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Communication

A Brief Overview of Türkiye Earthquake: Evidence of Higher Peak Ground Acceleration

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Received: 22 July 2025; **Revised:** 12 September 2025; **Accepted:** 16 September 2025; **Published:** 29 September 2025

Abstract: In February 2023, a devastating earthquake sequence struck southern Türkiye, marking one of the most destructive seismic disasters in the region's modern history. The M_W 7.8 mainshock, followed by several large aftershocks, produced catastrophic consequences, including extensive structural collapse, widespread ground failure, and severe liquefaction that collectively left millions displaced and caused tens of thousands of fatalities. The extraordinary intensity of the shaking was reflected in the recorded ground motion parameters, particularly spectral accelerations, which significantly exceeded the design thresholds stipulated in the Turkish Earthquake Code (2018). Such exceedances provide critical insights into the limitations of existing design provisions and underscore the urgent need to revisit seismic hazard and risk assessments. Field investigations documented severe manifestations of liquefaction, lateral spreading, and ground subsidence, especially in Holocene sedimentary basins where loose, water-saturated soils amplified shaking and induced ground instability. Structural surveys further revealed recurring vulnerabilities in the built environment, including weak or soft-story configurations, non-ductile reinforcement, and inadequate foundation practices, all of which amplified damage levels. The disaster highlights the urgent need for stricter enforcement of seismic building codes, the integration of resilient design methodologies, and the deployment of technologies such as base isolation systems and energy-dissipating devices to enhance structural safety. In addition, systematic performance audits and proactive urban planning are recommended to mitigate similar future catastrophes. This study integrates geological evidence with engineering perspectives, offering targeted strategies to strengthen earthquake preparedness and foster long-term urban resilience across Türkiye's high-risk seismic zones.

Keywords: Aftershock; Building; Damage; Earthquake; Shaking; Frequency

1. Introduction

A 7.8-magnitude earthquake occurred on February 6, 2023, in southern Turkey, near Syria's northern border. It was then followed by a magnitude 6.7 aftershock 11 minutes later. The M_w 7.8 was caused by shallow strike-slip faulting. A near-vertical left-lateral fault striking northeast-southwest or a right-lateral fault striking southeast-northwest were both ruptured by the event. According to preliminary information, the earthquake occurred close to a triple-junction of the African, Arabian, and Anatolia plates. The earthquake's mechanism and epicentre are consistent with it having happened on either the Dead Sea transform fault zone or the East Anatolia fault zone. Turkey's westward extrusion into the Aegean Sea is accommodated by the East Anatolia fault, and the Arabian

Peninsula's northward motion in relation to the African and Eurasian plates is accommodated by the Dead Sea Transform [1–5].

In 10 provinces across Turkey, there were at least 46,104 fatalities, 114,991 injuries, approximately 1,5 million people made homeless, at least 164,000 buildings severely damaged or destroyed, and 150,000 commercial facilities considerably affected. At least 490 structures were demolished and many more were damaged in northwest Syria, resulting in at least 6,795 deaths, 14,500 injuries, and 5,37 million people being made homeless. Turkey's Golbasi and Hatay experienced liquefaction and land subsidence. With wave heights of 17 cm at Famagusta, Cyprus; 13 cm at Erdemli; and 12 cm at Iskenderun, Turkey, a minor tsunami was produced. IXth highest intensity. Even though they are frequently represented on maps as single spots, earthquakes rupture planes with dimensions. A fault that is 190 km long and 25 km wide is frequently ruptured by a magnitude 7.8 strike-slip earthquake. Figure 1 shows the waveform of the main event [6]. The seismic record presented in **Figure 1** exemplifies the complex rupture process of the 2023 Türkiye earthquake. The near-epicentral recording displays a rapid onset of strong shaking indicative of fault slip acceleration, followed by an extended coda reflecting scattered wave propagation within heterogeneous crustal media. Analysis of the waveform's spectral characteristics provides constraints on the high-frequency radiation components and rupture velocity, informing models of dynamic fault rupture and seismic hazard assessment. These observations correlate with geophysical data suggesting multi-segment fault rupture and supershear propagation phenomena, which are critical for interpreting the pronounced ground motion intensities and ensuing widespread structural failures documented in the affected region.

