Mw 6.1 Duzce, Turkey Earthquake

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PRELIMINARY VIRTUAL RECONNAISSANCE REPORT (PVRR)

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PREFACE

The National Science Foundation (NSF) awarded an EAGER grant (CMMI 1841667) to a consortium of universities to form the Structural Extreme Events Reconnaissance (StEER) Network (see https://www.steer.network for more details). StEER was renewed through a second award (CMMI 2103550) to further enhance its operational model and develop new capabilities for more efficient and impactful post-event reconnaissance. StEER builds societal resilience by generating new knowledge on the performance of the built environment through impactful post-disaster reconnaissance disseminated to affected communities. StEER achieves this vision by: (1) deepening structural engineers' capacity for post-event reconnaissance by promoting community-driven standards, best practices, and training, as well as their understanding of the effect of natural hazards on society; (2) coordination leveraging its distributed network of members and partners for early, efficient and impactful responses to disasters; and (3) collaboration that broadly engages communities of research, practice and policy to accelerate learning from disasters.

Under the banner of the Natural Hazards Engineering Research Infrastructure (NHERI) CONVERGE node, StEER works closely with the wider Extreme Events Reconnaissance consortium to promote interdisciplinary disaster reconnaissance and research. The consortium includes the Geotechnical Extreme Events Reconnaissance (GEER) Association and the networks for Interdisciplinary Science and Engineering Extreme Events Research (ISEEER), Nearshore Extreme Event Reconnaissance (NEER), Operations and Systems Engineering Extreme Events Research (OSEEER), Social Science Extreme Events Research (SSEER), Sustainable Material Management Extreme Events Reconnaissance (SUMMEER), and Public Health Extreme Events Research (PHEER), as well as the NHERI RAPID equipment facility, the NHERI Network Coordination Office (NCO), and NHERI DesignSafe CI, curation site for all StEER products.

While the StEER network currently consists of the three primary nodes located at the University of Notre Dame (Coordinating Node), University of Florida (Southeast Regional Node), and University of California, Berkeley (Pacific Regional Node), StEER is currently expanding its network of regional nodes worldwide to enable swift and high quality responses to major disasters globally.

StEER's founding organizational structure includes a governance layer comprised of core leadership with Associate Directors for each of the primary hazards as well as cross-cutting areas of Assessment Technologies and Data Standards, led by the following individuals:

- **Tracy Kijewski-Correa (PI),** University of Notre Dame, serves as StEER Director responsible for overseeing the design and operationalization of the network and representing StEER in the NHERI Converge Leadership Corps.
- **Khalid Mosalam (co-PI),** University of California, Berkeley, serves as StEER Associate Director for Seismic Hazards, serving as primary liaison to the Earthquake Engineering community.
- **David O. Prevatt (co-PI),** University of Florida, serves as StEER Associate Director for Wind Hazards, serving as primary liaison to the Wind Engineering community.
- **Ian Robertson (co-PI),** University of Hawai'i at Manoa, serves as StEER Associate Director for Coastal Hazards, serving as a primary liaison to the coastal engineering community and ensuring a robust capacity for multi-hazard assessments.
- **David Roueche (co-PI),** Auburn University, serves as StEER Associate Director for Data Standards, ensuring StEER processes deliver reliable and standardized reconnaissance data suitable for re-use by the community.

This core leadership team works closely with StEER Research Associates, Data Librarians and its Student Administrator in event responses, in consultation with its Advisory Boards for Coastal, Seismic and Wind Hazards.

ATTRIBUTION GUIDANCE

Reference to PVRR Analyses, Discussions or Recommendations

Reference to the analyses, discussions or recommendations within this report should be cited using the full citation information and DOI from DesignSafe (these are available at https://www.steer.network/products).

Citing Images from this PVRR

Images in this report are a combination of images acquired by VAST members in the affected area and from third party sources.

- For images shown with identification of that source with author, year in the caption, please cite the original source listed in the references section. Note that public sources might still have copyright issues and depending on the use case, the user may need to secure additional permissions/rights from the original copyright owner.
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ACKNOWLEDGMENTS

This material is based upon work supported by the National Science Foundation under Grant No. CMMI 2103550. Any opinions, findings, and conclusions or recommendations expressed in this material are those of StEER and do not necessarily reflect the views of the National Science Foundation. All authors and editors listed on the cover page participate as volunteer professionals. Thus, any opinions, findings, and conclusions or recommendations expressed herein are those of the individual contributors and do not necessarily reflect the views of their employer or other institutions and organizations with which they affiliate.

Special thanks also go to Batuhan Aykanat, graduate student at Duzce University, for his help with field data collection.

The sharing of videos, damage reports and briefings via Slack by the entire NHERI community was tremendously helpful and much appreciated. StEER recognizes the efforts of the DesignSafe CI team who continuously supported and responded to StEER's emerging needs.

For a full listing of all StEER products (briefings, reports and datasets) please visit the StEER website: https://www.steer.network/products

TABLE OF CONTENTS

Common Terms and Acronyms

Acronym	General Terms	Brief Description
--	DesignSafe	Data Repository
--	DesignSafe-CI	Academic Organization within NHERI
ASCE	American Society of Civil Engineers	Professional Organization
BOCA	Building Officials and Code Administrators	Code Body
CC-BY	Creative Commons Attribution License	Code/Standard
CESMD	Center for Engineering Strong Motion Data	Governmental Agency
CI	Cyberinfrastructure	Research Asset
CLPE	Critical Load Path Elements	StEER Term
CMU	Concrete Masonry Unit	Building Material
DBE	Design Basis Earthquake	Design Terminology
DEQC	Data Enrichment and Quality Control	StEER Term
DOI	Digital Object Identifier	Common Term
EARR	Early Access Reconnaissance Report	StEER Term
EF	Enhanced Fujita Scale	Hazard Intensity Scale
EF	Equipment Facility	Academic Organization within NHERI
FAA	Federal Aviation Administration	Governmental Agency
FAQ	Frequently Asked Questions	Common Term
FAST	Field Assessment Structural Team	StEER Term
FEMA	Federal Emergency Management Agency	Governmental Agency
GEER	Geotechnical Extreme Events Reconnaissance	Academic Organization within NHERI
GSA	Government Services Administration	Governmental Agency
HWM	High Water Mark	Intensity Measure
IBC	International Building Code	Code/Standard
ICC	International Code Council	Code Body
IRC	International Residential Code	Code/Standard
ISEEER	Interdisciplinary Science and Engineering Extreme Events Research	Academic Organization within NHERI
LiDAR	Light Detection and Ranging	Measurement Technology
MCE	Maximum Considered Earthquake	Design Terminology
MMI	Modified Mercalli Intensity	Hazard Intensity Scale
NBC	National Building Code	Code/Standard
NEER	Nearshore Extreme Event Reconnaissance	Academic Organization within NHERI
NFIP	National Flood Insurance Program	Government Program

NHERI	Natural Hazards Engineering Research Infrastructure	Academic Organization within NHERI
NIST	National Institute of Standards and Technology	Governmental Agency
NOAA	National Oceanic and Atmospheric Administration	Governmental Agency
NSF	National Science Foundation	Governmental Agency
NWS	National Weather Service	Governmental Agency
OSEEER	Operations and Systems Engineering Extreme Events Research	Academic Organization within NHERI
PEER	Pacific Earthquake Engineering Research center	Academic Organization (Earthquakes)
PGA	Peak Ground Acceleration	Intensity Measure
PHEER	Public Health Extreme Events Research	Academic Organization within NHERI
PVRR	Preliminary Virtual Reconnaissance Report	StEER Term
RAPID	RAPID Grant	Funding Mechanism
RAPID-EF	RAPID Experimental Facility	Academic Organization within NHERI
RC	Reinforced Concrete	Building Material
SAR	Search and Rescue	Standard Hazads Terminology
SLP	Surface-Level Panoramas	Measurement Technology
SPC	Storm Prediction Center	Governmental Agency
SSEER	Social Science Extreme Events Research	Academic Organization within NHERI
StEER	Structural Extreme Events Reconnaissance network	Academic Organization within NHERI
SUMMEER	SUstainable Material Management Extreme Events Reconnaissance	Academic Organization within NHERI
UAS/V	Unmanned Aerial Survey/System/Vehicle	Measurement Technology
USD	US Dollar	Standard Currency
USGS	United States Geological Survey	Governmental Agency
VAST	Virtual Assessment Structural Team	StEER Term
WS	Windshield Survey	Measurement Technology

EXECUTIVE SUMMARY

A M_w 6.1 earthquake occurred in Golyaka, Duzce on November 23, 2022 with a focal depth of 10.0 km. At the location of this earthquake, which occurred on a strike-slip fault, the North Anatolian fault moves approximately 17 mm/year. The previous destructive earthquakes which struck the same area, within 100 km radius of Duzce, include: February 1, 1944 Gerede earthquake (M_w 7.5) with 3,959 deaths, May 26, 1957 Abant earthquake (M_s 7.1) with 52 casualties, July 22, 1967 Mudurnu earthquake (M_w 7.4) with 89 casualties, and November 12, 1999 Duzce earthquake (M_w 7.2) with 894 reported deaths. In addition to many other smaller destructive seismic events, these four 7+ magnitude earthquakes in less than 80 years show significant seismic activity in this region.

