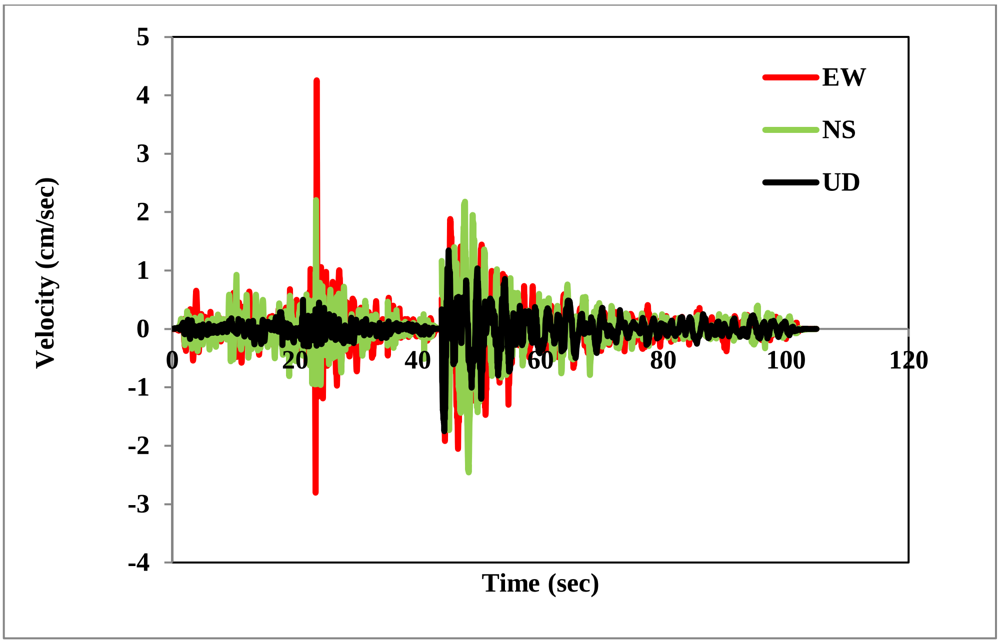


(c)

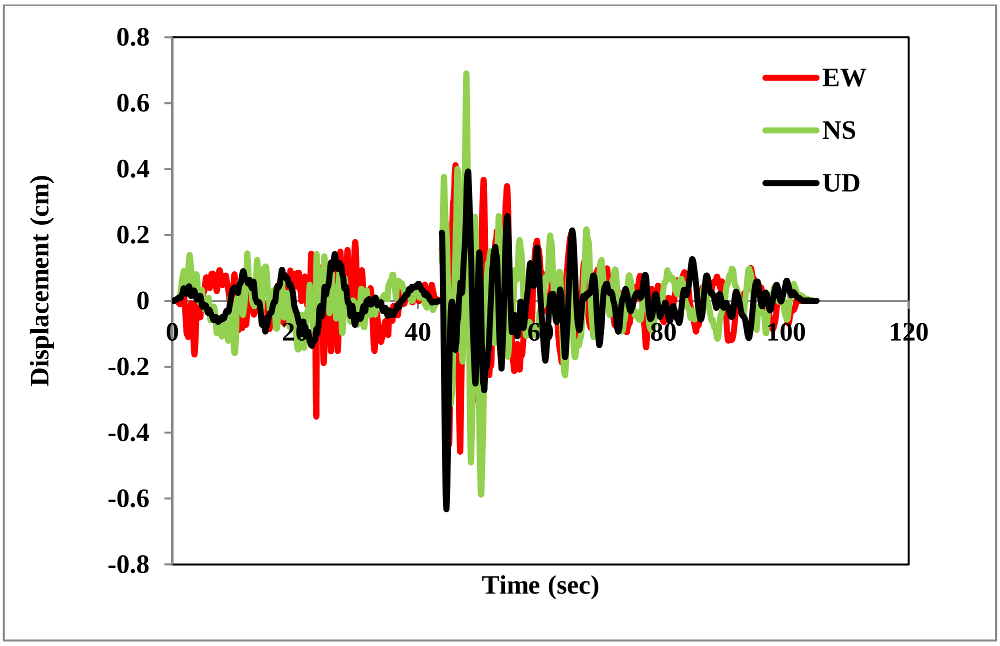
Fig. 3 Processed (a) acceleration, (b) velocity, and (c) displacement records of the first earthquake in three directions: East-West (EW), North-South (NS), and Up-Down (UD)



(a)



(b)



(c)

Fig. 4 Processed (a) acceleration, (b) velocity, and (c) displacement records of the second earthquake in three directions: East-West (EW), North-South (NS), and Up-Down (UD)

4. Failures and Collapses

Many photographs were analyzed to study the different structural failures and collapse mechanisms, in addition to the reasons that led to them.

