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Global Rapid Post-Disaster Damage Estimation (GRADE) Report

February 6, 2023 Kahramanmaraş Earthquakes

Türkiye Report

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Abbreviations

AFAD:	Disaster and Emergency Management Presidency
DaLA:	Damage and Loss Assessment
D-RAS:	Disaster-Resilience Analytics & Solutions, GPURL, World Bank Group
EAFZ:	East Anatolian Fault Zone
ELER:	Earthquake Loss Estimation Routine
ESRM:	European Seismic Risk Model
FCV:	Fragility, Conflict and Violence
GBV:	Gender-Based Violence
GFDRR:	Global Facility for Disaster Reduction and Recovery
GPURL:	Urban, Disaster Risk Management, Resilience and Land Global Practice
GRADE:	Global RApid post-disaster Damage Estimation
HOTOSM:	Humanitarian OpenStreetMap Team
JAK:	Gendarmerie Commando Special Public Security Command
JÖAK:	Gendarmerie Special Public Security Command
MoEUCC:	Ministry of Environment, Urbanization, and Climate Change
MTA:	General Directorate of Mineral Research and Exploration
OSM:	Open Street Map
PDNA:	Post-Disaster Needs Assessments
SuTP:	Syrians under Temporary Protection
TCIP:	Turkish Catastrophe Insurance Program
TEV:	Total Exposure Value
UMKE:	National Medical Rescue Team
US$:	United States Dollars
USGS:	United States Geological Survey

Exchange Rates

Turkish Lira (TRY) 1 = US$0.053 (Jan. - Feb. 2023 average)

Contents

Executive Summary

On February 6, 2023, two very large earthquakes of magnitude (Mw) 7.8 and 7.5[1,2] occurred nine hours apart on different fault lines in the southern region of Türkiye and northern Syria. These are referred to as the "Kahramanmaraş earthquakes". More than 6,212 aftershocks, including eight over magnitude 5.5[3] have occurred. Aftershocks are expected to continue for several months, with a decreasing frequency. These aftershocks could cause additional damage, especially in already weakened or damaged structures. A magnitude 6.3 earthquake on February 20, 2023, centered on Hatay area, is reported to have caused further damage.

In Türkiye, which is the focus of this report, these earthquakes have resulted in widespread damage across 11 provinces, where around 14.01 million (16.5 percent) of Türkiye's population live, including Adana, Adıyaman, Diyarbakır, Elazığ, Gaziantep, Hatay, Kahramanmaraş, Kilis, Malatya, Osmaniye and Şanlıurfa. As of February 19, 2023, more than 41,020 fatalities have been reported, 108,068 people injured, and more than 1,200,000 people displaced.

The objective of this report is to provide an early and preliminary estimate of the direct damage costs caused by these earthquakes, which in turn will inform the response of the World Bank Group and its partners and support planning for recovery and reconstruction. The report is based on a rapid and remote post-disaster damage assessment that follows the established GRADE methodology[4]. This assessment benefited from a range of data including: government damage data and reports; simulation of earthquake ground motion through hazard modelling that was verified against instrumental strong ground motion recordings; buildings and infrastructure exposure database[5] and capital stock information[6]; analysis of current unit costs of construction in Türkiye; and structural vulnerability analysis. GRADE is intended as a rapid remote estimate prepared within a short timeframe to inform early decision-making, and is not intended as a substitute for detailed on-the-ground analysis which may be additionally conducted in the weeks/months to come. The GRADE assessment should be interpreted as a first-order direct damages estimation, albeit with a significant degree of reliability. However, GRADE's

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[1] Based on figures from the United States Geological Survey

[2] Bogazici University Kandilli Observatory and Earthquake Research Institute estimate magnitudes as 7.7 and 7.6.

[3] Up until February 19, 2023

[4] Global Rapid post-disaster Damage Estimation (GRADE) approach developed at the World Bank and conducted by the Global Practice for Social, Urban and Rural Development, and Resilience (GSURR) Disaster-Resilience Analytics & Solutions (D-RAS) Knowledge Silo Breaker (KSB). The methodology aims to address specific damage information needs in the first few weeks after a major disaster. See: https://www.gfdrr.org/sites/default/files/publication/DRAS_web_04172018.pdf for details of the methodology.

[5] ESRM20 exposure model

[6] Capital Stock Information is derived by the GPDRA team using the Perpetual Inventory Method (PIM) and annual capital formation data from national accounts (e.g. Berlemann and Wesselhöft, 2014). This method produces a monetary estimate of the current value of physical capital stocks based on investment over a long time-series using a fixed asset depreciation rate.

outputs are still estimates; remote-based calculations that are influenced and updated from available ground-based data. While there is confidence in the overall economic estimates and distribution of damage, the confidence level at the individual asset level is very low. Furthermore, GRADE results do not include the losses and recovery and reconstruction needs that are also crucial for the comprehensive understanding of the impact of the disaster.

In this report, direct physical damage is quantified using the gross capital stock, which is the replacement cost of an asset newly rebuilt based on current unit costs and construction practice, and although it does include fixed/mobile industry capital, it does not take into account transport equipment, or technological changes, etc. **However, reconstruction costs will be higher depending on the extent of new construction codes and guidelines being used**. Reconstruction costs are expected to be proportionately higher for non-residential than residential buildings, due to the possibility of upgrades and "build back better" practices (because a large share of its capital stock and production technologies are outdated). Estimates of direct damages, presented in this report, do not include costs associated with humanitarian and emergency response, or the losses associated with economic flows (e.g., business interruption). Moreover, assessments of damage are still ongoing across many sectors.

Direct damages from the earthquakes are estimated at US$34.2 billion (equivalent to 4 percent of Türkiye's 2021 GDP). This represents the physical damage costs (see method section), but does not represent an estimation of indirect or secondary impacts of the earthquakes on Türkiye's economy, and hence is not an estimate of the impact on the growth of Türkiye's economy. These estimates do not consider uncertainty due to factors such as increased costs of materials and potentially labor, commonly experienced after disasters of this magnitude. **Based on global experience, recovery and reconstruction costs will be much larger, potentially twice as large[7], and that GDP losses associated to economic disruptions will also add to the cost of the earthquakes.**

The total damages presented here are broadly consistent with other reported damages. Verisk has published economic damages in excess of $20 billion, JPMorgan estimates around $25 billion, and Karen Clark and Company estimate around $20 billion, all three which use risk models as a basis for estimates[8]. Turkish Enterprise and Business Confederation has published an estimate of $84 billion, based on a comparison with the 1999 Izmit, Türkiye, earthquake[9].

The total direct damages are dominated by damages to residential buildings (US$18 billion, or 53 percent of total), followed by damages to non-residential buildings (US$9.7 billion, or 28 percent), while effects on infrastructure account for the remaining 19 percent (US$6.4 billion).

[7] The recovery and reconstruction needs include costs associated with building back better, recovery needs beyond the built environment, surge pricing, and so forth.
[8] More information can be found at the following links: Karen Clark and Company, JPMorgan, and Verisk
[9] Turkish Enterprise and Business

Other key observations and findings are:

- **The most extensive damage to buildings and infrastructure occurred in Hatay, Kahramanmaraş, Gaziantep, Malatya and Adıyaman provinces**, which together account for 81% of the estimated damages and are home to around 6.45 million people (around 7.4 percent of the total population of Türkiye). Of the total damages, 36 percent occurred in Hatay province (population 1.69 million), followed by 17 percent in Kahramanmaraş province (population 1.18 million) and 14 percent in Gaziantep province (population 2.15 million). See Table 1 for further information on provincial damages.
- **Damage as a proportion of total building/infrastructure stock is highest in Hatay, Kahramanmaraş, and Adıyaman.** In Hatay, the damage ratio[10] is almost 42 percent for residential buildings, 40 percent for non-residential buildings, and almost 34 percent for infrastructure. In Kahramanmaraş, 29 percent of residential buildings, 29 percent of non-residential buildings, and 24 percent of the infrastructure is damaged. In Adıyaman, 27 percent of residential buildings, 26 percent of non-residential buildings, and 21 percent of the infrastructure is damaged. See Table 2 for further information.
- **The regions[11] that include the provinces most affected by the earthquakes also have some of the highest poverty rates in Türkiye[12] and host more than 1.7 million Syrians under Temporary Protection (SuTP) comprising almost 50 percent of total SuTPs in country[13].** The higher poverty rates and hosted SuTP will be key considerations for the recovery and reconstruction.
- **More than 105,000 low-rise houses and multi-story apartment buildings have been reported as severely damaged, or collapsed, of which 9,432 buildings are reported as collapsed[14].** Buildings constructed prior to the introduction of modern seismic design building codes, which were introduced in 1998, appear to have been particularly susceptible to severe damage and collapse.
- **At some locations in the affected area, such as Antakya, recorded ground motions associated with the earthquakes were very high**. These high levels of ground motion may have contributed, alongside other critical factors, to the extensive damage observed in the affected areas (Annex A1.7 provides further information). Liquefaction[15] was also observed in some areas.
- **It is estimated that more than 1.25 million people have been rendered temporarily homeless.** The Government's strategy includes the complete demolition of buildings found to be severely damaged. Similarly, buildings found to be moderately damaged are evacuated until structural strengthening can be undertaken.