It was important to have local authors of this report. In the early reports released by the government, it was stated that the maximum acceleration was measured at station 8105. Later, it was determined that the accelerations measured at this station were not reliable. Consequently, it was decided to relocate station 8105. Therefore, the recordings measured at station 8102 (not 8105) near Duzce city center are used and analyzed in this report. The accelerations measured at station 8102 showed a typical near field motion with a short duration and maximum peak ground acceleration (PGA) of 0.41g. We conclude that the observed damage is consistent with this level of shaking, including accelerations measured at four other stations in the region.

In the region affected by the earthquake, the maximum number of stories is limited to four in buildings constructed after 1999. These buildings are expected to have a fundamental period less than 0.5 s. Comparisons of the design response spectra and those from the recorded motions show that the spectral accelerations of the recorded motions are generally smaller than the design response spectra. While five ground motions from three stations had response spectra less than the design spectra, the response spectra for one ground motion exceeded the corresponding design spectra for fundamental period of vibration larger than 0.9 s. However, considering that the design spectra accelerations are divided by response modification factors, as large as 8, to compute the design forces, seismic demand experienced by some of the buildings near the Duzce city center were still larger than the seismic design loads specified by the current seismic code (TEC-2018). The improved overall quality of the buildings since the 1999 earthquakes and the inherent overstrength available in these buildings reduced the damage experienced in this earthquake; the enforced seismic design details enhanced ductility and avoided any collapses.

The vast majority of the buildings in the region affected by the November 23, 2022 earthquake, including government and school buildings, have been either retrofitted or rebuilt after the August 17, 1999 M_w 7.6 Kocaeli and November 12, 1999 M_w 7.2 Duzce earthquakes. No structural damage and limited nonstructural damage were reported in these buildings during this most recent earthquake. This low level of damage affirms the effectiveness of retrofit measures and recent strict seismic design requirements enforced for the buildings constructed after 1999.

In summary, limited collapse and structural damage were observed during the November 23, 2022 earthquake. Moreover, there were no reports of damage to roads and bridges, and power, water, telecommunications, and other infrastructure & lifelines. However, the economic losses due to nonstructural damage and business interruption were significant.

1. Introduction

Turkey is located in one of the most seismically active regions in the world. It lies mostly on the Anatolian plate and is surrounded by three main tectonic plates, namely the Arabian plate, the African plate, and the Eurasian plate. Consequently, many devastating earthquakes have occurred in this region over the last century, including the 1939 Erzincan earthquake (Surface wave magnitude M_s 7.9), 1976 Çaldıran earthquake (Moment magnitude M_w 7.0), 1999 Kocaeli earthquake (M_w 7.6), 1999 Duzce earthquake (M_w 7.2), 2003 Bingöl earthquake (Duration magnitude M_d 6.1), 2011 Van earthquake (Local "Richter" magnitude M_L 6.7), 2020 Elazığ earthquake (M_w 6.8), and 2020 Izmir Seferihisar earthquake (M_w 6.6) (AFAD 2022a). In total, 313 earthquakes ($M_w \geq 4.0$) have occurred since 1900 in the region, with the biggest ($M_w = 7.6$) in 1999 (AFAD 2022b). The past tectonic activity in the region is shown in Fig. 1.1.

This report focuses on the M_w 6.1 earthquake with a depth of 10.0 km and epicenter coordinates of 40.847°N 30.967°E that struck Golyaka and Duzce at about 4:08 am local time on November 23, 2022 (USGS 2022a). This earthquake was caused by shallow strike-slip faulting in the crust (USGS 2022a). The populations of Golyaka and Duzce central districts are approximately 10,000 and 200,000, respectively, and they are less than 3 kilometers away from the earthquake's epicenter (AFAD 2022b). This earthquake resulted in two fatalities and significant property damage. Although most of the reported damage was in residential buildings, structural and nonstructural damage was also observed in mosques, the Duzce Courthouse, and the Duzce Provincial Directorate of Health building. Damage was also reported in many commercial buildings and stores. One of the largest glass factories in the country, Duzce Cam, also suffered significant nonstructural damage.

Although the deaths, injuries, and the demand for emergency assistance were low for this shallow earthquake, many researchers and government agencies quickly launched investigations or released reconnaissance reports describing the nonstructural and structural damage caused by the earthquake (MTA 2022; IMO 2022; KTU-DU 2022; Yeditepe 2022). This report focuses only on reports released by the Disaster and Emergency Management Presidency (AFAD) of the Ministry of Interior of Turkey.

1.1. Societal Impact

After the earthquake, it was observed that many people who have experienced any structural damage in their houses hesitated to return to their homes. The main reason for this is the negative experience during the August 17, 1999, Kocaeli and November 12, 1999 Duzce earthquakes, which caused significant damage in the region. Similar to these two major events, people worried about the possibility of a large subsequent earthquake after the November 23, 2022 earthquake. Therefore, the authorities positively responded to people's demand for temporary tents. However, the large number of the tents distributed by the government was not proportional to the damage observed during the earthquake, triggered an expectation among the public of a possibly large future earthquake. Authorities, experts, and psychologists visited tents attempting to persuade those whose homes had not experienced any serious damage during the earthquake or aftershocks to return to their residences.

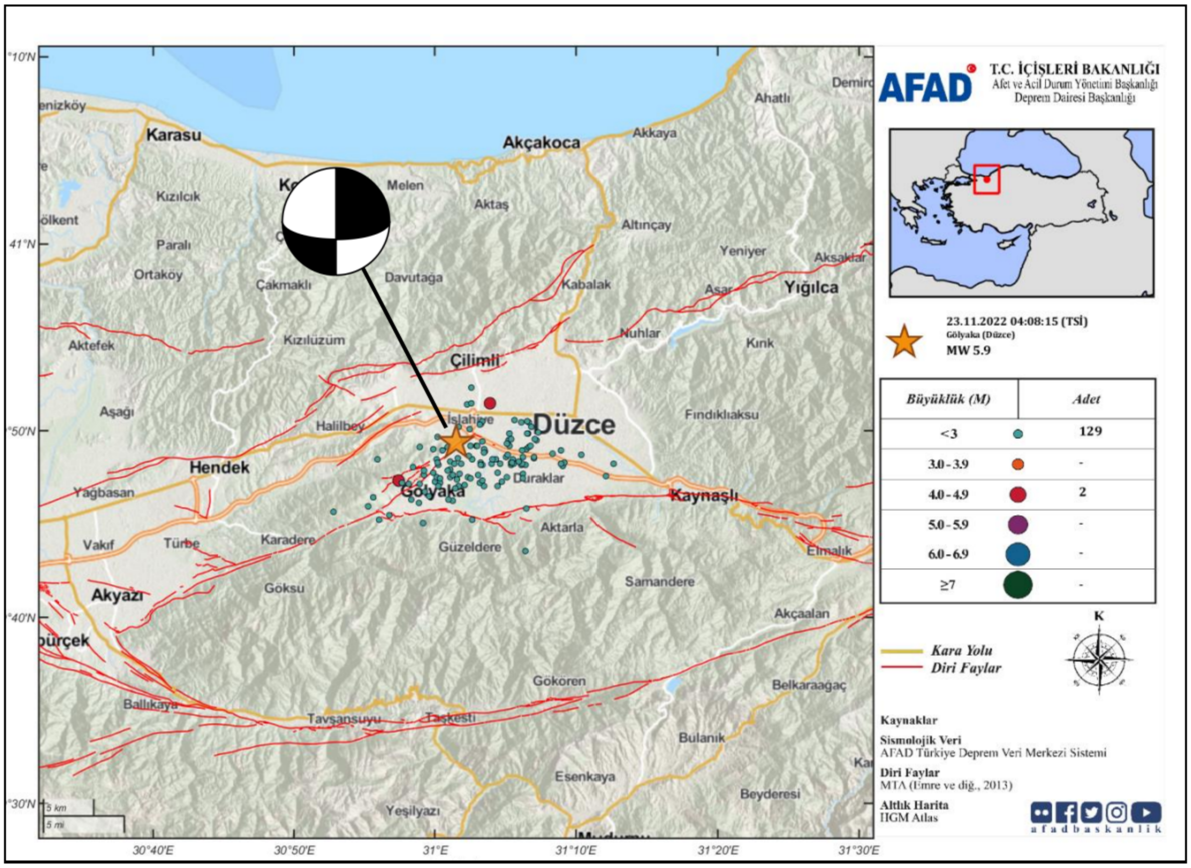


Figure 1.1. Past tectonic activity in the region and aftershocks within 12 hours after the mainshock (AFAD 2022b).