The damages in buildings are classified according to the damage types illustrated in Fig. 5, while other types of damages are listed afterwards. The engineering failures and collapses are classified as the following:

4.1. Pan-Cake Collapse

Total shear failure of small reinforced concrete column sections occurs in the absence of significant shear walls. This led to the well-known pancake collapse pattern, either for all stories, as shown in Figure 6, or for lower stories, as shown in Fig. 7, or for an intermediate story, as shown in Fig. 8. Such failures usually result in huge amounts of building waste. Using these huge amounts in new concrete mixes can be feasible, which helps save landfill spaces and have more sustainability in natural resources.

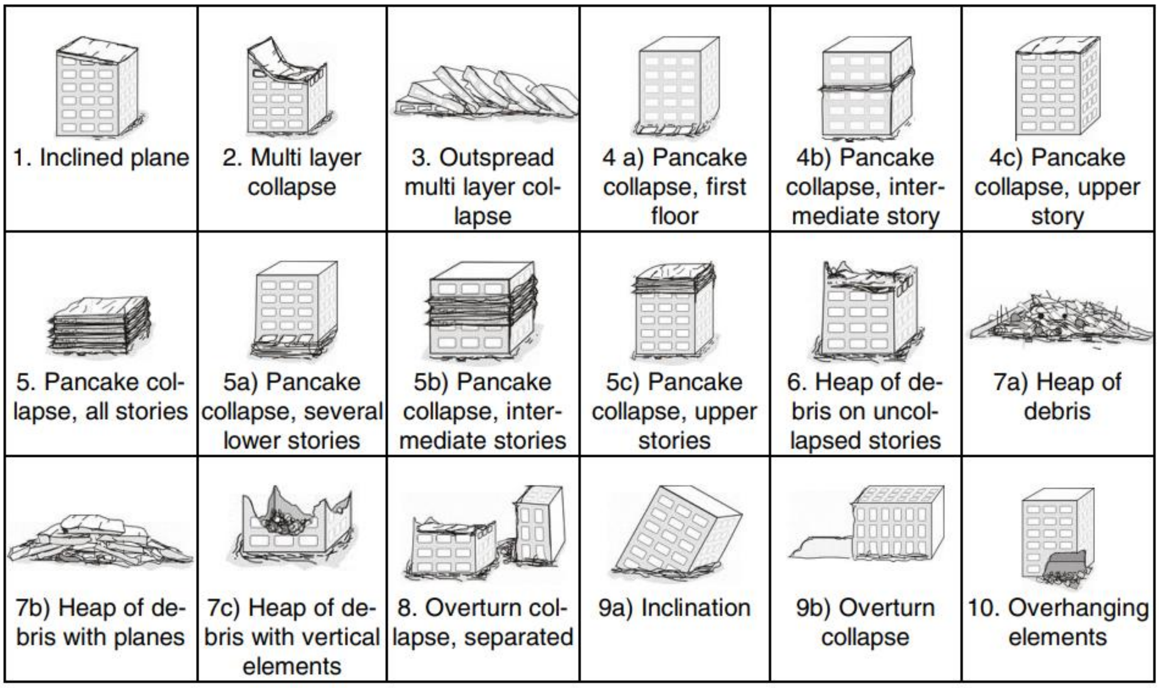


Fig. 5 Compilation of damage types (Schweier and Markus, 2004)

Fig. 6 Pan-cake collapse of buildings in Kahramanmaras, Turkey. (Sky News, 2023)

Fig. 7 Pan-cake collapse of a lower-story damaged building in Diyarbakir, Turkey (Sertac Kayar/Reuters)

Fig. 8 Pan-cake collapse of the intermediate story of a damaged building in Kahramanmaras, Turkey (Sky News, 2023)

4.2. Inclination or Overturning Collapse of Buildings

This can be caused either by failure in some of the story's columns or by geotechnical soil failure under one side of the building. This is illustrated in Fig. 9a, where it looks like the columns on one side of the building have failed, and the whole building is overturned. The building slabs seem distorted due to the columns' failure. Another overturned building is shown in Fig. 9b but with less distorted slabs. This could indicate a geotechnical soil failure in the form of liquefaction, especially since the building is close to a water source.