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[10] Damage ratio is defined as, the cost of damages / capital stock. E.g. where the report defines the damage ratio as 42% for residential buildings in Hatay, this means that the cost of damages to residential buildings in Hatay is 42% of the capital stock of the residential buildings.
[11] NUTS2 definition
[12] Defined as below US$6.85 per day, Source: Survey of Income and Living conditions 2020. or (SILC 2020)
[13] https://www.goc.gov.tr/gecici-koruma5638, February 2, 2023
[14] Yıkık in the Hasar Tespit database, MoEUCC, February 18, 2023
[15] A description of liquefaction (USGS).

- **At least 15 hospitals have suffered partial or severe damage, with damage assessments still ongoing[16].** Hospitals or hospital wings with risk of collapse have been evacuated by emergency services, with patients referred to facilities across the country and field hospitals established to provide continuity of care.
- **The minimum expected direct damages for the most affected provinces are shown below for the key sectors: residential (housing), non-residential buildings[17], and infrastructure[18].** Estimates cover buildings and contents; however, the analysis does not include costs associated with humanitarian and emergency response, or the losses associated with economic flows (e.g. business interruption). Moreover, damage assessments are ongoing in the affected areas

Table 1: Estimate of the direct damages by sector and province in absolute values (in US$ millions). This includes the 11 Provinces which were named as "Disaster Areas" by the Government of Türkiye, plus all other Provinces which experienced damage.

Province	Residential	Non-Residential	Infrastructure	Total		
				Median	Lower	Upper
HATAY	6,601	3,516	2,331	12,448	11,236	13,643
KAHRAMANMARAS	3,182	1,609	1,040	5,831	5,037	6,720
GAZIANTEP	2,285	1,516	1,066	4,867	3,907	5,996
MALATYA	1,493	660	450	2,604	2,105	3,197
ADIYAMAN	1,190	525	295	2,011	1,714	2,372
ADANA	915	475	394	1,783	1,308	2,352
DIYARBAKIR	883	518	315	1,716	1,283	2,296
OSMANIYE	654	453	251	1,358	1,084	1,716
SANLIURFA	447	273	137	856	632	1,144
ELAZIG	127	61	52	240	160	474
KILIS	88	37	26	152	116	199
MERSIN	58	15	32	105	36	159
MARDIN	27	7	9	42	8	73
KAYSERI	22	10	7	40	13	104
SIVAS	23	9	5	37	22	50
NIGDE	23	4	9	37	-	66
BINGOL	15	2	5	23	1	40
OTHER	1	0	0	2	1	147
TOTAL	18,036	9,691	6,424	34,151	28,665	40,751

[16] WHO Flash Appeal

[17] Non-residential buildings include buildings that are private or public, commercial (offices, hotels, trade/retail, etc.), educational, hospitals and clinics/health centers, public administration, and industrial/warehouses.

[18] Infrastructure covers roads, bridges, ports, airports, railways, embankments, culverts as well as underground infrastructure.

Table 2: ***Direct damages relative to exposure*** *per sector (excl. building contents) in the 11 worst affected provinces and Türkiye as a whole (bottom row) due to the February 6, 2023 earthquakes.*

Province	Residential	Non-Residential	Infrastructure	Total
HATAY	41.8%	40.2%	33.9%	39.6%
KAHRAMANMARAS	29.0%	28.6%	23.8%	27.8%
GAZIANTEP	10.1%	10.7%	9.9%	10.2%
MALATYA	15.0%	12.9%	12.0%	13.9%
ADIYAMAN	26.8%	25.5%	20.5%	25.3%
ADANA	4.3%	4.7%	4.3%	4.4%
DIYARBAKIR	5.3%	4.9%	5.4%	5.2%
OSMANIYE	12.0%	13.9%	10.8%	12.3%
SANLIURFA	4.6%	5.5%	4.9%	4.9%
ELAZIG	1.8%	1.2%	1.6%	1.5%
KILIS	7.2%	6.7%	5.7%	6.8%
TOTAL	1.6%	1.6%	1.1%	1.5%

1.0 Introduction

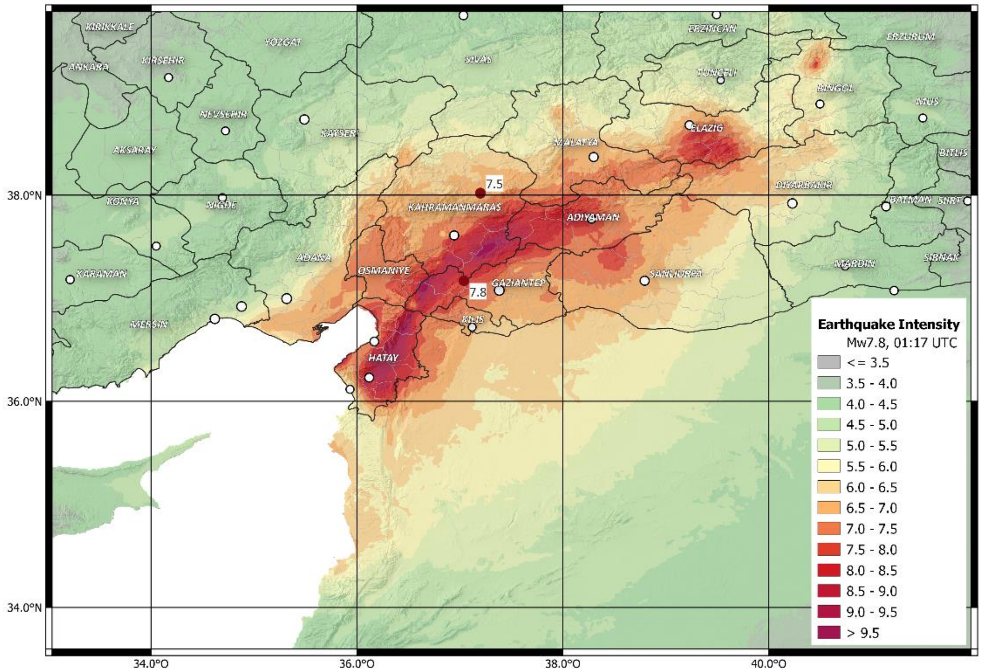
The objective of this report is to provide a preliminary estimate of the direct damages caused by the magnitude 7.8 and 7.5 earthquakes on February 6, 2023. This report also provides information on the nature of the earthquake events, fixed capital damage costs, and the spatial distribution of damages, which could support recovery and reconstruction planning.

1.1 Earthquake Characteristics and Description

The first magnitude (Mw) 7.8 southern Türkiye earthquake occurred on February 6, 2023, at 04:17 Türkiye local time, at a depth of approximately 18 km, and was centered about 35 km to the northwest of Gaziantep city. This earthquake is the strongest and most destructive in Türkiye since the December 27, 1939 Erzincan earthquake, which had a similar magnitude and which occurred in the northeast of Türkiye, with the loss of around 33,000 lives and the destruction of nearly 117,000 buildings. This first magnitude 7.8 earthquake was followed 11 minutes later by a magnitude 6.7 aftershock. The shallow depth of these earthquakes may have contributed to the devastating impacts.

Nine hours later, at 13:24 Türkiye local time, a second major earthquake with a magnitude of 7.5 and depth of 10 km took place on another fault line to the northeast. This earthquake was centered near Ekinözü town and Elbistan city, about 60 km to the northeast of Kahramanmaraş city and about 110 km to the north of Gaziantep city. Figures 1 and 2 show the Modified Mercalli Intensity (MMI) shaking intensity of the magnitude 7.8 and magnitude 7.5 earthquakes, which are derived for this assessment. Given the large magnitude of these earthquakes, aftershocks can be expected to last months, with a magnitude 6.3 earthquake taking place on February 20, 2023.