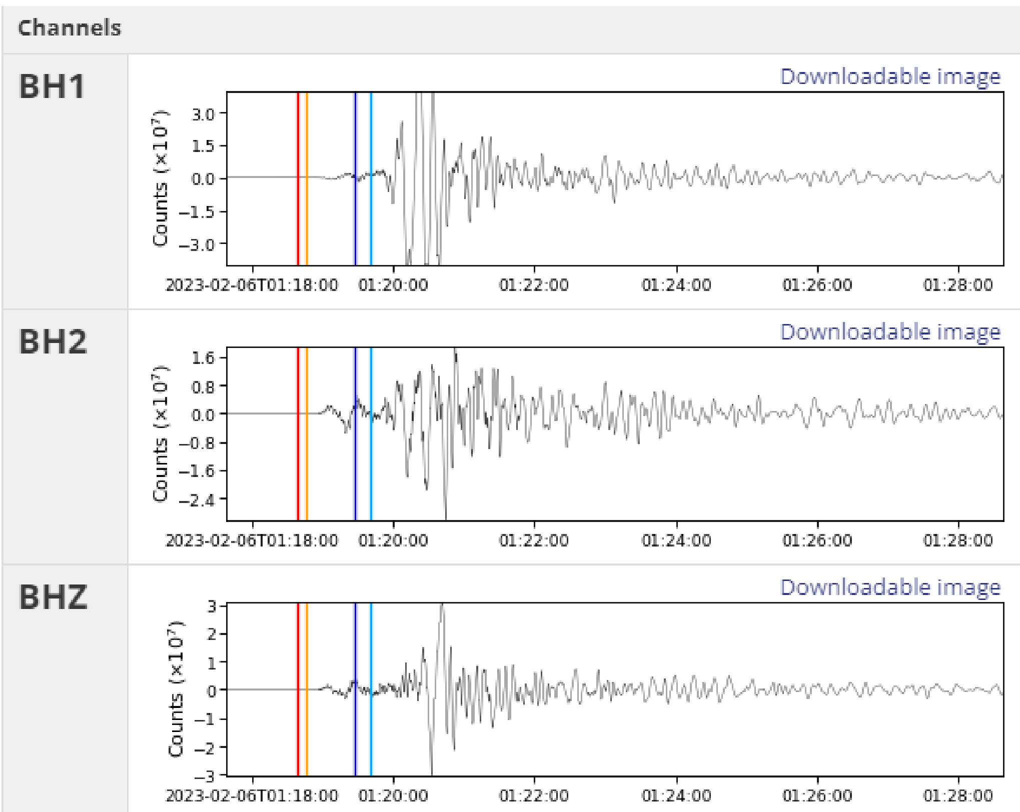

Figure 1. Seismic waveform of the M_W 7.8 earthquake (Courtesy: USGS). Epicentral location: 37.2251° N, 37.0209° E, with an origin time of 2023-02-06 01:17:34 UTC and a depth of 10.0 km.

This short communication aims to briefly overview the seismicity of Türkiye in relation to the devastating main event, assisted by liquefaction observation, along with the outlining of the causes of building damage that resulted in huge fatalities in the decade so far. Accordingly, the first section deals with past seismicity. The second section focuses on the liquefaction pattern observed due to an earthquake. The third section analyzes the building damage, followed by recommendations.

2. Past Seismicity and Sequence of Events

The earthquake that occurred on February 6 took place in a seismically active area. Since 1970, there have only been three earthquakes with a magnitude of 6 or higher that have happened within 250 kilometers of the February 6 quake. On January 24, 2020, the largest of these, with a magnitude of 6.7, occurred to the northeast of the February 6 earthquake. These earthquakes all happened around or along the East Anatolia fault. Southern Turkey and northern Syria have previously been subjected to big and destructive earthquakes, notwithstanding the relative seismic quiescence of the epicentral region of the February 6 earthquake. Although the locations and magnitudes of these earthquakes are unknown, Aleppo, in Syria, has traditionally been devastated by big earthquakes. In 1138 and 1822, earthquakes with estimated magnitudes of 7.0 and 7.1, respectively, both struck Aleppo. There were 20,000–60,000 estimated fatalities for the 1822 earthquake [1–5].