(a)

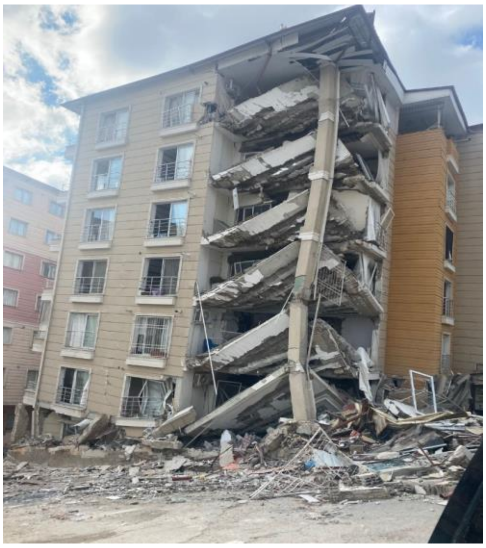
(b)

Fig. 9 An aerial view showing the overturning collapse of two buildings in Hatay, Turkey (Umit Bektas/Reuters)

4.3. Partial Collapse of Buildings

Failure of one part of the building would occur while the rest of the building is still standing, as illustrated in Figure 10. Apparently, the stiffness of one side of the building is lower than the rest of the structure, which led to the partial collapse. Such asymmetry in building and structures are unfavourable in such active seismic zones and should be avoided or properly designed for the anticipated seismic activity.

(a)



(b)

(c)

Fig. 10 Partial collapse of buildings in (a) Hatay, Turkey (REUTERS/Emilie Madi), (b) Hatay, Turkey (Cem Yenidogan/Linkedin), (c) Nurdağı district, Turkey. (Egemen Sönmez/Linkedin)

4.5. Torsional Spiral Cracking in Concrete Columns

This was captured in a building in Malatya, as illustrated in Fig. 11. Apparently, the torsional vibrational mode was significant in this building during the earthquake. It could be the reason behind the collapse of many buildings.

Fig. 11 Torsional cracking of concrete columns in a building in Malatya, Turkey. (Ihlas News Agency, 2023)

4.6. Columns and Walls Failure Due to Ties

Despite the fact that longitudinal steel reinforcement in columns and walls mostly looks appropriate, large and inappropriate tie spacing was noticed in many pictures of the buildings columns and walls, as can be seen in Fig. 12, 13, and 14.

During the earthquake, the concrete usually disintegrates, adding higher axial compressive loads on the longitudinal steel bars on the one hand and losing the lateral confinement for the longitudinal bars on the other hand, causing the longitudinal reinforcement bars to buckle on short lengths. The good thing is that longitudinal bars showed high ductility and deformation, indicating good reinforcement bar quality.

Another problem with the ties is that they are executed with a 90-degree ending hock instead of the required 135-degree ending hock. This led many ties to open during the earthquake and lose the axial confinement of the element. In addition, no stirrups-densified end zones were seen in most of the columns and walls, as per seismic code requirements.

The lack of such reinforcement details prevented the columns from manifesting the higher levels of ductility they needed during the earthquake. It also prevented the columns from forming plastic hinges near the joints, which could have prevented many brittle column failures.

Fig. 12 Large tie spacing is noticed in buildings in the Nurdağı district (Egemen Sönmez/Linkedin)

Fig. 13 Large tie spacing is noticed in buildings in the Türkoğlu district (Egemen Sönmez/Linkedin)

(a)

(b)

(c)

Fig. 14 Damages and buckling in columns reinforcement in Hatay (Cenk Ustundag/LinkedIn)

4.7. Beams Failure

The earthquake has raised the stresses significantly in beams, leading to shear failure, as seen in Fig. 15, or to excessive compressive stresses, leading to buckling and eventually rupture of longitudinal steel bars at the bottom of the beams, as seen in Fig. 16. The bottom concrete cover is usually separated from the beams. The spacing of the beams' stirrups (designed to resist shear) was insufficient to provide lateral confinement for longitudinal bars against local buckling. It is also clear that there is a debonding problem between concrete and steel bars.

(a)

(b)

Fig. 15. Near support shear failure in concrete beams in a building in (a) Türkoğlu district and (b) Nurdağı district (Egemen Sönmez/Linkedin).