Further technical details on the earthquake event characteristics are provided in the report Annex.



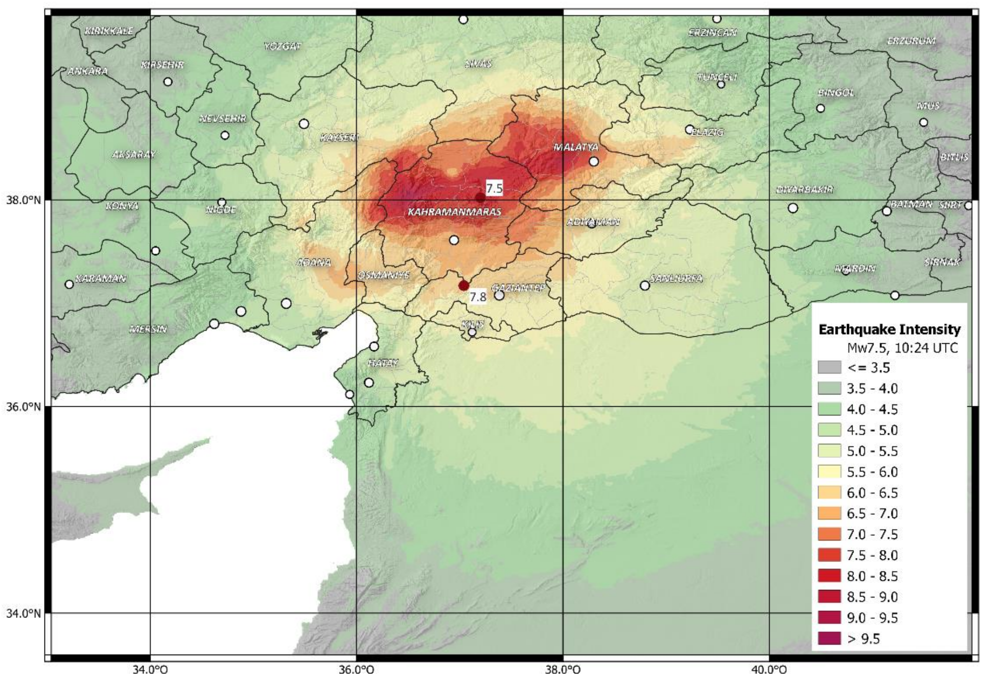


***Figure** 1 **(top):** Recreated Modified Mercalli Intensity (MMI) shaking intensity of the Mw7.8 earthquake of February 6, 2023 (NB: multiple solutions were used as part of the study). According to the MMI scale, MMI 7 is very strong with some damage in well-built structures; MMI 9 is violent with considerable damage even in specially designed structures and with the potential to shift buildings off foundations; and MMI 10 is extreme, with the potential to bend structures such as rail (which has been seen in the region). **Figure 2 (bottom):** Recreated Modified Mercalli Intensity (MMI) shaking intensity of the second earthquake: the Mw7.5 earthquake of February 6, 2023. Epicenters are indicated on both maps of the mainshock and the 2nd mainshock.*

Source: World Bank.

1.2 Reported Impacts of the Earthquakes

The two major earthquakes and aftershocks, including eight aftershocks of magnitude 5.5 to 6.0 (up until February 19, 2023), have affected 22 provinces in Türkiye as well as five governorates in northwestern Syria (Aleppo, Idlib, Latakia, Hama, and Tartus). Moderate shaking and minor damage were also reported in parts of Lebanon, and Israel.

In Türkiye, the most affected **11 provinces have been designated by the Turkish authorities as "disaster areas":**[19] Adana, Adıyaman, Diyarbakır, Elazığ, Gaziantep, Hatay, Kahramanmaraş, Kilis, Malatya, Osmaniye and Şanlıurfa. **Around 14.01 million people (or 16.5 percent of Türkiye's population) live in these 11 provinces,** and around 1.7 to 2.0 million SuTPs are also living in these provinces. **The most extensive damage to buildings and infrastructure occurred in Hatay, Kahramanmaraş, Gaziantep, Malatya and Adıyaman provinces**, which together account for 81% of the estimated damages and are home to around 6.45 million people (around 7.4 percent of the total population of Türkiye). In addition, provinces that were not designated as disaster areas but have reported earthquakes damages include Mardin, Mersin, Kayseri, Sivas, Niğde, and Bingöl. Harsh weather conditions (cold, rain, and snow) at the time of the earthquakes complicated the early emergency and humanitarian response.

The first and bigger earthquake occurred at 04:17 Türkiye local time when people were sleeping in their homes. As of February 19, 2023, the human casualties in Türkiye had reached 41,020 dead and 108,068 injured. The main cause of death is understood to be building collapse, with a reported 105,000 buildings being severely damaged or collapsing from the earthquakes. Of these, at least 9,432 buildings are collapsed as reported by the Ministry of Urbanization, Environment, and Climate Change (MoEUCC)[20].

Damage surveys conducted by more than 7,328 Turkish engineers and experts, including 400 professors and associate professors from more than 20 universities, began soon after the event and focused first on the worst affected cities in the 11 provinces declared as "disaster zones". Local technical universities and technical chambers have also been involved in the process, including structural/civil engineering students. Many volunteer civil engineers from different institutions and organizations who wanted to take part in the building damage assessment studies were evaluated and, after training, were sent to the affected regions according to the determined needs. This tremendous effort is coordinated by the General Directorate of Construction of MoEUCC.

[19] Elazığ province was added last on February 15, 2023.
[20] "Yıkık" in the "Hasar Tespit" database, MoEUCC, February 18, 2023

Many historical buildings are also reported damaged in the earthquakes. Of 433 buildings and monuments examined, 121 are found to be heavily damaged, 66 moderately damaged, and 57 slightly damaged.[21]

Of the more than 20,000 public buildings used for education purposes, 24 buildings are reported as collapsed and 83 buildings reported as heavily damaged by the Ministry of National Education (MoNE). MoNE has a target to finalize their damage assessment by end of February 2023[22].

With the need of health facilities at an unprecedented peak, it is also important to note that at least 15 hospitals have suffered partial or heavy damage, with damage assessments still ongoing[23]. Among these, the state hospitals in İskenderun and Antakya (Hatay province) were destroyed[24]. Those hospitals or hospital wings at risk of collapse have been evacuated, with patients referred to facilities across the country and field hospitals established to provide continuity of care. **There are also reports of damage sustained to emergency response and coordination buildings[25].**

An extensive local and international search and rescue response in Türkiye was undertaken to rescue people trapped in buildings. At the peak of the search and rescue effort, a total of 166,334 search and rescue personnel, consisting of Türkiye's Disaster and Emergency Management Presidency (AFAD), Gendarmerie Special Public Security Command (JÖAK), DİSAK, PAK, Gendarmerie Commando Special Public Security Command (JAK), DAK, Ministry of National Defense, National Medical Rescue Team (UMKE), Ambulance staff, Fire Department, Ministry of National Education, Güven, NGOs, Volunteers, Security Units, Local Support Teams as well as international search and rescue personnel, were working in the region. By February 16, 2023, more than 8,000 people had been rescued, with the latest rescues taking place 296 hours after the earthquakes. With the search and rescue efforts gradually coming to a close, heavily damaged buildings are starting to be demolished across the worst affected areas.

At least 1,250,000 people have lost their homes following the event, when looking at the 385,000 individual sections (dwellings/apartments) which will be demolished. According to AFAD, more than 200,000 people have been evacuated to other provinces and 5,800 students have been transferred to schools in other cities. In addition, 890,000 earthquake survivors are sheltering in public dormitories and 50,000 in hotels. Moreover, approximately 387,000 tents

[21] https://www.aa.com.tr/en/turkiye/many-of-turkiyes-historical-monuments-stand-strong-after-earthquakes/2824750
[22] https://www.meb.gov.tr/bakan-ozer-10-ildeki-tum-okullarin-hasar-tespit-calismasini-yapmadan-okullari-acmayacagiz/haber/29046/tr
[23] WHO Flash Appeal - https://reliefweb.int/report/turkiye/who-flash-appeal-earthquake-response-turkiye-and-whole-syria-10-february-2023
[24] https://www.diken.com.tr/hatayda-iki-devlet-hastanesi-depremde-yikildi/.
[25] https://reliefweb.int/report/turkiye/turkey-earthquake-emergency-situation-report-07022023

were sent to the region by local and international organizations, with 172,265 tents set up as of February 16, 2023.