The USGS PAGER (Prompt Assessment of Global Earthquakes for Response) tool, which is a computerized program that produces notifications regarding the consequences of significant seismic events around the globe, estimated economic losses to be between $1 and $10 million, between $10 and $100 million, between $100 and $1,000 million, between $1,000 and $10,000 million, and between $10,000 and $100,000 million with probabilities of 4%, 23%, 43%, 25%, and 4%, respectively, as shown in Figure 1.2. The orange alarm in Figure 1.2 marks the potential alert for considerable economic losses due to this earthquake, estimated at less than 1% of Turkey's GDP. From this data, emergency responders, state and local governments, relief organizations, and media outlets can assess the severity of a potential crisis.

Approximately 6.89 million people felt the 2022 Duzce earthquake as *Weak*, 18.126 million as *Light*, 983,000 as *Moderate*, 135,000 as *Strong*, 181,000 as *Very Strong*, and 52,000 as *Severe*, based on the Modified Mercalli Intensity (MMI) scale. The contour map in Figure 1.3 illustrates the estimated population exposure.

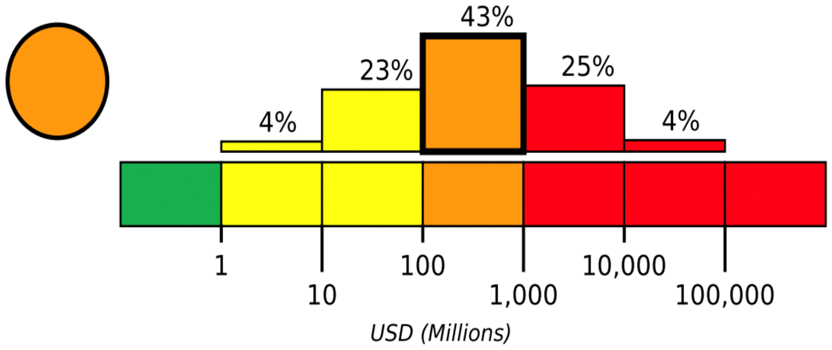
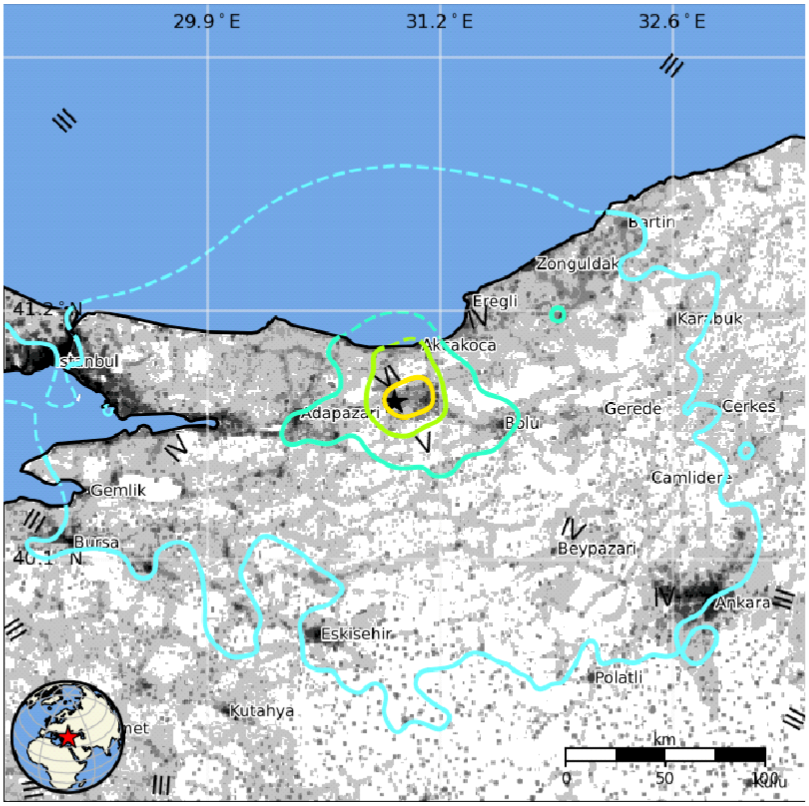


Figure 1.2. Estimated economic losses (USGS 2022b).



Not Felt	0 k*
Weak	6,861 k
Light	18,119 k
Moderate	984 k
Strong	134 k
Very Strong	181 k
Severe	52 k
Violent	0 k
Extreme	0 k

*Estimated exposure only includes population within map area (k=×1,000)

Figure 1.3. Estimated population exposure to the 2022 Duzce earthquake (USGS 2022b).

1.2. Economic Loss Due to Nonstructural Damage

Significant loss was reported due to nonstructural damage in the commercial areas of Golyaka and Duzce. In most cases, shelves collapsed, or items fell in the stores during the strong shaking as shown in Figure 1.4. Although the commercial buildings did not experience severe structural damage during the earthquake, consistent with the nonstructural damage examples shown in Figures 1.4 to 1.7, the economic loss due to damage to the assets, goods, and products appeared to be relatively high, such as the glass manufacturing factory in Figure 1.6. As shown in Figure 1.5, even if there was no damage in some shops and stores, due to nonstructural damage in the area, they had to be closed for a period of time until cleanup was complete. There was no report of structural damage in the Duzce Glass factory during the earthquake (Fig. 1.6). However, significant losses occurred as the vertical stacks of ready-to-ship glass products were shattered.

(a) (b)

(c) (d)

Figure 1.4. Nonstructural damage in stores (Sources: (a) T4Haber (2022), (b) Daily Sabah (2022), and (c) & (d) Tasdemir (2022)).

Figure 1.5. Damage in shopping areas and store fronts (Source: Yenisafak (2022)).

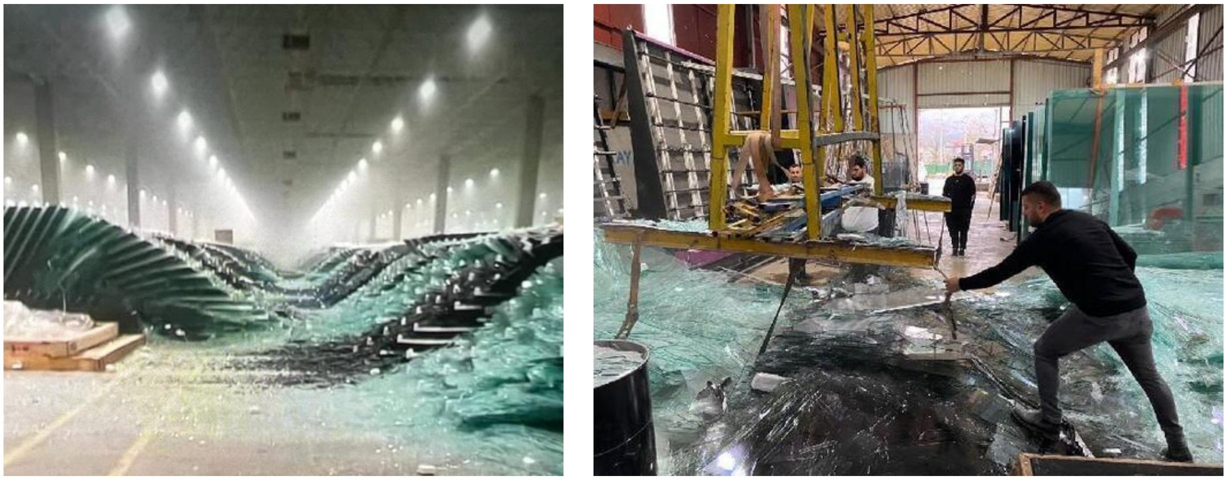


Figure 1.6. Damage in a glass manufacturing facility (Sources: Ensonhaber (2022) (left) & DHA (2022) (right)).

During the field investigation in Duzce after the earthquake, another example of economic loss was identified because of the collapse of a parking structure that was not engineered (Fig. 1.7). In this case, damage to a parked vehicle inside the parking structure was significant.

Figure 1.7. Damage to a parked vehicle due to damage to a non-engineered parking structure (Source: Arslan).

1.3. Loss of Life and Injuries

There was no loss of life due to structural or nonstructural damage that occurred during the Duzce earthquake. Two deaths were reported due to associated medical issues, e.g., heart attack (AFAD 2022c). The reported 93 earthquake-related injuries included 37 in Duzce, 26 in Sakarya, 14 in Bolu, 10 in Zonguldak, 4 in Bursa, and 2 in Istanbul.

The USGS PAGER system analyzes the number of people exposed to various shaking intensities and uses economic and casualty loss models to predict expected losses. PAGER estimated some fatalities and casualties related to the shaking (PAGER 2022b). Although PAGER estimated casualties to most likely be between 10 to 100 deaths (Fig. 1.8), no direct fatalities were reported after the earthquake.