(a)

(b)

(c) (d)

Fig. 16 Buckling and rupture of bottom steel reinforcement bars in a building beam in Antakya. (Egemen Sönmez/Linkedin)

4.8. Buildings' Façade Failure and Peeling Off

This is illustrated in the buildings shown in Figure 17. The façade was not restrained appropriately to the building's structure, which does not comply with seismic provisions requirements. In addition, the falling of ribbed slab blocks was observed in one building in the Nurdagi district (Fig. 18). This could impose serious life-threatening risk since these blocks are considered heavy falling objects, even though the structural system could be safe in the event of losing these blocks.

(a) (b)

Fig. 17 Peeling off of façade in a building (a) in Aleppo, Syria (Sky News, 2023), (b) in Adiyaman, Turkey. (Emrah Gurel / Associated Press)

Fig. 18 Falling of ribbed slab blocks in a building in Nurdağı district. (Egemen Sönmez/Linkedin)

4.9. Masonry Infill Walls Failure and Crumbling

Masonry walls are common in residential buildings in Turkey. In many cases, the structural system was able to withstand the earthquake, but masonry walls cracked or crumbled. A sample building is shown in Fig. 19. Much research (for example, Murty and Jain (2000) and Elouali (2008)) have been conducted on the effect of masonry walls on the seismic performance of building frames.

(a)

(b)

(c)

Fig. 19 Masonry infill walls failure and fallout (Mike Mieler/Linkedin)

4.10. Bridges Damages and Failure

This was observed in the girders of the Hatay State Hospital Road bridge in north Antakya, Turkey (Fig. 20). Lateral diaphragms were missing in the bridge, which in turn allowed lateral displacement and deformation of the beams to take place. The webs of girders were heavily damaged, which could indicate the development of high shear stresses in the webs during the earthquake. Similar bridges are expected to be constructed the same way around the country and hence can be seismically vulnerable. They should be checked, and lateral diaphragms should be added as necessary. Rubber bearing pads were noticed on the ground, as they were not appropriately fastened to the bridge structure. There are also no girders stopers at the piers to prevent girders from moving laterally and hitting each other. It is clear that the bridge lacks the application of some seismic provisions' requirements. These damages are similar to those reported by Kawashima et al. (2011).

(a) **(b)**

(c) **(d)**

Fig. 20 Damage in concrete bridge parts (Farzad Haghi/Linkedin)

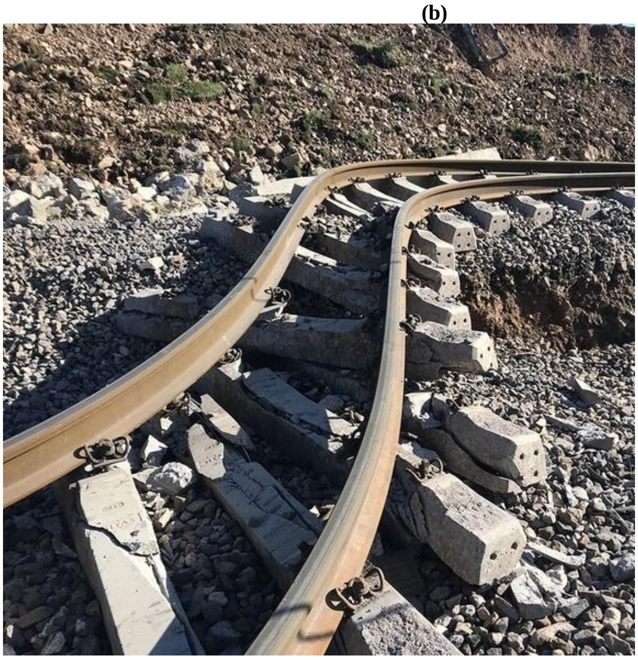
4.11. Fault Line Damages

The fault line deformation and movement caused some damage, as seen in the building in Altinuzum, as shown in Fig. 21. Although the earthquake vibration could not collapse the building, the fault line movement cracked and separated the corner of the building. Also, the movement of the fault line causes damage to a railway between the Türkoğlu district of Kahramanmaraş and the İslahiye district of Gaziantep, as shown in Fig. 22. Major earthquakes may cause multiple types of damage to railways, such as slippage, bending, misalignment due to the shaking and failure in the supporting subgrade resulting in trains derailment and suspension of operations (Byers, 2004). It is a major safety concern since moving trains will be affected and may derail, leading to accidents and loss of lives (Cmsadmin, 2011). In Turkey, the railway network has 10.68 billion passenger kilometres in passenger traffic (WorldData, 2023). More than 1,275 km of railways, passing 11 provinces, were damaged due to this earthquake. The total damage, including railways, electric, phone lines, rail stations, bridges, tunnels, and signal and communication facilities, was estimated to be around 785 million US dollars (Artymiuk, 2023). Furthermore, some areas' landslides occurred along the railways and affected the railway's operation (Fig. 23).