Figure 2 depicts the level of liquefaction as observed. Unexpectedly, most liquefaction and lateral spreading sites manifested along and near coastal sites, fluvial valleys, and drained lake/swamp areas, covered by Holocene loose sediments. The distribution of mapped liquefaction sites along the fault rupture shows that most concentrations are found in Holocene sediment-filled basins [4,5].

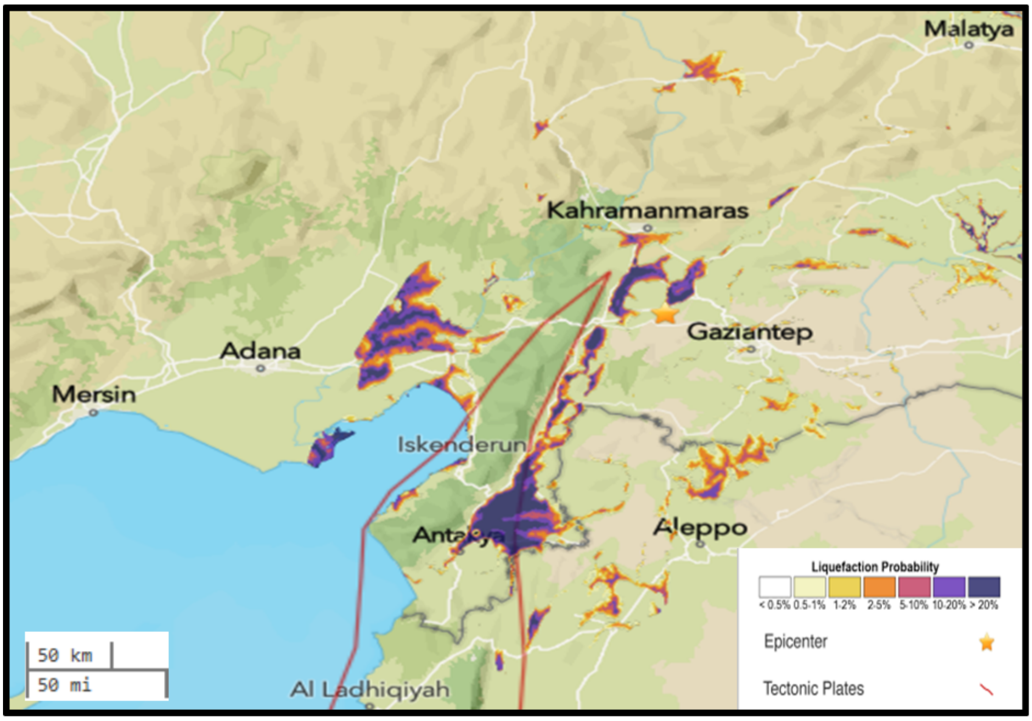

Figure 2. Liquefaction map (Courtesy: USGS). The yellow star represents the main event. The red line represents the tectonic plates.

The Türkiye Earthquake possesses some intriguing facts. Precisely, there was an occurrence of two great earthquakes. However, the causative faults for these two were not identical as claimed by researchers. Interestingly, the first earthquake, M_W 7.8, resulted in activation of the causative fault of the succeeding earthquake. After the M_W 7.1 2021 Izmir earthquake, the seismicity around Turkey had been quite active. According to the national seismic database, there have been sizable events occurring intermittently. This process can be construed as gradual stress accumulation. Nonetheless, energy nucleation in and around Anatolian faults had been continuously happening—thereby leading to these most destructive earthquakes.

As per Zhou [6] and UNFPA [7], there is a possibility of high-frequency sources causing high-frequency radiation. Apart from that, super shear ruptures were likely to propagate on smooth faults. Likewise, Baltzopoulos et al. [8] advocated a multi-fault rupture sequence with the major portion occurring across the East Anatolian Fault. The fault-mediated interactions played a major role in this event, as reported by them. Liu et al. [9] showed via coand inter seismic observations that the main event, M_W 7.8, possessed stress enhancement of ~2 bar for the other M_W 7.7 event occurring 9 hours later. As per reports, there has been a prevalence of a preparation phase that bears resemblance to the failure process [9–11]. However, they refrained from making any conclusive argument related to the precursory nature of the foreshocks owing to the complex kinematics of the Türkiye earthquake sequence. Meanwhile, Jia et al. [11] while observing acoustic wave emanation from the Türkiye Earthquake sequence, highlighted anisotropic perturbation amplitudes pertaining to the events. They estimated a larger magnitude in the former event.