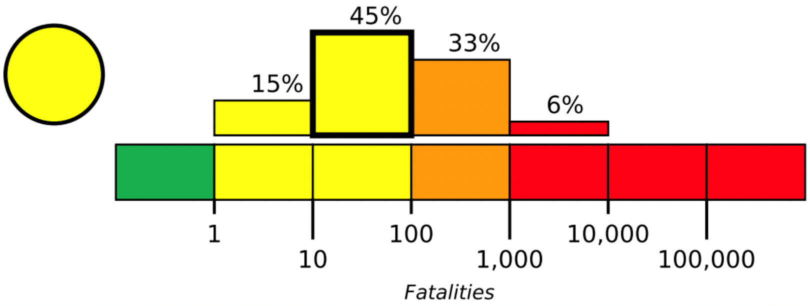


Figure 1.8. PAGER-estimated fatalities (USGS 2022b).

1.4. Official Response

The search and rescue (SAR) teams of the Disaster and Emergency Management Presidency (AFAD) of the Interior Ministry of Turkey were sent to the affected region immediately after the earthquake. A total of 3,748 personnel and 812 vehicles from many official organizations and volunteers were assigned to the earthquake region, under the coordination of AFAD, in addition to other damage assessment teams. Psychosocial support services were provided to 3,141 people by the Disaster Psychosocial group. Approximately 1,000 tents, 14,210 blankets, 2,341 beds, 1,358 portable heaters, and 3,500 raincoats were supplied to the area. Goods support reached 7,500 affected households. Two portable kitchen trucks, one mobile coordination truck, two helicopters, and ten portable base stations for mobile phones provided temporary infrastructure to support the response. The Turkish government sent approximately $4.5 million USD in emergency aid allowance to Duzce province after the earthquake (AFAD 2022c).

1.5. Report Scope

StEER's Virtual Assessment Structural Team (VAST) has prepared this **Preliminary Virtual Reconnaissance Report (PVRR)** as the primary product of its Level 1 response to the 2022 Duzce, Turkey earthquake. However, unlike the typical PVRR, this report is informed by local observations of the contributing authors, e.g., M.E. Arslan lives in Duzce, experienced the earthquake, and participated in structural assessment and field investigations. Other authors, e.g., A. Demir, N. Caglar and A.C. Altunisik, either live near the affected area or traveled there shortly after the earthquake and bring their first-hand observations to this report. This report intends to:

1. Provide an overview of the 2022 Duzce, Turkey earthquake with respect to its impact on the built environment;
2. Summarize the regulatory environment and construction practices in the affected area;
3. Synthesize preliminary reports of damage to buildings, roads, bridges, and other infrastructure; and
4. Provide recommendations for continued study of this event by the StEER Network and the broader natural hazards engineering community.

2. Hazard Characteristics

On November 23, 2022, at approximately 4:08 am local time (1:08 am UTC), an earthquake struck 3 km Northeast of the Golyaka District and 7 km West of Duzce, Turkey. According to the Ministry of Interior of Turkey (AFAD 2022b), the earthquake was reported as having a moment magnitude M_w = 5.9, a depth of 6.81 km, and an epicenter: 40.823°N, 31.025°E (Fig. 1.1). On the other hand, according to USGS (2022a), the earthquake had M_w=6.1 and a depth of 10.0 km.

Immediately after an earthquake in Turkey, AFAD produces a map of the expected intensities in the affected region using several pre-defined seismological models through the AFAD-RED system to guide responders to a possible disaster. The expected intensity map of this earthquake is shown in Figure 2.1. A similar map produced by USGS (2022b) was provided in Figure 1.3.

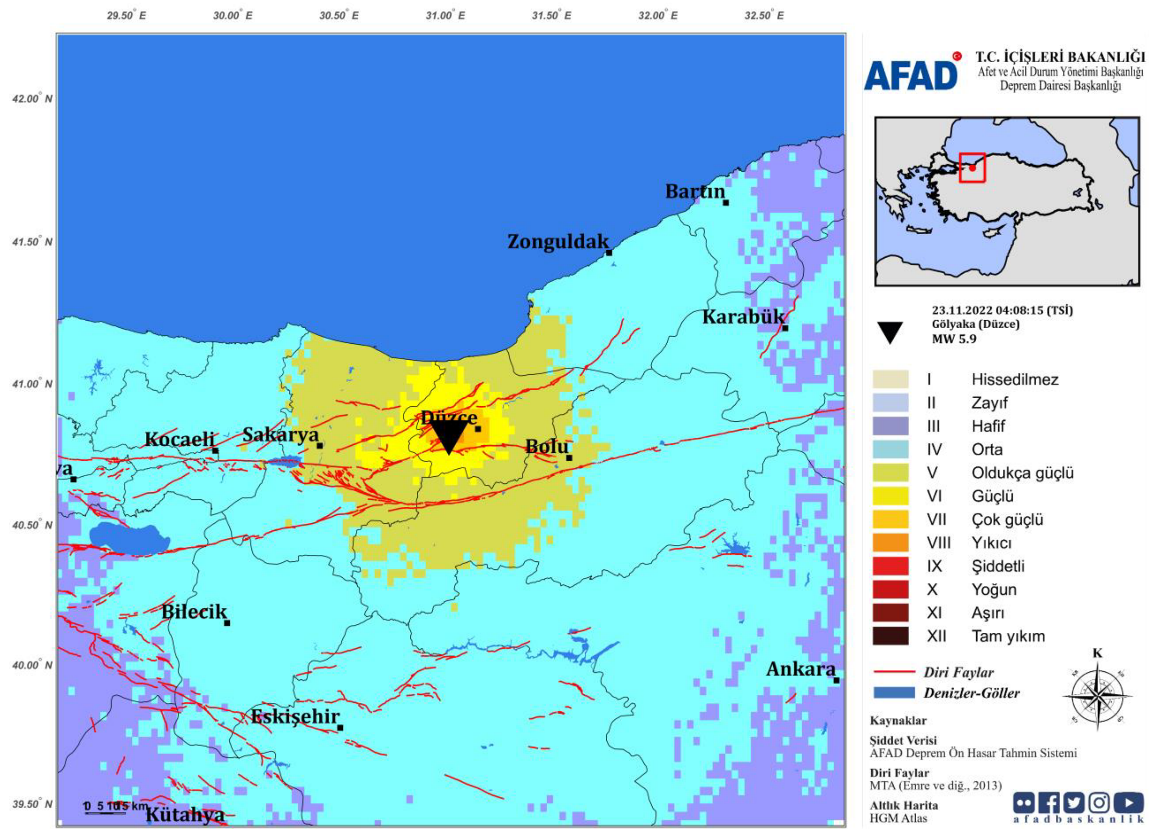


Figure 2.1. Expected intensity map prepared by AFAD-RED software (AFAD 2022b). A black triangle marks the epicenter and red lines indicate the active faults in the region.

2.1. Earthquake Features and Tectonic Summary

The earthquake occurred due to the strike-slip faulting at a shallow depth of 10 km within the crust (USGS 2022a). The USGS focal mechanism solutions for the earthquake indicate that rupture occurred on either a moderately-dipping right-lateral fault striking west-southwest, or a steeply dipping left-lateral strike-slip fault striking north-northwest. USGS (2022a) reports that the earthquake’s depth, location, and focal mechanism are consistent with the east-west trending, right-lateral North Anatolian Fault, which accommodates most of the right-lateral horizontal motion with a rate of 23-24 mm/yr between the Eurasian plate and the Anatolian micro-plate. Such motion occurs as the Anatolian micro-plate is being pushed westward to further accommodate closure of the Mediterranean basin that is caused by the collision of the African and Arabian plates in south-eastern Turkey. At the earthquake location, the Arabian plate moves north-northwest at a velocity of about 17 mm/yr relative to the Eurasian plate (USGS, 2022a).

2.2. Recorded Ground Motions

Five ground motion stations closest to the epicenter are shown in Figure 2.2. Table 2.1 lists the peak ground acceleration (PGA) values recorded at these stations as well as at station 8105, which is not shown in Figure 2.2 by AFAD (2022b). In Table 2.1, the maximum PGA is 0.59g (592 cm/s^2), which was recorded in the East-West direction at station 8105 (40.903°N, 31.152°E) of the AFAD network, located 13.88 km away from the epicenter and approximately 7 km away from the Duzce city center. Co-authors M. E. Arslan and A. C. Altunisik confirmed with AFAD authorities that the accelerations measured at station 8105 were not reliable. During the on-site inspections carried out by AFAD after the earthquake, it was determined that this station's current location and state was not suitable for making reliable measurements. Therefore, it was decided to relocate the station (Fig. 2.3). As a result, the data obtained from station 8105 was not considered in the preliminary evaluation report published by AFAD (2022b). Similarly, recordings at station 8105 are disregarded in this report although they are included in Table 2.1. Based on this assessment, the largest measured PGA in Table 2.1 was 407.76 gal at station 8102. Accordingly, recordings from station 8102 are analyzed herein.