Even though railway damage due to earthquakes may not be avoided, measures should be implemented to avoid loss of lives due to the derailment of trains during an earthquake, especially high-speed passenger (bullet) trains. In Japan, which is well known for experiencing frequent major earthquakes, a detection and alarm system (UrEDAS) is utilized to detect earthquakes and predict the expected effects and severity. UrEDAS consists of seismometers installed at 97 locations in the country. Based on the severity of a detected earthquake, the system will transmit warning signals to shut down the power supply, stopping trains. This system is designed to reduce the derailment of moving electric passenger trains, hoping to save lives (Cmsadmin, 2011).

Fig. 21 A satellite image shows a building before and after the earthquake, where a fault line damaged the building, in Altinuzum, Turkey. (Reuters)

(a) (b)



(c)

Fig. 22 A damaged train track between the Türkoğlu district of Kahramanmaraş and the İslahiye district of Gaziantep. Photograph: (a) and (b) Anadolu Agency/Getty Images, (c) Harber|Global, 2023

Fig. 23 Landslide near Fevzipaşa train station, Gaziantep, Turkey (After Daily Sabah with DHA, 2023)

4.12. Pavements and Road Damages

Road networks are considered a major and essential part of a country's infrastructure. With the recent expansion of its economy and trading, Turkey's road network was intensively expanded to a total of 67,333 km in 2021 (WorldData, 2023). Most roads were affected in the disaster areas during this earthquake. Several types of damage were reported in roads and pavements, including slicing, major cracks, and shifting due to the movement of subbases and/or subgrade, as shown in Fig. 24, making roads unusable. Although this may not cause a major loss of lives, roads are essential to ensure the free movement of people to different places, supplying goods, and, most importantly, providing emergency services and rescue crews. Damaged roads that prevent access to disaster zones in desperate need of help after an earthquake could undermine rescue attempts and raise the death toll.

Different methods can be adopted to repair damaged pavements, including sealing, patching, resurfacing, or a total reconstruction (Yin et al., 1997), which do not differ from normal repairs of pavements. However, this will cause a massive strain on rebuilding costs and efforts, but it cannot be avoided. Repairing road networks is essential for rebuilding efforts (transporting equipment and construction materials). Different approaches to designing roads in frequently earthquake-affected regions should be evaluated and implemented to reduce the effects of an earthquake on roads. Using high ductility modified asphalt binder, such as rubberized asphalt or fiber-reinforced asphalt mixes, will increase the resistance to deformation due to earthquakes. Adding rubber-derived aggregates to asphalt mixes or unbound subbases may absorb the shocks resulting from an earthquake. In addition, increasing the stability of subbases and subgrades should be considered. Incorporating geogrids between pavement layers may reduce the shifting of unbound materials due to the shaking and vibrations induced by an earthquake. Thus reducing the damage to pavements and repairing efforts.

(a) **(b)**

(c)

(d)

Fig. 24. Damaged roads in (a) Fevzipasa, Turkey. (Emin Sansar / Anadolu Agency), (b) Demirkopru village (Reuters), (c) D420 road in Demirkopru. (Benoit Tessier / Reuters), (d) the Tarsus-Adana–Gaziantep (TAG) Highway.