Buildings found to be severely damaged will be evacuated immediately and demolished after the damage assessment process is completed. "Moderately damaged" buildings are those that have been damaged to such an extent that they will require structural repair and strengthening; therefore, these buildings are mandatorily evacuated until structural strengthening is completed. It is also possible that subsequent and more detailed damage assessments will be made for "Moderately damaged" buildings to support decision making on whether to demolish or repair/strengthen these buildings. Entry to these moderately damaged buildings, as well as to those with heavy damage that may still be standing, is not permitted until this process has been finalized. People who were living in heavily and moderately damaged buildings will therefore need to be provided alternative housing until such buildings are strengthened or reconstructed. Further information on the damage assessments undertaken by MoEUCC is provided in Annex 1.5.

Infrastructure damage is extensive. Fissures on highways and roads and damages to the bridges have been reported either due to the fault rupture on the surface or other ground deformation, which in some cases impeded the rapid mobilization of international aid and transportation. However, most critical transport routes were kept operational after temporary repairs. 1,275 km of railways at the region were reported as impacted, and 1,060 km of the lines following repairs are operational. Railways were also obstructed by rock falls and six trains parked at the train maintenance station in Gaziantep were derailed and overturned during the earthquake. Apart from railway roads and rail vehicles, it is also reported that a total of 252 buildings in the station areas which are used in the management and operational activities were damaged.

Hatay Airport was shut due to damage on the runway. The runway in the Hatay was split and uplifted, but repairs were completed by February 12. It served relief flights at Gaziantep Oğuzeli International Airport on February 6 and 7. As of February 8, it has been opened to all flights, primarily humanitarian and relief flights. Kahramanmaraş, Malatya and Adıyaman Airports, where only relief flights can be served after the earthquakes, were opened to all flights on February 7, 17 and 18, respectively. In the port of Iskenderun (Hatay province), there was a large fire that was extinguished on February 10 and the port reopened shortly after. For municipal water supply infrastructure, it has been reported that repair works were substantially completed for 72 local authorities (of 151 in the region) following damage assessments. Due to damages to the water supply network and sewerage pipelines, the possibility of acute problems in water supply and wastewater removal has been raised in the Istanbul Technical University reconnaissance report[26]. Regarding the communication infrastructure, 90 percent of the 8,900 base stations in the region are in service following the repair and reactivation of the 15 percent

[26] https://haberler.itu.edu.tr/haberdetay/2023/02/17/itu-den-2023-deprem-raporu

that were damaged after the earthquake (Joint Statement – Turkcell, Türk Telekom and Vodafone).

Major damages have been reported on the main natural gas transmission lines serving the earthquake region due to pipe ruptures, leaving Gaziantep, Hatay, Kahramanmaraş and Adıyaman without natural gas. Following the repair works by BOTAS, private gas distribution companies responsible for in-city distribution are in the process of damage assessment. An explosion and fire occurred in the natural gas pipeline in the Topboğazı village of Kırıkhan district of Hatay province. The natural gas flow has been stopped in nine out of 31 districts of Gaziantep, Hatay and Kahramanmaraş provinces, due to damage to the gas pipeline network.

Agricultural impacts are also significant. At least 9,972 agricultural facilities, including holding pens and other structures, have been recorded as destroyed. However, agricultural stock and crops have not been assessed. So far, reports indicate at least 8,424 cattle and 62,342 sheep have been killed, representing a significant loss (Fuat Oktay, February 18, 2023 press conference). In addition, damages to olive groves have also been seen.

2.0 Rapid Post-Disaster Damage Estimation Methodology

The well-established GRADE approach[27] was used to derive the direct damage estimates for these earthquakes in Türkiye, with the general types of data described in Box 1 and Figure 3. The occurrence of two major earthquakes created additional complexity in all aspects of the modelling. Technical aspects of the modelling are included in Annex A1.4.

Based on the completed exposure dataset, a total of US$246 billion in capital stock is located in the 11 provinces of Türkiye designated as disaster areas (Figure 4). Given that the total capital exposure of buildings and infrastructure for Türkiye is estimated at around US$2.33 trillion, **almost 11 percent of the capital exposure in Türkiye was exposed to the damaging effects of these earthquakes.**

[27] https://www.gfdrr.org/en/publication/methodology-note-global-rapid-post-disaster-damage-estimation-grade-approach

Box 1: GRADE Approach for Türkiye earthquakes

The rapid and remote assessment uses a range of datasets to assess damages, with historical data, scientific data such as ground motion, information on the built environment and population, engineering information on vulnerability as well as available data through government sources, as well as reports on the ground (Figure 3)

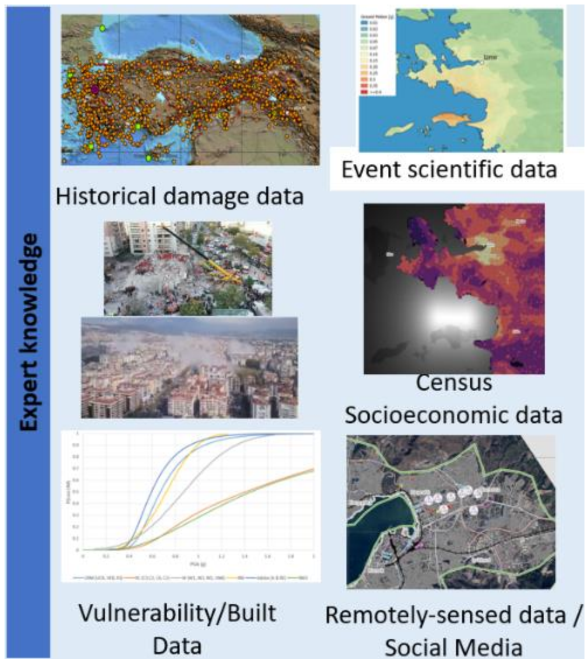


Figure 3: Example of some of the methods/datasets used for the analysis. While the maps show the entire country of Türkiye, the analysis focused on the damaged region.

For the Türkiye earthquakes, hazard footprint datasets and shaking intensity maps were developed based on recorded ground shaking, remote sensing damage assessments and other relevant data (such as TADAS response spectra). These estimates were checked against ground truthing of the shaking and modified where needed. Both ground-based and satellite images and social media feeds were used to derive a composite spatial damage distribution analysis.

For exposed residential and non-residential buildings, collectively known as building exposure, the GlobalML dataset of building footprints was combined with GHS BUILT-C MSZ in order to characterize the building heights and sizes. This information was then compared to Address Register (ADNKS) data which allowed for the determination of numbers of dwellings and additional population data down to Mahalle and Köy level. Additional information on building typologies was derived from the ESRM2020 database (ESRM - http://risk.efehr.org/esrm20/)

The building typologies were split into residential and non-residential (where mixes of industrial, commercial, public, and other stock are contained), where the monetary values were then determined via unit costs of construction derived for different typologies such as wall type, building age and story heights. Infrastructure modelling was undertaken using Open Street Map (OSM) and government data on roads, bridges, electricity, water, sanitation, ICT and other infrastructure.