3. Exploring the Peak Ground Acceleration During the Occurrence of an Earthquake

The peak ground acceleration as observed in the Türkiye Earthquake was quite high. As opined by strong motion seismologists, PGA generated by these two earthquakes in the immediate neighborhood of the epicentral region exceeded the prescribed one by the Turkish Seismic Code 2018. In many cases, there was evidence of higher spectral ground acceleration, thereby leading to devastation on an immense scale [12–16].

As per reports, a network of 280 strong-motion accelerometers captured PGA from the M_w 7.8 earthquake. The maximum recorded PGA of 1.23 g was at the Antakya station—just 20 km from the coast adjacent to the probable tsunami source location. This value indicates a very strong shaking that could cause severe damage to structures and infrastructure. The Antakya station was located on the North Anatolian Fault, which was one of the fault segments that ruptured during the earthquake. Other stations that recorded high PGA values were Gaziantep (0.86 g), Adana (0.82 g), and Osmaniye (0.79 g) [4–9].

The site-specific PGA recorded during the February 2023 Türkiye Earthquake could provide useful information for assessing the seismic hazard and risk in the region, as well as for designing and retrofitting buildings and infrastructure to withstand future earthquakes. As per reports of Wikimedia Commons [16], the structures were overloaded far beyond their normal design levels. As such, there is a plausible need for modifications of the Turkish Seismic Code 2018 to account for higher spectral acceleration values, especially in earthquake-prone regions.

4. Looking Into Building Damage: Probable Loopholes

The two coupled earthquakes, with magnitudes of 7.8 and 7.5, devastated the infrastructure of two urban settlements, causing major to minor damage. Several buildings had collapsed in response to the heavy shaking of the two earthquakes.

Looking at the pattern of building damages that occurred in Turkey, most of them were soft-storied buildings (**Figure 3**). If we look at the tectonic settings of Turkey, it is quite complex. There are three plates that collided with each other, leading to the occurrence of these huge earthquakes.

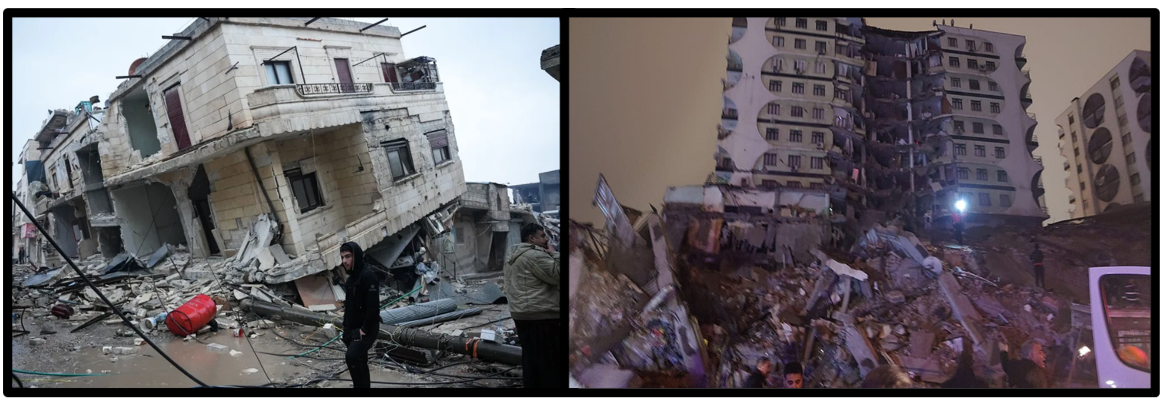

Figure 3. Illustration of building damage [16,17].