5. Conclusion

The magnitude 7.8 and 7.5 earthquakes that occurred on February 6, 2023, resulted in extensive damage to all structures and infrastructures. The present paper reports and discusses the severity of the damage in different cities, villages, and urban areas. The damage seen may offer engineers and authorities some very important lessons, summarized as the following:

- The inspections that were conducted show that the building sector in Turkey is still not earthquake-ready. Although making existing buildings earthquake-safe is costly, creating new earthquake-resistant buildings to replace collapsed ones is achievable. It will be the most crucial step in limiting future earthquake losses.
- Damage to buildings was mainly due to structural deficiencies, such as the small size of columns, the absence of shear walls, the large spacing of stirrups in columns and at the beam-column joints, and irregularities in building shapes, whether horizontally or vertically. To have more resilient buildings and reduce earthquake damage in the future, it is crucial to use proper seismic design, high-quality construction materials, and authorized construction techniques.
- Building collapses due to geotechnical failure were not widely seen. They were noticed when water sources existed near buildings. This can be attributed to good geotechnical engineering designs and practices. However, special care should be taken when the groundwater level is high.
- Earthquakes are seen to crumble concrete, which directly leads to collapsing structures. Using random steel fibers in concrete can resist crumbling significantly, provide some ductility to the concrete member, and increase energy dissipation capacity (Deng and Zhang, 2018), preventing buildings collapse. However, this was not seen used in any of the surveyed damaged buildings. This technique is recommended to be used and added as a requirement in the seismic codes.
- Using typical cement-made blocks in ribbed slabs can impose life risks on building occupants. They can either be replaced by lightweight blocks such as polystyrene blocks, or another slab system can be used.
- Bridges seem to miss seismic requirements, such as lateral diaphragms and girder stoppers. These should be enforced and applied in all bridges in active seismic zones.
- As earthquakes cause bending and misalignment to train rails, it is important to develop a detection and alarm system that can stop trains in the event of a strong earthquake to avoid train derailment and, eventually, losses.
- Road pavements suffered hugely from the earthquake in the form of cracking and slicing. Using high ductility modified asphalt binder, such as rubberized asphalt or fiber reinforced asphalt mixes, is recommended to increase the resistance to deformation due to earthquakes.

Data Availability

Data sharing is not applicable to this article as no datasets were generated or analyzed during the current study.

Authors' Contribution Statement

AHA collected information and analyzed structural damages. AMA analyzed road and railway damages. NMO wrote the manuscript. OM reviewed and formatted the paper. All authors read and approved the manuscript.

References

[1] Bahadir Aktuğ et al., "Establishment of Regional Reference Frames for Quantifying Active Deformation Areas in Anatolia," *Studia Geophysica et Geodaetica*, vol. 53, pp. 169-183, 2009. [CrossRef] [Google Scholar] [Publisher Link]

[2] Simon Artymiuk, Turkey and Syria Battle Impact of 7.8-Magnitude Earthquake, International Railway Journal, 2023. [Online]. Available: https://www.railjournal.com/infrastructure/turkey-and-syria-battle-impact-of-7-8-magnitude-earthquake/