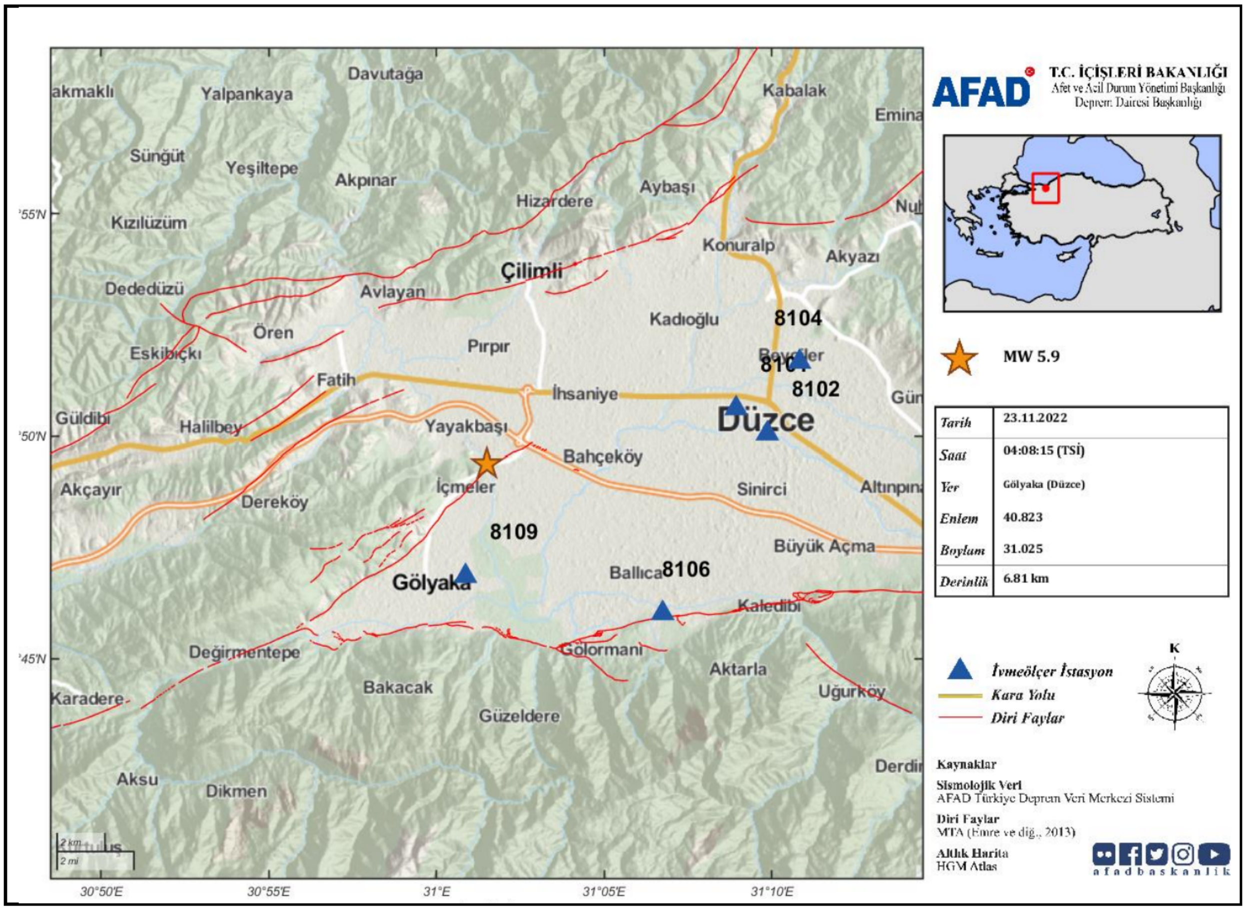


Figure 2.2. Map of the closest five stations (blue triangles) to the epicenter where the ground motions were recorded (AFAD 2022b).

Figure 2.3. Photographs of station 8105 (Source: Arslan & Altunisik).

Table 2.1. Ground motion stations and recorded PGA values (AFAD 2022b).

Station					**Measured PGA [gal]**			**Distance, R_{epi} [km]**
Code	**Province**	**District**	**Latitude**	**Longitude**	**N-S**	**E-W**	**Vertical**	
8109	Duzce	Golyaka	40.7810	31.0144	265.33	356.87	237.47	4.75
8106	Duzce	City Center	40.7670	31.1124	343.10	377.30	226.16	9.63
8101	Duzce	City Center	40.8436	31.1489	291.64	306.75	251.97	10.62
8102	Duzce	City Center	40.8342	31.1644	218.04	407.76	244.31	11.79
8104	Duzce	City Center	40.8611	31.1804	353.19	367.14	226.69	13.74
8105	Duzce	City Center	40.9028	31.1520	581.91	592.03	212.96	13.88

Figure 2.4 displays the recorded horizontal ground motions at station 8102 with V_{s30} = 280 m/s. The maximum PGAs measured by that station were 0.41g and 0.22g in the E-W and N-S directions, respectively. The duration and predominant period information are listed in Table 2.2. The E-W component of this ground motion shows a characteristic sine pulse starting shortly after 5.0 s and includes one peak in the positive direction (0.41g at 6.05 s) and two peaks (0.26g and 0.29g at 5.32 and 6.55 s, respectively) in the negative direction. This typical near-field E-W motion is consistent with the E-W strike-slip fault mechanism identified by USGS (2022b).

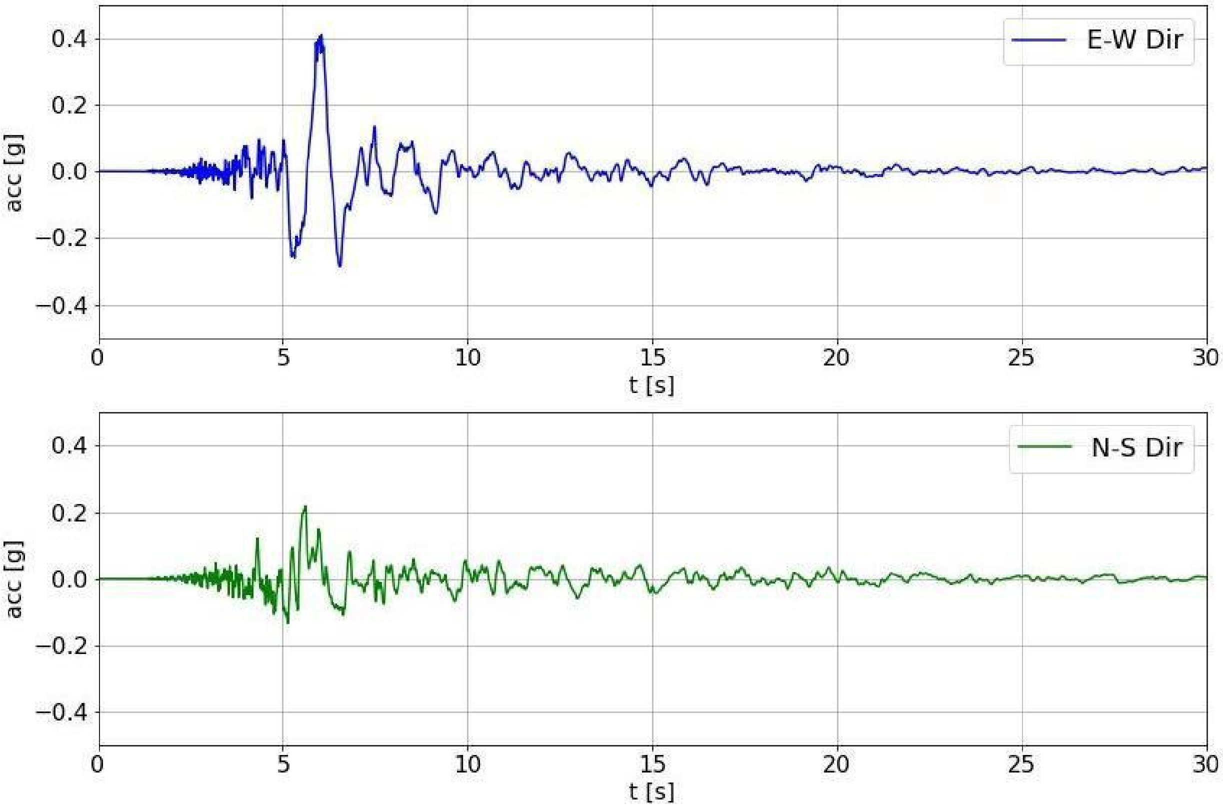


Figure 2.4. Horizontal ground motions recorded at station 8102 (AFAD 2022d).

Table 2.2. Features of the recorded ground motions from station 8102 (AFAD, 2022d)

Direction	**E-W**	**N-S**
PGA [g]	0.41	0.22
Uniform duration [s][1]	13.25	14.81
Significant duration [s][2]	5.06	14.32
Predominant period [s]	1.18	1.64

[1] The duration during which the acceleration is larger than 5% of PGA.

[2] The duration between 5% and 95% Arias intensity.