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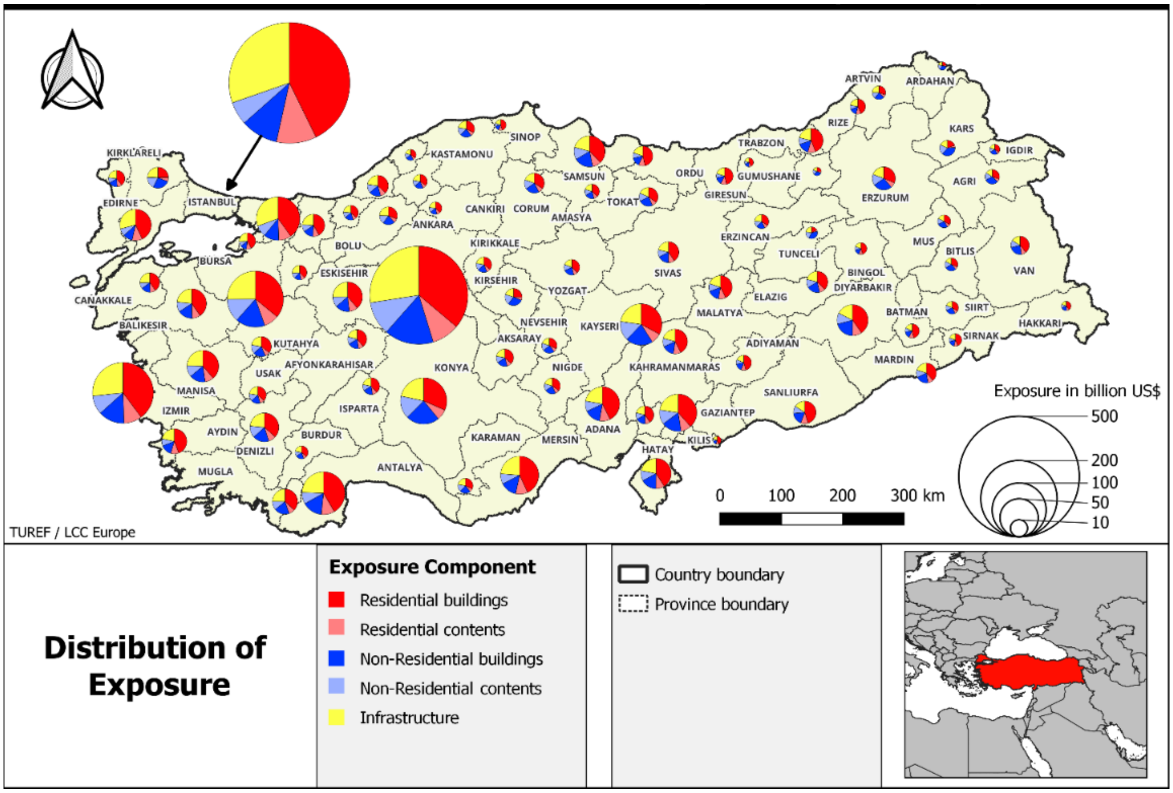

Figure 4: Map of the buildings and infrastructure exposure by province in absolute values (in US$ billions)

Table 3: Exposure per sector (including building contents) in the 11 worst affected provinces and Türkiye as a whole (bottom row) due to the February 6, 2023 earthquake sequence in Türkiye (in US$ billions).

Province	Residential (inc. Contents)	Non-Residential (inc. Contents)	Infrastructure	Total
HATAY	15.8	8.8	6.9	31.4
KAHRAMANMARAS	11.0	5.6	4.4	21.0
GAZIANTEP	22.6	14.2	10.7	47.6
MALATYA	9.9	5.1	3.7	18.8
ADIYAMAN	4.4	2.1	1.4	7.9
ADANA	21.4	10.1	9.1	40.6
DIYARBAKIR	16.6	10.7	5.8	33.0
OSMANIYE	5.4	3.3	2.3	11.0
SANLIURFA	9.7	5.0	2.8	17.5
ELAZIG	7.2	5.1	3.3	15.6
KILIS	1.2	.6	.5	2.2
MERSIN	26.7	11.3	11.9	49.9
MARDIN	6.4	4.5	2.7	13.6
KAYSERI	24.2	21.4	13.4	59.0
SIVAS	7.5	4.3	3.2	15.0
NIGDE	3.8	3.2	1.8	8.7
BINGOL	2.6	1.2	.9	4.8
ERZINCAN	2.9	2.3	1.7	6.9
AKSARAY	4.7	3.3	2.3	10.3
KONYA	28.7	28.9	15.9	73.6
MUS	2.4	2.4	1.0	5.7
TUNCELI	1.0	2.7	1.1	4.8
Total in affected Provinces	**236.3**	**155.9**	**106.7**	**499.0**
Other Provinces in Türkiye	*888.8*	*461.9*	*482.0*	**1,832.7**
TOTAL	**1,125.1**	**617.8**	**588.8**	**2,331.7**

There is a higher degree of uncertainty than usual in the GRADE exposure estimates because:

- Construction cost indices are volatile when examining for unit costs of construction values due to high inflation (in the order of 60% annually) and fluctuations in the exchange rate.
- Material costs are currently highly volatile, and are typically even more volatile and higher after major disasters. While this primarily impacts reconstruction and recovery costs rather than damage estimates, this is still a major source of uncertainty. Estimates in the order of US$650 million were given for the demolition costs, assuming costs are around 4 to 5 percent of a building.

This GRADE assessment also analyzed and rectified damage distributions produced by local and international agencies (e.g. EU COPERNICUS) to account for already derelict buildings before the earthquake and to offset the potential miscalculation of damage. For the education sector, detailed data from the MoNE was used to determine spatial distribution of schools (both public and private). However, the complex nature of the building typologies and unknown damage statistics mean an estimate was not derived specifically for this sector.

The GRADE assessment covers replacement cost, rather than reconstruction cost, of buildings in the affected region. Replacement cost is defined as the actual cost to replace an asset at its pre-damage condition. However, this may not be the cost to reconstruct the asset which could include costs related to build back better. Unit costs of construction appropriate for the area were derived from local information, such as the costs of existing housing projects in the area, construction statistics, as well as on the costs proposed after the earthquake. Unit costs of construction for the replacement of destroyed, or the repair of damaged buildings (depending on the damage level), were thus obtained. For example, for residential structures, depending on construction type, unit costs of construction values based on statistics published by MoEUCC were used that indicate final values in the range of US$500/m^2. This figure is a current replacement cost, but note that there is a lot of uncertainty in this over the coming months due to spiking demand in construction materials, inflation and labor. To verify the exposure values, disaggregated macro-economic (capital stock) information was also used and corroborated with detailed estimates. Data (including county data) on capital investment was also used to differentiate capital stock building and non-building proportions. These exposure values were also checked against other independent data sources such as TCIP, ELER and CATDAT data[28].

Building Damage Assessments used for Validation

Over the course of the analysis, damage data was aggregated from local reports, news, government data and releases from province level as well as MoEUCC. Damage surveys coordinated by the General Directorate of Construction Affairs of MoEUCC have been a critical part of this assessment. These damage surveys classify a building as heavily damaged, moderately damaged, slightly damaged, or undamaged, and the data is available at www.hasartespit.csb.gov.tr.

The building damage statistics by damage level, district and *Mahalle* were assembled for this report, as of February 15, 2023, at high resolution. At that point, around 387,000 buildings with 1.86 million individual properties (including units) had been processed. Note there are also comments in the archive file such as "unable to access", etc. **Although incomplete as a percent of buildings in a lot of the Mahalles/Districts, this data was an excellent source of validation for the modelled results.**

[28] Daniell, J. (2014). Development of socio-economic fragility functions for use in worldwide rapid earthquake loss estimation procedures (Doctoral dissertation, Karlsruher Institut für Technologie).

The latest summary of the building damage assessments at Province Level, as of the morning of February 19, is shown in the Annex. On the morning of February 19, the number of buildings inspected had risen to 830,806, containing around 3.273 million individual properties. A detailed breakdown has not yet been released, but the number of buildings “to be demolished” by the evening of February 18 has risen to 105,000 containing around 385,000 individual properties/apartments/dwellings. Damage surveys are expected to continue for weeks to come and will also include locations outside the 11 provinces and possible re-visits to some of the buildings. Therefore, the data presented here are preliminary, as the numbers will likely continue to rise until the damage assessments are completed.

3.0 GRADE Results – Direct Damage Estimates

Direct damages from the earthquakes are estimated at US$34.2 billion (equivalent to 4 percent of Türkiye‘s 2021 GDP). The direct damages are dominated by damages to residential buildings (US$18 billion, or 53 percent of total), followed by damages to non-residential buildings (US$9.7 billion or 28 percent), while effects on infrastructure account for the remaining 19 percent (US$6.4 billion). The GRADE report measures direct damages, however, there will also be significant indirect losses in the event due to disruptions to economic activity including downtime of businesses, agriculture production issues and general employment and delays, although the reconstruction itself will add to economic activity. Recovery and reconstruction costs, which consider social protection, humanitarian and emergency response, actions to reduce human development impacts, surge pricing due to increased construction material and labor costs, actions to build back better and so forth, are often found to be more than twice direct damage costs.