[3] İhsan Engin Bal, and Eleni Smyrou, "Simulation of the Earthquake-Induced Collapse of a School Building in Turkey in 2011 Van Earthquake," *Bulletin of Earthquake Engineering*, vol. 14, pp. 3509-3528, 2016. [CrossRef] [Google Scholar] [Publisher Link]
[4] Rejina Joshi et al., "Damage to Cultural Heritage Structures and Buildings Due to the 2015 Nepal Gorkha Earthquake," *Journal of Earthquake Engineering*, vol. 22, no. 10, pp. 1861-1880, 2018. [CrossRef] [Google Scholar] [Publisher Link]
[5] William G. Byers, "Railroad Lifeline Damage in Earthquakes," *13th World Conference on Earthquake Engineering*, pp. 1-12, 2004. [Google Scholar] [Publisher Link]
[6] Naci Caglar et al., "Structural Damages Observed in Buildings after the January 24, 2020, Elaziğ-Sivrice Earthquake in Türkiye," *Case Studies in Construction Materials*, vol. 18, pp. 1-21, 2023. [CrossRef] [Google Scholar] [Publisher Link]
[7] Cmsadmin, How Japan's Rail Network Survived the Earthquake, Railway Technology, 2011. [Online]. Available: https://www.railway-technology.com/features/feature122751/
[8] Daily Sabah with DHA, Roads, Railways, Walls, Fields Moved by Türkiye Quake: Report, Daily Sabah, 2023. [Online]. Available: https://www.dailysabah.com/turkey/roads-railways-walls-fields-moved-by-turkiye-quake-report/news
[9] KM Pathan et al., "A Forensic View to Structures' Failure Analysis," *SSRG International Journal of Civil Engineering,* vol. 2, no. 1, pp. 25-31, 2015. [CrossRef] [Google Scholar] [Publisher Link]
[10] Mingke Deng, and Yangxi Zhang, "Seismic Performance of High-Ductile Fiber-Reinforced Concrete Short Columns," *Advances in Civil Engineering*, vol. 2018, pp. 1-11, 2018. [CrossRef] [Google Scholar] [Publisher Link]
[11] Timothy Danjuma et al., "Assessment of Concrete Elements of a Collapsed Building Using Ultrasonic Pulse Velocity Test," *International Journal of Recent Engineering Science*, vol. 8, no. 2, pp. 16-19, 2023. [CrossRef] [Google Scholar] [Publisher Link]
[12] Aynur Dikbaş et al., "Paleoseismic History and Slip Rate Along the Sapanca-Akyazi Segment of the 1999 Izmit Earthquake Rupture (Mw = 7.4) of the North Anatolian Fault (Turkey)," *Tectonophysics*, vol. 738-739, pp. 92-111, 2018. [CrossRef] [Google Scholar] [Publisher Link]
[13] Disaster and Emergency Management Presidency (DEMP) in Turkish, 2020. [Online]. Available: https://deprem.afad.gov.tr
[14] T. Elouali, "Effect of Infill Masonry Panels on the Seismic Response Offrame Buildings," *14th World Conference on Earthquake Engineering (14WCEE)*, 2008. [Google Scholar] [Publisher Link]
[15] Tuba Gurbuz et al., "Damages and Failures of Structures in İzmir (Turkey) during the October 30, 2020, Aegean Sea Earthquake," *Journal of Earthquake Engineering*, vol. 27, no. 6, pp. 1565-1606, 2023. [CrossRef] [Google Scholar] [Publisher Link]
[16] Harber|Global, Earthquakes that hit 10 Provinces Bent Train Tracks, 2023. [Online]. Available: https://haberglobal.com.tr/gundem/10-ili-vuran-depremler-tren-raylarini-buktu-230728
[17] Ihlas News Agency, 2023. [Online]. Available: https://www.youtube.com/watch?v=p_bjivK7bTo.
[18] Kazuhiko Kawashima et al., "Damage of Bridges due to the 2010 Maule, Chile, Earthquake," *Journal of Earthquake Engineering*, vol. 15, no. 7, pp. 1036-1068, 2011. [CrossRef] [Google Scholar] [Publisher Link]
[19] Nobuo Mimura et al., "Damage from the Great East Japan Earthquake and Tsunami - A Quick Report," *Mitigation and Adaptation Strategies for Global Change*, vol. 16, pp. 803–818, 2011. [CrossRef] [Google Scholar] [Publisher Link]
[20] Masoud Moradi, and Reza Shah-Hosseini, "Earthquake Damage Assessment Based on Deep Learning Method Using VHR Images," *Environmental Sciences Proceedings*, vol. 5, no. 1, pp. 1-12, 2021. [CrossRef] [Google Scholar] [Publisher Link]
[21] C.V.R. Murty, and Sudhir K. Jain, "Beneficial Influence of Masonry Infill Walls on Seismic Performance of RC Frame Buildings," *12th World Conference on Earthquake Engineering,* pp. 1-6, 2000. [Google Scholar] [Publisher Link]
[22] Christine Schweier, and Michael Markus, "Assessment of the Search and Rescue Demand for Individual Buildings," *Proceedings of the 13th World Conference on Earthquake Engineering*, [Google Scholar] [Publisher Link]
[23] Sky News, Turkey and Syria Earthquake: Pictures show Devastation of 7.8 Magnitude Tremor, 2023. [Online]. Available: https://news.sky.com/story/turkey-and-syria-earthquake-pictures-show-devastation-of-78-magnitude-tremor-12804544
[24] Haluk Sucuoğlu et al., "Engineering Evaluation of the 1 October 1995 Dinar Earthquake (Ml = 5.9)," *Journal of Earthquake Engineering*, vol. 1, no. 3, pp. 581-602, 1997. [CrossRef] [Google Scholar] [Publisher Link]
[25] WorldData, Road Network Information, Transport and Infrastructure in Turkey, 2023. [Online]. Available: https://www.worlddata.info/asia/turkey/transport.php
[26] Kengun Yin, Yoshitaka Hachiya, and Ken Nakamura, "Structural Evaluation of Airport Asphalt Pavement Cracked by Earthquake," *Journal of Pavement Engineering*, vol. 2, pp. 81-88, 1997. [CrossRef] [Google Scholar] [Publisher Link]