2.3. Response Spectra

As described in Section 2.2, horizontal components of the ground motion record, measured near the city center of Duzce (stations 8101, 8102 & 8104 in Fig. 2.2), are used to calculate the response spectra to compare with the design spectrum for the design basis earthquake (DD-2) in the current Turkish Earthquake Code, TEC-2018 (Fig. 2.5). Stations 8101 and 8102 are located on soft soils (e.g., V_{s30} = 280 m/s at station 8102), which corresponds to site class ZD in TEC-2018. Station 8104 is located on soil with shear wave velocity V_{s30} = 298 m/s, corresponding to site class ZC in TEC-2018. Due to differences in soil properties, the design spectrum presented in Figure 2.5 differs between the site of station 8104 and that of stations 8101 and 8102. Since these three stations are located 10.62 to 13.74 km away from the epicenter (see Table 2.2) and near Duzce city center (see Fig. 2.2), they provide good estimates for the seismic demand experienced by the structures in Duzce. Figure 2.5 indicates that the spectral accelerations were less than the corresponding seismic design accelerations specified in the current design code, TEC-2018, except for the ground motion measured in the E-W direction at station 8102. For this ground motion, spectral accelerations for periods between approximately 0.9 and 2.4 s are larger than those implied in the design code.

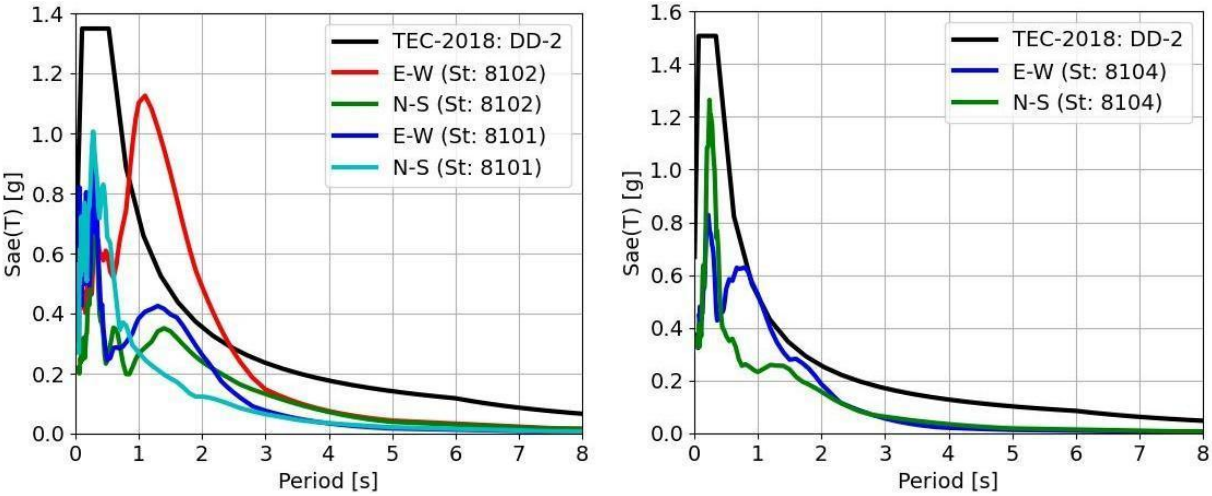


Figure 2.5. Comparison of acceleration response spectra of the recorded ground motions at three stations with the design spectrum DD-2 per TEC-2018.

3. Local Codes and Construction Practices

Earthquake-resistant design of buildings in Turkey is regulated by the Turkish Earthquake Code, TEC (2018). Prior to the latest revision in 2018, TEC has undergone seven revisions (1947, 1953, 1961, 1968, 1975, 1998, and 2007). Most of these revisions were based on the advances in earthquake engineering and lessons learned from the earthquakes around the world and particularly in Turkey. For example, the 2007 version of the code has been highly influenced by the observations made after the 1999 Kocaeli and Duzce earthquakes (Sezen et al., 2000). The current version of the code includes state-of-the-art earthquake engineering principles such as performance-based design. Moreover, seismic hazard maps are available for the entire country corresponding to Design Basis Earthquake (DBE) and Maximum Considered Earthquake (MCE) levels.

Anecdotally, it was reported that approximately 70% to 80% of the current building stock in the earthquake affected region has been constructed after the 1999 earthquakes (Hurriyet, 2022). Depending on the year of construction and design, these buildings were designed to meet the requirements of the 1997, 2007, or 2018 versions of the Turkish Earthquake Code (TEC), which helped to prevent the collapse and heavy damage that could have occurred otherwise. The number of damaged buildings and their damage levels are reported later in Table 4.3.

As shown previously in Figure 2.5, recorded ground shaking at station 8102 led to spectral accelerations larger than 1.1g at approximately 1.0 s period. Currently, construction of buildings with more than four stories is not allowed in Duzce. Therefore, natural periods of these buildings are expected to be smaller than 0.5 s. Figure 2.5 shows that these buildings are expected to experience spectral accelerations at or less than approximately half of the 1.3g spectral acceleration in the short period range. However, considering that the forces used in design are obtained by dividing this acceleration of 1.3g by response modification factors as large as 8, seismic demands are larger than the seismic design forces.

Despite the demands being larger than the design loads, minimal damage was observed in recently constructed buildings during the earthquake. Reasons for the overall low levels of observed damage can be attributed to the overstrength available in the buildings due to various factors including nominal strength values, presence of infill walls, strength increase due to minimum design requirements, load redistribution, and other factors. In TEC (2018), an overstrength factor of 3 is used for well-detailed ductile reinforced concrete (RC) buildings. Considering, this typical level of overstrength, a design spectral acceleration of 1.0g (specified in the 2007 version of TEC in the short period range at locations with the most significant earthquake hazard) and a strength reduction factor of R=8, the expected yield base shear normalized by the building weight (V_y/W) is around 0.4. Very limited or no damage in the recently constructed buildings is likely due to increased base shear capacity from such overstrength. Another major contributor to the low levels of damage is limiting the number of stories to four. It is also noted that the enforced seismic design details in recently constructed buildings enhanced the ductility capacity and avoided any collapses.

This observation may have implications for the future of seismic codes and performance design practices in the US and worldwide. There are ongoing discussions for potential updates of the building codes in the US to achieve certain functionality objectives (e.g., achieving re-occupancy, functional recovery, and full recovery within target durations) beyond the collapse prevention and basic life safety intent of prescriptive codes. One of the proposed changes to achieve these objectives is to increase the importance factors to increase the design forces. The observations from the 2022 Duzce earthquake show that this may be a reasonable approach to achieve functional recovery (at least for buildings with fundamental periods within certain period ranges).

This earthquake also shows the importance of taking action to reduce the number of buildings with seismic deficiencies. Poor design practices and structural design deficiencies were identified after the 1999 Kocaeli and Duzce earthquakes (Sezen et al., 2000). The majority of the buildings in the region affected by the November 23, 2022 earthquake were new. Effectively, they replaced the older buildings that were designed and constructed before 1999. Similarly, many buildings including government and school buildings in the region have been retrofitted since 1999. The low level of damage observed during this earthquake shows the effectiveness of code-specified seismic design requirements on newer buildings with four or less stories and is a testimony to the effectiveness of the retrofit measures taken since 1999.

4. Building Performance

The following sections provide notable case studies of the typical performance of buildings in this event, respectively organized by occupancy. Readers may consult the imagery compiled in the accompanying Media Repository, curated with this report in DesignSafe, to access a wider collection of georeferenced visual evidence cataloged by occupancy.

4.1. Residential Buildings

After the earthquake, 51,267 buildings have been evaluated by rapid visual assessment methods to determine their damage status (DARCMBAE 2016; PDRS 2019). The Turkish Chamber of Civil Engineers Disaster Preparedness and Response Board developed the DARCMBAE (2016). The DARCMBAE post-earthquake rapid visual screening method considers the dimensions of horizontal and vertical structural system elements and uses empirical equations to calculate the rate or amount of structural damage. Damage to the vertical load-carrying elements is respectively classified as Low, Moderate, or High if <20%, 20-50%, or >50% of columns are damaged. In addition, the percentage of damaged beams is considered when determining the building's damage state. For example, damage is classified as Low or Moderate if respectively less than 75% or more than 75% of the beams are damaged. PDRS (2019) uses a post-earthquake rapid visual screening form to collect data for masonry and RC structures. The form includes various parameters, such as the number of stories, plan and vertical irregularities, plinth area, diaphragm type, short column potential, roof type, site soil properties, and visual quality of construction. For RC structures, it distinguishes between RC frame structures and RC frame & shear wall structures. The method also differentiates between different types of masonry structures, such as unreinforced masonry and reinforced masonry.

Table 4.1 is a summary of the investigation conducted by the Ministry of Environment, Urbanization & Climate Change following the DARCMBAE (2016) and PDRS (2019) procedures. While most of the building stock in the region has experienced limited or no damage, a limited number of buildings (1.54% of the surveyed buildings) experienced severe damage; a few instances of complete building collapses were also observed.

The reported damage was typically localized in the infill walls in the form of in-plane and out-of-plane separations or failures and damage to nonstructural components. Some examples of observed infill wall damage are shown in the next sequence of figures. Figures 4.1a and 4.2c show clear examples of diagonal shear failure of infill walls and wall separation from the RC beam-column frame system.