The most extensive damage to buildings and infrastructure occurred in Hatay, Kahramanmaraş, Gaziantep, Malatya and Adıyaman provinces, which are home to around 6.45 million people (around 7.4 percent of the population). Of the total damages, 36 percent occurred in Hatay province (population 1.69 million), followed by 17 percent in Kahramanmaraş province (population of 1.18 million) and 14 percent in Gaziantep province (population of 2.15 million). See Table 4 and Figures 5 and 6 for further information.

Damage as a proportion of total building/infrastructure stock is highest in Hatay, Kahramanmaraş, and Adıyaman, as shown in Table 5. In Hatay, almost 42 percent of residential buildings are estimated to be damaged, 40 percent of non-residential buildings, and almost 34 percent of infrastructure. In Kahramanmaraş, 29 percent of residential buildings, 29 percent of non-residential buildings, and 24 percent of the infrastructure is damaged. In Adıyaman, 27 percent of residential buildings, 26 percent of non-residential buildings, and 21 percent of the infrastructure is damaged. See Table 5 for further information.

Table 4: *Estimate of the breakdown of the direct damages by sector and province in absolute values (in US$ millions).*

Province	Residential	Non-Residential	Infrastructure	Total		
				Median	Lower	Upper
HATAY	6,601	3,516	2,331	12,448	11,236	13,643
KAHRAMANMARAS	3,182	1,609	1,040	5,831	5,037	6,720
GAZIANTEP	2,285	1,516	1,066	4,867	3,907	5,996
MALATYA	1,493	660	450	2,604	2,105	3,197
ADIYAMAN	1,190	525	295	2,011	1,714	2,372
ADANA	915	475	394	1,783	1,308	2,352
DIYARBAKIR	883	518	315	1,716	1,283	2,296
OSMANIYE	654	453	251	1,358	1,084	1,716
SANLIURFA	447	273	137	856	632	1,144
ELAZIG	127	61	52	240	160	474
KILIS	88	37	26	152	116	199
MERSIN	58	15	32	105	36	159
MARDIN	27	7	9	42	8	73
KAYSERI	22	10	7	40	13	104
SIVAS	23	9	5	37	22	50
NIGDE	23	4	9	37	-	66
BINGOL	15	2	5	23	1	40
OTHER	1	0	0	2	1	147
TOTAL	18,036	9,691	6,424	34,151	28,665	40,751

Table 5: ***Capital damages relative to exposure*** *per sector (excl. building contents) in the 11 worst affected provinces and Türkiye as a whole (bottom row) due to the February 6, 2023 earthquakes in Türkiye.*

Province	Residential	Non-Residential	Infrastructure	Total
HATAY	41.8%	40.2%	33.9%	39.6%
KAHRAMANMARAS	29.0%	28.6%	23.8%	27.8%
GAZIANTEP	10.1%	10.7%	9.9%	10.2%
MALATYA	15.0%	12.9%	12.0%	13.9%
ADIYAMAN	26.8%	25.5%	20.5%	25.3%
ADANA	4.3%	4.7%	4.3%	4.4%
DIYARBAKIR	5.3%	4.9%	5.4%	5.2%
OSMANIYE	12.0%	13.9%	10.8%	12.3%
SANLIURFA	4.6%	5.5%	4.9%	4.9%
ELAZIG	1.8%	1.2%	1.6%	1.5%
KILIS	7.2%	6.7%	5.7%	6.8%
TOTAL	1.6%	1.6%	1.1%	1.5%

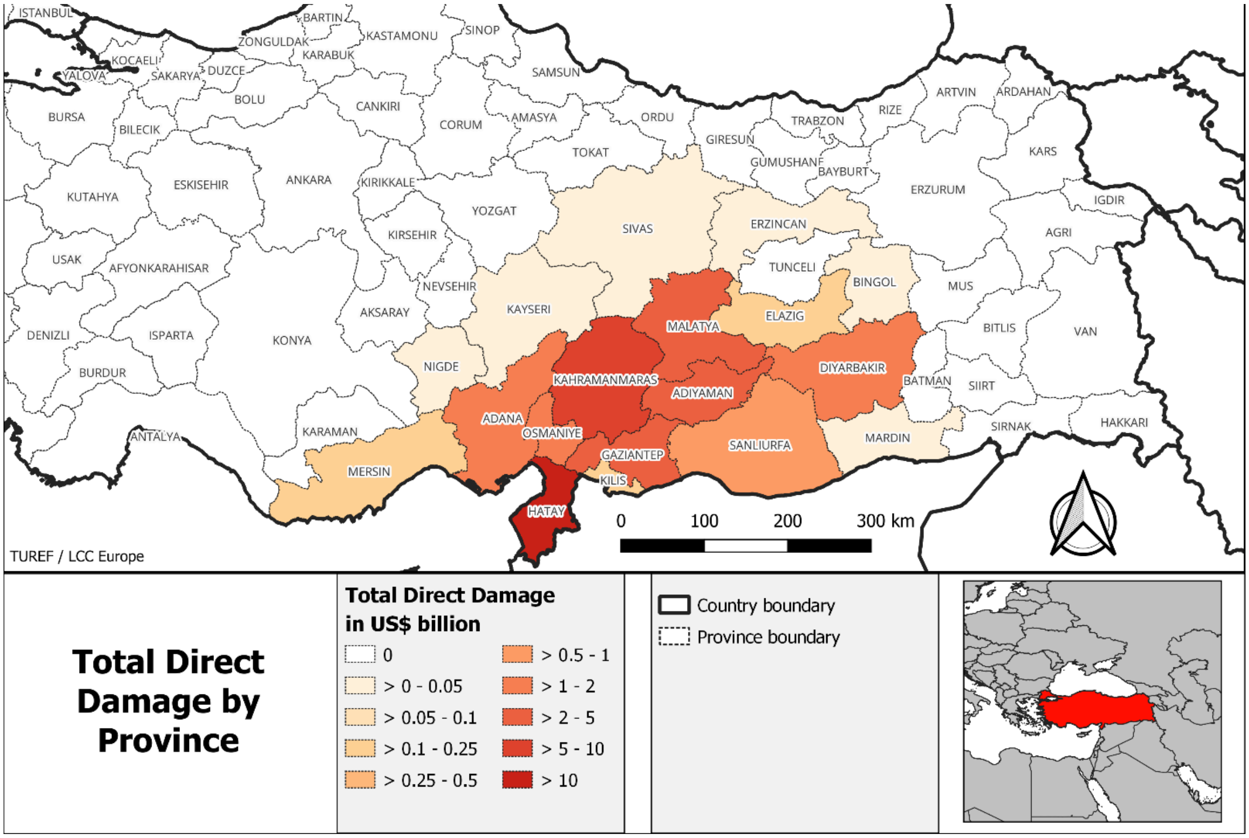

Figure 5: Map of the median direct damages by province in absolute values (in US$ billions)