We know that every high-rise structure is prone to shaking. All such structures have a fundamental frequency. When seismic waves travel through a medium of low density, their velocity decreases. Therefore, it spends more time in that medium. As a result, if the predominant frequency matches with frequency of the above structure, there occurs resonance and the building sways with maximum amplitude—leading to eventual collapse. Buildings mostly collapsed during the tragedy because of poor construction, inferior materials. Surprisingly, the earthquake caused damage to some brand-new apartment buildings that were marketed as being built to the greatest earthquake specifications, to collapse.

The Turkish Earthquake Code (2018) design levels were not met by the buildings in the provinces of Gaziantep, Hatay, Kahramanmaras, and Adiyaman, according to the report by a team of scientists from Middle East Technical University (METU), Ankara, and colleagues. Notwithstanding the fact that the earthquakes were exceptional, the experts highlighted that buildings should have survived and not collapsed in the manner that they did.

According to the international team's "Preliminary Reconnaissance Report," buildings built after 2002 are likely to be far better during earthquakes than earlier structures. The analysis reveals that more than 1,000 buildings built after 2000 suffered significant damage or collapsed, contravening the performance aim outlined in the code that evaluates the seismic risk of a building in relation to its location. This looked to be a significant observation, according to the report, necessitating more research into the caliber of those structures' design and construction. Again, inadequacies could also emerge due to the existence of soft stories—which are entrances or basements without continuous walls that connect to those of the upper storeys. It was found that the "pancake" collapses of numerous structures were, in fact, caused by inadequate foundations. This type of structural collapse, known as a "pancake collapse," happens when the upper floors of a building sink into lower ones. Examples of "severe alterations" that were categorically unacceptable in the amended requirements include the use of low-quality materials, unribbed reinforcement bars used in construction, and insufficient stirrup tightening (which is intended to laterally constrain steel reinforcement). Many new structures constructed after 2000 that were not adequately engineered, well inspected, or whose soil-structure link remained unestablished, were damaged or destroyed beyond expectations. 6 cm-long stones were found in concrete samples recovered from a fallen structure in Adiyaman. These were employed to bulk out the concrete and came from a nearby river.

A key lesson from the 2023 Türkiye Earthquake is the urgent need to strengthen both the implementation and enforcement of seismic building codes. To reduce future risk, it is essential that construction practices strictly adhere to the Turkish Earthquake Code (2018) and other relevant standards. All new and renovated buildings must be subject to mandatory quality control inspections that focus on critical issues—such as proper material selection, correct reinforcement bar placement, and adequate stirrup tightening. The adoption of seismic resilience strategies—like base isolation, energy-dissipating dampers, and foundation improvements—should become standard practice for high-risk zones. Furthermore, builders and contractors must be held accountable through regular audits and severe penalties for non-compliance or code violations. These targeted measures, when rigorously enforced, will substantially improve the safety and durability of structures in earthquake-prone regions and safeguard lives during future seismic events.

5. Way Forward

Given the level of damage that had occurred due to the earthquakes, the main agenda before Türkiye Government is to rebuild the area, which may amount to $100 billion, as per UN reports [1]. The common mass should be more aware and vigilant so that maximum damage can be reduced. The fundamental tenet of construction is to leave some degree of damage inside the structure. This damage guarantees that the building still stands erect but does not collapse by absorbing the earthquake's force. Likewise, it is possible to include elements like dampers, which function as shock absorbers as the building sways, and rubber bearings, which are installed underneath buildings and absorb earthquake energy. Similarly, base isolation or isolators can be introduced in order to make buildings more resilient to earthquakes. However, strict monitoring and compliance with building codes should be implemented with strict measures. Any violation of such codes should be penalized.

6. Conclusions

This brief communication overviews the recent Türkiye Earthquake and liquefaction caused by it. The past seismicity is also delineated. The probable causes/pitfalls associated with collapsed structures are reviewed. As we know, earthquakes cannot be averted; however, the seismic hazard can be mitigated. With strict measures and earthquake-resilient structures, the devastated nation Türkiye is expected to recover in the coming days.

Funding

This work received no external funding.

Institutional Review Board Statement

Not applicable.

Informed Consent Statement

Not applicable.

Data Availability Statement

Data will be made available on reasonable request to the corresponding author.

Conflicts of Interest

The author declares that there is no conflict of interest.

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