Table 4.1. Damage status of buildings in the region as of January 2, 2023 following DARCMBAE (2016) and PDRS (2019) procedures.

Damage Status	Number of Buildings	Damaged Buildings (%)
Severe damage	792	1.54
Moderate damage	5	0.01
Limited damage	5,594	10.91
No damage	44,876	87.53

(a) (b) (c)

Figure 4.1. Examples of representative infill wall and tile damage in buildings at (a) 40.840°N, 31.144°E and (b) & (c) 40.838°N, 31.143°E. (Source: Demir).

(a) (b) (c)

Figure 4.2. Examples of out-of-plane damage of infill and partition walls (coordinates: (a) & (b) 40.814°N, 31. 014°E, and (c) 40.791°N, 30.994°E). [source: Arslan & Altunisik].

Some representative examples of observed damage in RC beams and columns are shown in Figures 4.3 and 4.4, respectively. Figures 4.4a and 4.4b show characteristic column shear failures, and Figure 4.4a presents typical short column damage. It should be noted that the sizes of the longitudinal and transverse steel in Figure 4.4c are almost equal. The exposed column in Figure 4.4c seems to have low concrete quality and a low amount of longitudinal steel.

(a) (b) (c)

Figure 4.3. Examples of RC beam damage observed as shear and flexural cracks in buildings at (a) & (c) 40.891°N, 31.049°E and (b) 40.891°N, 31.049°E. (Source: Arslan & Altunisik).

(a) (b) (c)

Figure 4.4. Examples of damage observed in RC columns in buildings at (a) 40.851°N, 30.947°E, (b) 40.809°N, 31.234°E, and (c) 40.810°N, 31.198°E. (Source: Arslan & Altunisik).

The four-story RC building shown in Figure 4.5b was built in 1988. This building pounded with the adjacent building on the left in Figure 4.5a during the earthquake. Due to insufficient gap between the two buildings, damage occurred in the load bearing concrete columns over the entire height of both buildings, including the parapet wall on of the building on the left in Figure 4.5a. The building in Figure 4.5b also experienced infill wall damage in the second and third stories above the overhangs (see Fig. 4.5c).

(a) (b) (c)

Figure 4.5. Damage to an RC apartment building at 40.838°N, 31.158°E (Source: Demir).

The four-story RC frame building shown in Figure 4.6 was built in 1992. Infill wall damage is visible on the left in the second story of the building. The wall damage occurred just above the approximately 0.5 m long overhang in that corner and spread around the window. The owner of the building said that it has not been designed or approved by an engineer. This is not unusual for the buildings constructed in this region before 1999. It should be noted that this building survived the 1999 M_w 7.6 Kocaeli and 1999 M_w 7.2 Duzce earthquakes with limited damage.

Figure 4.6. Damage to an RC apartment building in Golyaka at 40.779°N, 30.989°E (Source: Demir).

4.2. Government Facilities and Schools

No significant structural damage was observed or reported in the region's governmental buildings, schools, and hospitals, other than the damage in nonstructural elements including infill walls, facades, etc. An example of damage to a governmental building is provided in Figure 4.7. The Duzce courthouse was heavily damaged during the two 1999 earthquakes and demolished 23 years ago. The construction of the new courthouse shown in Figure 4.7 started in 2006 and was completed in 2008. The façade, including the gable end of the roof, was damaged in the November 23, 2022 earthquake (see Fig. 4.7). Broken façade materials are a falling hazard near the entrance and could have led to fatalities or injuries if the earthquake had not occurred at 4:08 am.

Figure 4.7. Facade damage in the Duzce courthouse located at 40.827°N, 31.189°E. (Sources: Deutsche Welle (2022) (left) & Demir (right)).

Figure 4.8 shows representative examples of observed damage in school buildings. Typical damage in these multi-story RC structures with unreinforced masonry infill walls include: (1) diagonal shear cracks in infill walls and separation from the surrounding beam-column frame (Figs. 4.8a,b), (2) cracks in the staircases (Fig. 4.8c), and (3) other nonstructural damage including damage to suspended ceilings (Fig. 4.8b).

(a) (b) (c)

Figure 4.8. Damage in school located at 40.903°N, 31.181°E (Source: Arslan & Altunisik).

4.3. Masonry Buildings

In rural areas or remote villages, there are older one- or two-story buildings with masonry or timber-masonry load bearing walls. Figure 4.9 shows a timber-masonry building that was built in the 1970s. This one-story building in Golyaka experienced significant cracking, but damaged wall elements did not collapse (see large cracks and broken plaster on interior, as well as large vertical cracks on the exterior left of the building in Fig. 4.9).

Figure 4.9. Damage in timber-masonry load-bearing walls of a building in Golyaka (coordinates: 40.824°N, 31.001°E) (Source: Demir).

4.4. Mosques

The November 23, 2022 Duzce earthquake caused substantial damage in multiple mosques, including Kiremitoğlu Mosque in downtown Duzce, Saridere Village Mosque in Golyaka (Duzce), Cedidiye Mosque in Duzce, Ayşe Metin Neighborhood Mosque in Cumayeri (Duzce), Yaka Neighborhood Mosque in Cumayeri (Duzce), and Saz Village in Kaynaşli (Duzce). Kiremitoğlu Mosque in downtown Duzce was built in 1968 and includes unreinforced brick masonry load bearing walls with many window openings. The mosque's central dome experienced a vertical displacement of approximately 100 mm. Major shear cracks were observed on the entrance walls around the windows as shown in Fig. 4.10.

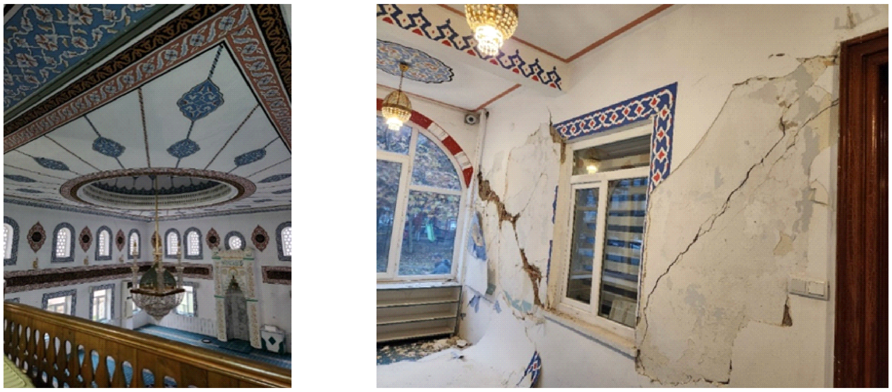


Figure 4.10. Damage on the dome (left) and walls (right) of Kiremitoğlu mosque at 40.838°N, 31.145°E. (Source: Demir).

Another mosque that experienced significant damage due to the earthquake is the Saridere village mosque. The infill walls had diagonal cracks and separated from the RC beams (along horizontal cracks near the top in the left photograph in Fig. 4.11). The plaster also spalled off

(Fig. 4.11). This mosque was demolished a few days after the earthquake. It appears that the demolition decision was based on cost of repairs because there was no evidence of structural damage in the RC columns or beams.

Figure 4.11. Damage to Saridere village mosque in Golyaka at 40.819°N, 30.994°E. (Source: Demir).

Two minarets of Cedidiye mosque in downtown Duzce had collapsed and were built after November 12, 1999 earthquake. Only the pulpit inside the Cedidiye mosque was destroyed during the November 23, 2022 earthquake, as shown in Figure 4.12a. Meanwhile, horizontal and vertical cracks developed in the front walls of the Saz village mosque in Kaynaşli, Duzce (Fig. 4.12b).

(a) (b)

Figure 4.12. Damage to (a) Duzce Cedidiye mosque at 40.838°N, 31.163°E and (b) Saz village mosque in Kaynaşli, Duzce (Sources: (a) Anadolu Ajansi (2022), (b) KARAR.tv (2022)).

4.5. Stairwells

During the inspections of buildings, damage was reported in many staircases or stairwells. Structural walls on the perimeter of the stairwells tend to carry a large portion of the lateral loads and thus deform during earthquakes; such relative movement of the walls with respect to the staircases not monolithically connected may explain observed damages in Figures 4.13. A large diagonal shear crack below the window in Figures 4.13a,b is an indication of the large lateral shear demand on such walls.


(a) (b) (c)

Figure 4.13. Examples of the damage observed in stairwells of a building at 40.814°N, 31.014°E. (Source: Arslan & Altunisik).

5. Infrastructure Performance

No damage was observed in power, telecommunications, water, and other infrastructure or lifelines. There was no interruption of internet and telephone services. No road or bridge damage was observed, although there was one incident of road pavement cracking reported in early media coverage. Overall infrastructure performance is summarized in Table 5.1.

Table 5.1. Summary of performance by infrastructure class (Source: Arslan).