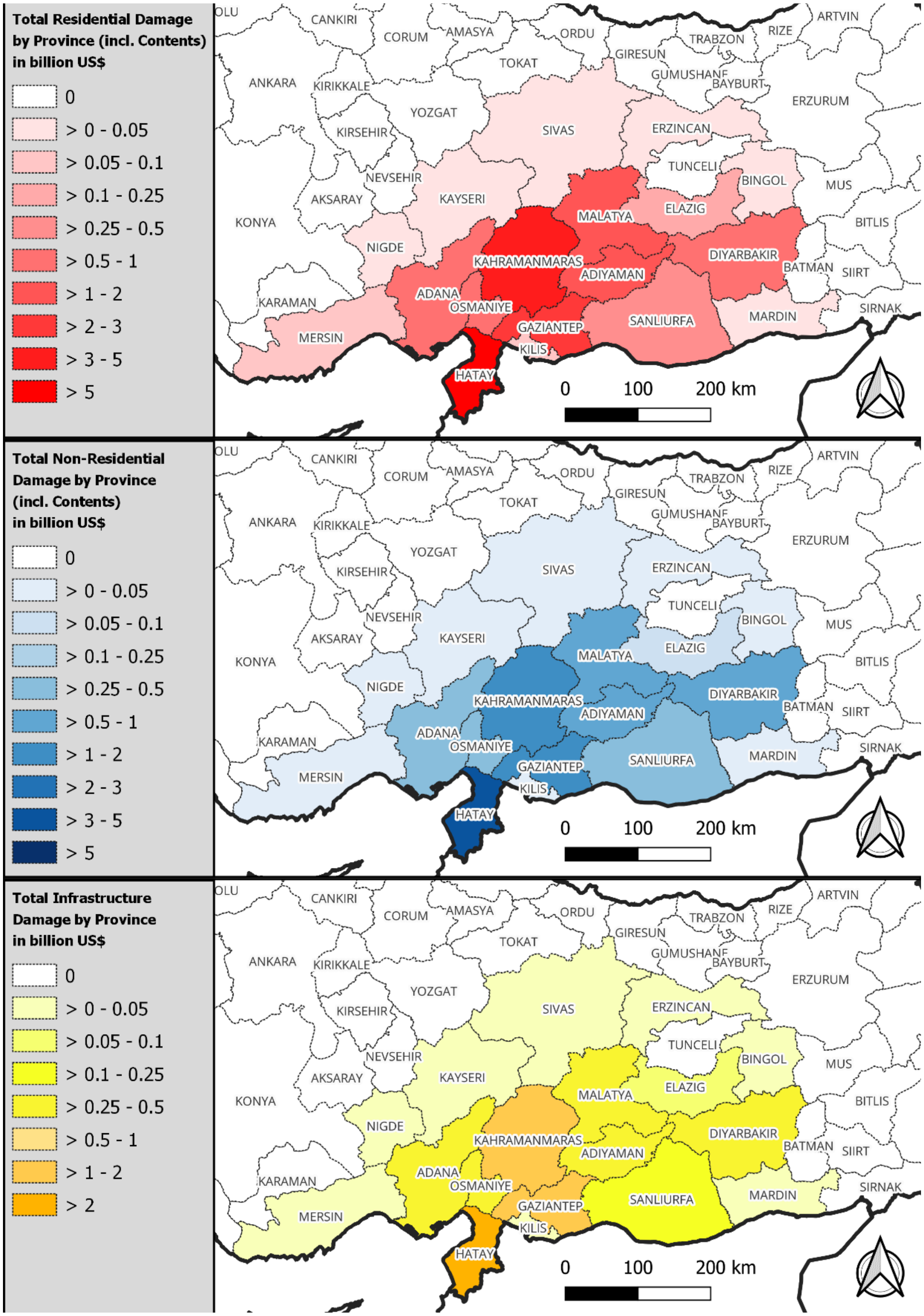

Figure 6: Map of the median direct damages by province and sector in absolute values (in US$ billions).

4.0 Discussion

4.1 What factors contributed to such significant damage

The results show that the direct damages are dominated by damages to residential buildings (US$18 billion i.e., 53 percent of the total US$34 billion), followed by damages to non-residential buildings (28 percent of the total), while effects on infrastructure account for the remaining 19 percent of the total. Of the total damages, 36 percent occurred in the province of Hatay (population 1.69 million), followed by 17 percent in Kahramanmaraş (population of 1.18 million) and 14 percent in Gaziantep province (population 2.15 million).

Damage in Hatay amounts to nearly 40 percent of the province's capital stock. This is a very high damage ratio, and indicative of the level of destruction in this province. The decision of which buildings will be demolished leads to much uncertainty in this event, as heavily damaged and destroyed buildings will be demolished; however, many moderately damaged buildings will also be pulled down and rebuilt. This leads to higher damage ratios given demolition costs. The magnitude 6.3 earthquake on February 6, 2023, is expected to have increased this damage further. This is also the case for two other provinces - Kahramanmaraş and Adıyaman - which also experienced very high damage ratios, with damages amounting to 28 percent and 25 percent respectively.

In terms of damage patterns, the magnitude 7.8 earthquake directed a significant amount of the shaking towards the south, causing major damage in Hatay and other locations along the fault rupture. As described in the Methodology (Section 2.0), the damage estimates presented in this report are calibrated against the damage assessments conducted by the Government of Türkiye through the Ministry of Environment, Urbanization and Climate Change (MoEUCC), with additional information on these assessments provided in Annex 1.

As noted in the report, the key factors that drove such significant damage in buildings and infrastructure across southern Türkiye are as follows:

- The juxtaposition of two very large and shallow earthquakes of magnitude 7.8 and 7.5, plus thousands of aftershocks that were as high as magnitude 6.7. These earthquakes resulted in severe to extreme shaking, as measured by the Modified Mercalli Intensity (MMI) scale, across a very large geographic area where ground motions recorded were, in some places, more than double that specified in the 2019 building code (Figure 7).
- Early anecdotal evidence seems to suggest that a high proportion of the affected buildings were constructed prior to 2000, which is when the 1997 building code is seen to have been regularly implemented in construction.

- Potential lack of code compliance, which refers to buildings not being designed, built, and inspected in accordance with Türkiye seismic building codes[29]. In such cases, these buildings may be susceptible to damage, and a number of investigations have already been reported in the media[30].
- Lack of recent major seismic events in the region may have reduced awareness on how to prepare for, and respond to, major earthquakes. With the exception of smaller events, such as the 2020 Elazig earthquake (M6.8), the last major quake of similar magnitude was in 1822 around Hatay.

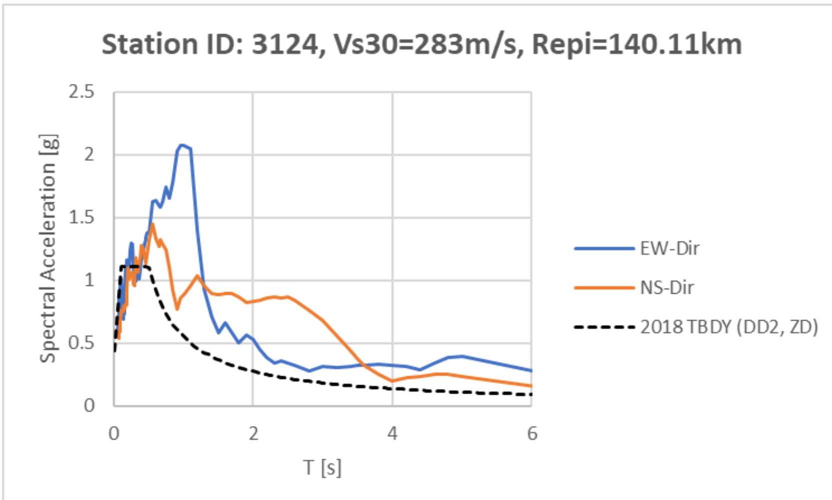

Figure 7: Plots comparing the EW and NS components of spectral acceleration at a station in Antakya to the horizontal elastic response spectrum according to the seismic design code in Türkiye (2019). Recording relates to the magnitude 7.7 earthquake occurring on 06/02/23 at 01:17 UTC. More recordings are provided for multiple locations in Annex 0.

4.2 How does the GRADE Direct Damages Compare to Other Assessments?

Türkiye is considered one of the most at-risk countries globally from earthquakes, with devastating earthquakes in 1939 and 1999. Using global risk models, the loss associated with this earthquake for Türkiye is equivalent to a return period event of around 80 years[31].

The GRADE analysis can be compared to additional loss estimates published by various companies and institutions. Most estimates have been undertaken either from assumptions about take-up rates in Türkiye from insurance data and the observed claims, and then scaled up in terms of damages as a proportion of the uninsured stock. Other estimates such as Verisk

[29] Significant seismic codes were implemented in 1998, 2007 and 2019. Therefore, code-compliant buildings designed and built after these dates are expected to have behaved better than those built prior to 1998.
[30] https://www.pbs.org/newshour/world/turkey-detains-building-contractors-as-earthquake-deaths-rise-past-33000
[31] Europe and Central Asia Risk Profiles: https://www.gfdrr.org/sites/default/files/publication/-Europe%20and%20Central%20Asia%20Country%20Risk%20Profiles%20for%20Floods%20and%20Earthquakes%20smaller.pdf

Analytics often use existing stochastic catastrophic risk models and event losses to choose similar events, and then remodel the potential damage to the economy or a combination approach.

Estimates from Verisk Analytics (as of February 14, 2023, at 5am) expect that the direct damages will exceed US$20 billion, and that insurance losses will exceed US$1 billion. JP Morgan estimated the direct costs from the destruction of physical structures in Türkiye to be around US$25 billion. Karen Clark & Company (KCC) also estimated direct damages at close to US$20 billion, with the insurance and reinsurance industry losses at somewhere in the order of US$2.4 billion.