Power & Telecommunication	After the earthquake, electricity was cut off in a controlled manner for ~2 hours. Phone lines and the internet were unaffected.
Roads & Bridges	No significant damage observed on roads and bridges.
Other Lifelines	Water & natural gas were cut off in a controlled manner for ~2 hours.

6. Geotechnical Performance

No major damage was observed on the soil supporting the foundations of structures and infrastructure.

7. Recommended Response Strategy

Based on the information gathered by the VAST and summarized in this Preliminary Virtual Reconnaissance Report (PVRR), the following recommendations for further study:

1. Overall damage observed in this earthquake was limited due to improved seismic codes, compliance of design and construction with the current seismic codes, and aspects of regional planning such limiting the number of stories to four. However, other hazard-related factors, such as the relatively moderate levels of shaking and short duration of ground motions also contributed to the limited damage that was observed. With the data and observations from this earthquake, it is recommended to further evaluate the efficacy of these measures by projecting the extent of damage that would be anticipated in a more severe and longer duration future earthquake.

2. The vast majority of the buildings in the region affected by the November 23, 2022 earthquake were either retrofitted or rebuilt after the August 17, 1999 M_w 7.6 Kocaeli and November 12, 1999 M_w 7.2 Duzce earthquakes. No structural damage and limited nonstructural damage are reported in these recently constructed/retrofitted buildings. The November 23, 2022 earthquake thus provides a good opportunity to study the effectiveness of retrofit measures and the strict seismic design requirements enforced for the buildings constructed after the 1999 earthquakes.

3. Incidences of severe structural damage and collapse were limited. There were no reports of damage to roads, bridges, power, water, telecommunications, and other infrastructure & lifelines. However, the economic losses due to nonstructural damage and business interruption were significant. It should be explored how these economic losses can be reduced in future earthquakes with the use of protective systems and other technologies.

4. One of the occupancy types that experienced the largest damage was mosques. The reasons for this damage and potential retrofit needs should be explored.

Based on the criteria summarized in Table 7.1, and supported by the preliminary observations outlined in this report, StEER's response to this event will remain at Level 1 with no activation of a Field Assessment Structural Team (FAST) (though this PVRR did benefit from the direct field observations of some authors). As a result, this PVRR represents the extent of StEER's official response. StEER will continue to coordinate with other organizations responding to this event to encourage consideration of the above recommendations and will monitor their assessments.

Should these ongoing efforts reveal new information that would satisfy one or more of StEER's escalation criteria, StEER may re-evaluate its decision and deploy a FAST.

Table 7.1. Summary of Escalation Criteria Satisfied by Mw 6.1 Duzce, Turkey Earthquake

Activation Level	Hazard	Exposure	Feasibility
Level 1: Major hazard event with **potential** to generate new knowledge	*Unique Hazard characteristics* • Major intensity event (e.g., EF4, Cat 3, Mw 5.5, Tsunami alert issued)	*Infrastructure of interest* • Sufficiently populated area to create measurable impacts • Noteworthy code or construction practices (e.g., test of revised codes, mitigation measures/retrofits) • Communities with history of recovery OR those rarely exposed	*Resources* • Availability/interest of members in the impacted region • Sufficient media/social media coverage on event, including the potential to automate mining of information

References

AFAD (2022a). "Earthquake Catalog." https://deprem.afad.gov.tr/event-catalog [Date accessed: December 28, 2022]

AFAD (2022b). "Duzce Earthquake Preliminary Report". Nov. 23rd, 2022. https://deprem.afad.gov.tr/assets/pdf/23kasim2022GolyakaDuzceMW59.pdf

AFAD (2022c). "BASIN BULTENI" https://www.afad.gov.tr/duzcede-meydana-gelen-59-buyuklugundeki-deprem-hk-basin-bulteni-24112022-saat-1950-itibariyla [Date accessed: December 1, 2022]

AFAD (2020d). "AFAD - TADAS" https://tadas.afad.gov.tr/

Anadolu Ajansi (2022). https://www.aa.com.tr/tr/gundem/duzcede-1999daki-depremde-de-zarar-goren-caminin-minberi-yikildi/2745964 [Date accessed: January 2, 2023]

Daily Sabah (2022). https://www.dailysabah.com/turkey/59-earthquake-shakes-turkiyes-duzce-frightens-whole-region/news

DARCMBAE (2016). Damage Assessment of Reinforced Concrete and Masonry Buildings Affected by the Earthquake, IMO, Ankara. https://istanbul.imo.org.tr/TR,90143/depremin-etkiledigi-betonarme-ve-yigma-binalarda-h

asar-tespiti.html [Date accessed: January 4, 2023]
https://drive.google.com/file/d/15GFkztsFuKXt58_Fn3VNznngHt1IgGTg/view

Deutsche Welle (2022). https://www.dw.com/tr/d%C3%BCzce-depremi-181-yap%C4%B1-a%C4%9F%C4%B1r-hasarl%C4%B1/a-63900028

DHA (2022). Düzce'de depremin yaraları sarılıyor.https://www.dha.com.tr/foto-galeri/duzcede-depremin-yaralari-sariliyor-2167094/1 [Date accessed: January 18, 2023]

Ensonhaber (2022). Duzce'de depremin ardından cam fabrikası görüntülendi. https://www.ensonhaber.com/3-sayfa/duzcede-depremin-ardindan-cam-fabrikasi-goruntulendi [Date accessed: December 1, 2022]

Hurriyet (2022). Düzce'deki kentsel dönüşüm yıkımı önledi. https://www.hurriyet.com.tr/gundem/duzcedeki-kentsel-donusum-yikimi-onledi-42175934 [Date accessed January 2, 2023]

IMO (2022). *23.11.2022 Golyaka-Duzce Earthquake Preliminary Report*. Chamber of Civil Engineers. https://www.imo.org.tr/Eklenti/8115,golyaka-deprem-raporupdf.pdf?0&_tag1=D2A204FCD61ACD26AEB2AB1B4F74C5C48F66ED06

KARAR.tv (2022). https://www.karar.com/guncel-haberler/evin-besik-gibi-sallandigi-soke-eden-anlar-kamerada-1707272 [Date accessed: January 2, 2023]

KTU-DU (2022). Altunisik A. C., Arslan M. E., and Aykanat B. *November 23, 2022 Golyaka* (*Duzce*) *Earthquake* (*Mw 5.9*) *Field Observations and Investigation Report.* Karadeniz Technical University and Duzce University. https://www.ktu.edu.tr/dosyalar/insaat_b5481.pdf

MTA (2022). Ozalp S. and Kurcer A. *November 23, 2022 Golyaka* (*Duzce*) *Earthquake (Mw 6.0) Field Observations and Investigation Report*. General Directorate of Mineral Research and Exploration, Ankara https://www.mta.gov.tr/v3.0/sayfalar/bilgi-merkezi/deprem/pdf/23.11.2022_Duzce_Golyaka.pdf

PDRS (2019). Principles on Detection of Risky Structures, Ministry of Environment, Urbanization and Climate Change, Ankara https://www.resmigazete.gov.tr/eskiler/2019/02/20190216-1-1.pdf [Date accessed: January 4, 2023]

Sezen, H., Elwood, K. J., Whittaker, A. S., Mosalam, K. M., Wallace, J. W., and Stanton, J. F. (2000). *Structural engineering reconnaissance of the August 17, 1999, Kocaeli* (*Izmit*), *Turkey, earthquake*. PEER Report 9. Pacific Earthquake Engineering Research Center, University of California, Berkeley https://peer.berkeley.edu/publications/2000-09

T4Haber (2022). https://www.t4haber.com.tr/deprem-is-yerlerinde-buyuk-hasar-birakti/374064/ [Date accessed: January 2, 2023]

Tasdemir, Z. N. (2022). https://www.birgun.net/haber/duzce-merkezli-6-buyuklugunde-deprem-istanbul-ankara-ve-bircok-kentten-hissedildi-410973

TEC (2018). Turkish Earthquake Code. Ministry of Environment, Urbanization and Climate Change, Ankara. https://www.resmigazete.gov.tr/eskiler/2018/03/20180318M1-2-1.pdf [Date accessed: January 4, 2023]

US Geological Survey (USGS) (2022a). “M - 16 km W of Duzce, Turkey - Overview”. Nov. 23rd, 2022. https://earthquake.usgs.gov/earthquakes/eventpage/us7000irp8/executive

US Geological Survey (USGS) (2022b). “M 6.1 - 16 km W of Duzce, Turkey - PAGER”. Nov. 23rd, 2022. https://earthquake.usgs.gov/earthquakes/eventpage/us7000irp8/pager

Yeditepe (2022). Saygili O., Vuran E., Uzel A., and Olgun S. E. *November 23, 2022 Golyaka-Duzce Earthquake Investigation Report*. https://eng.yeditepe.edu.tr/tr/duyuru/6342

Yenisafak (2022). https://www.yenisafak.com/foto-galeri/gundem/duzcede-buyuk-deprem-hasar-goren-binalar-goruntulendi-2073011