A third method uses a single historical event and scales it, using economic metrics to a new event. This method is often very difficult and may have high uncertainty due to changes in building codes, exposure, inflation, and construction trends as well as unknowns in the original event losses. In this case, only one analysis has been published so far, that of Türkonfed (Turkish Enterprise and Business Confederation) with an estimate of US$84 billion of which 84.1 percent is housing damage, based on the 1999 Izmit, Türkiye, earthquake.

4.3 Special Considerations for Recovery and Reconstruction

The provinces where the earthquakes occurred are some of the provinces with lower incomes than average of Türkiye and also host more than 1.7 million SuTPs; almost half of the total SuTPs in Türkiye. There have been efforts to scale up municipal infrastructure and public services to support host communities and SuTPs to meet the increased demand with respect to education, health, jobs and so forth, but these efforts would have been significantly challenged by the earthquakes. Among those, European Union's ongoing Facility for Refugees in Türkiye (FRIT) program covers six densely SuTP populated provinces in the earthquake region, focusing on humanitarian assistance, education, migration management, health, municipal infrastructure, and socio-economic support.

Given that reconstruction will be a multi-year, possibly even decadal process, outmigration and/or displacement of Turkish populations to surrounding areas/countries will present new challenges for those on the move, as well as recipient host communities. Programs designed to support this transition will need to consider the dynamic nature of human mobility, and the specific contexts at the local level.

Natural hazards are gender and demographically neutral, but their impacts are not. The youth, the elderly, women, minority groups, and the poor are most affected by disasters, in terms of life expectancy, labor force participation, unemployment, relative asset losses, among other outcomes. Based on global experience, disasters are also associated with an increase in Gender Based Violence (GBV) and mental health issues. For example, in terms of negative effects on mental and emotional health, 54 percent of women compared to 49 percent of men experienced stress and anxiety because of the COVID-19 pandemic, and more women reported experiencing

GBV, with the most vulnerable group being young women between the age of 25 and 35[32]. Based on global experience, without careful consideration of the needs of women and vulnerable groups, the impacts of the earthquakes will be greater through time.

5.0 Conclusions and References

The objective of the GRADE assessment was to estimate the direct damages caused by the two shallow earthquakes of magnitudes 7.8 and 7.5 and evaluate the spatial distribution of damages. The main conclusions from the assessment are summarized below:

- The two earthquakes and associated aftershocks caused widespread damage in 17 out of 81 provinces of Türkiye in the south of the country and near the border with Syria. The most affected areas are the **11 provinces designated by the Turkish authorities as "disaster areas"** [33] : Adana, Adıyaman, Diyarbakır, Elazığ, Gaziantep, Hatay, Kahramanmaraş, Kilis, Malatya, Osmaniye and Şanlıurfa. **Around 16.5 percent of Türkiye's population lives in these 11 provinces**.
- **The most severe damage occurred in Hatay, Kahramanmaraş, Gaziantep, Malatya and Adıyaman provinces, which are home to around 6.45 million people (around 7.4 percent of the country's population)**. In addition, provinces that have experienced moderate to light damage are: Kayseri, Mardin, Mersin, Niğde, Sivas and Van.
- Thousands of low-rise and multi-story apartment buildings collapsed. As a result, the loss of life in Türkiye as of late on February 19, stands at 41,020 people, making this the **most lethal earthquake in the country since 1939.**
- The consequences of such major earthquakes were exacerbated due to: a) many aging buildings that were constructed prior to the introduction of modern seismic design principles and the 1997 code, b) severe to extreme shaking from the two shallow earthquakes, and c) cases where buildings may have not been built in compliance with the building codes.
- **The best preliminary estimate of direct damages from this event is US$34.1 billion** (or equivalent of 4 percent of the Turkish 2021 GDP). **However, recovery and reconstruction costs will be much larger, potentially twice as large, and that GDP losses associated to economic disruptions will also add to the cost of the earthquakes.**

[32] UN Women. 2020. Rapid Gender Assessment of COVID-19 Implications in Turkey. https://wrd.unwomen.org/explore/library/economic-and-social-impact-covid-19-women-and-men-rapid-gender-assessment-covid-19.

[33] Elaziğ province was added last on February 15, 2023.

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Datasets Used

Hazard Data:

- Local Station Data (AFAD TADAS database)
- TDTH portal for hazard data
- Social media sourced data on intensities
- CATDAT (historical info)
- KOERI USGS, EMSC, CATNews, EarthquakeReport data on intensities, and evaluation of Shakemap results
- COPERNICUS, Maxar, UNOSAT satellite analysis
- Fault Rupture data from Sentinel-2, Sentinel-1, InSAR
- Bogazici University Reports v1-v5

Exposure Data:

- Basis of SERA-EU Exposure models adjusted with updated unit costs of construction and capital estimates.
- IRAP Master Plans and Earthquake Scenarios including infrastructure and non-residential datasets
- TUIK datasets including Provincial ARIO GDP, and checks against TCIP, ELER, CATDAT data, Investment Data
- OSM and HOTOSM additions across Türkiye for all footprints and reanalysis
- GlobalML Footprints, GHS BUILT Products
- Capital Stock Modelling (Daniell, 2014; GAR; IMF WEO; World Bank)
- GEM, USGS, KOERI, TCIP exposure checks
- Subnational Crime Database (Brand et al., 2021)
- ADNKS Lists and Population Data
- Official Building/Construction Costs data (YYBM)
- GPSS Schools study, Planopolis, Ministry data, Health statistics

Vulnerability and Damage Data:

- MoEUCC Damage Survey (Hasar Tespit)
- Building codes of Türkiye, and European Seismic Code Index work of ESRM
- Historical event data (DaLA, PDNA, CATDAT)
- TBDY 2018, which became effective in 2019, and previous codes
- Global Seismic Code Index and Building Practice Factor
- Empirical vulnerability functions, semi-analytical fragility functions, Turkish risk studies

- Social media and ground photo analysis and loss adjusting
- Situation Reports (Reliefweb, AFAD etc.)
- Daily Ground Briefs
- VOSOCC, Humanitarian Response Data

Annex 1

A1.1 Seismotectonic Background and Earthquake History

The Türkiye-Syria earthquake sequence of February 6, 2023, originated on a large fault system, called the Eastern Anatolian Fault (EAF); a 700 km long, northeast–southwest left-lateral transform fault which forms the boundary between the Anatolian and Arabian plates and accommodates the westward extrusion of Türkiye into the Aegean Sea, with a relative movement of about 10 mm per year [Aktug et al., 2016]. The EAF extends between the Karlıova triple junction in the East near Bingöl (where the EAF meets the eastern reaches of the Northern Anatolian fault) to the Marash triple injunction, where the Africa, Anatolian, and Arabia plates converge, and which is located near the mainshock epicenter. Here, the EAF splits into two smaller segments, called the Karataş-Osmaniye fault to the West towards Adana and the Karasu fault to the South towards Antakya. Further south, it connects to the Dead Sea Transform Fault system which extends from Antakya to the Gulf of Aqaba.

The first earthquake (Mw 7.7 (AFAD), Mw 7.8 (USGS)) at 01:17 UTC ruptured a large segment of the EAF between Elazig and Gaziantep and the complete Karasu fault, on a length of almost 300 km. It was followed 11 minutes later by a Mw 6.7 aftershock centered around 10 km to the west.

The second major earthquake (Mw 7.6 (AFAD), Mw 7.5 (USGS)) at 10:45 UTC occurred on a smaller fault branch off the EAF, rupturing the Çardak and Sürgü faults around Elbistan, centered around 95 km north-northeast of the mainshock. According to the USGS, a fault plane of approximately 120 km length and 18 km width on a different fault strand/segment of the broad EAFZ ruptured and could be considered an aftershock or possibly a contingent event, that would likely not have happened had the mainshock not occurred.

The EAF is highly active and historically its eastern segments (from Bingöl to Adıyaman) have ruptured in an East-West progression in the period 1866 to 1905 in five major earthquakes (in 1866, 1874, 1875, 1893 and 1905); while the southwestern segments (around Antakya) ruptured in 1822 north of Antakya and then in 1872 nearer to Antakya (Bayrak et al., 2015). The central-western segments, broadly between Adıyaman and Gaziantep and including Kahramanmaraş to the north, had ruptured in a large event (estimated magnitude 7.4) in 1513 and then just over 250 years later, on November 29, 1795, in a destructive event near Kahramanmaraş (estimated magnitude 7.0).

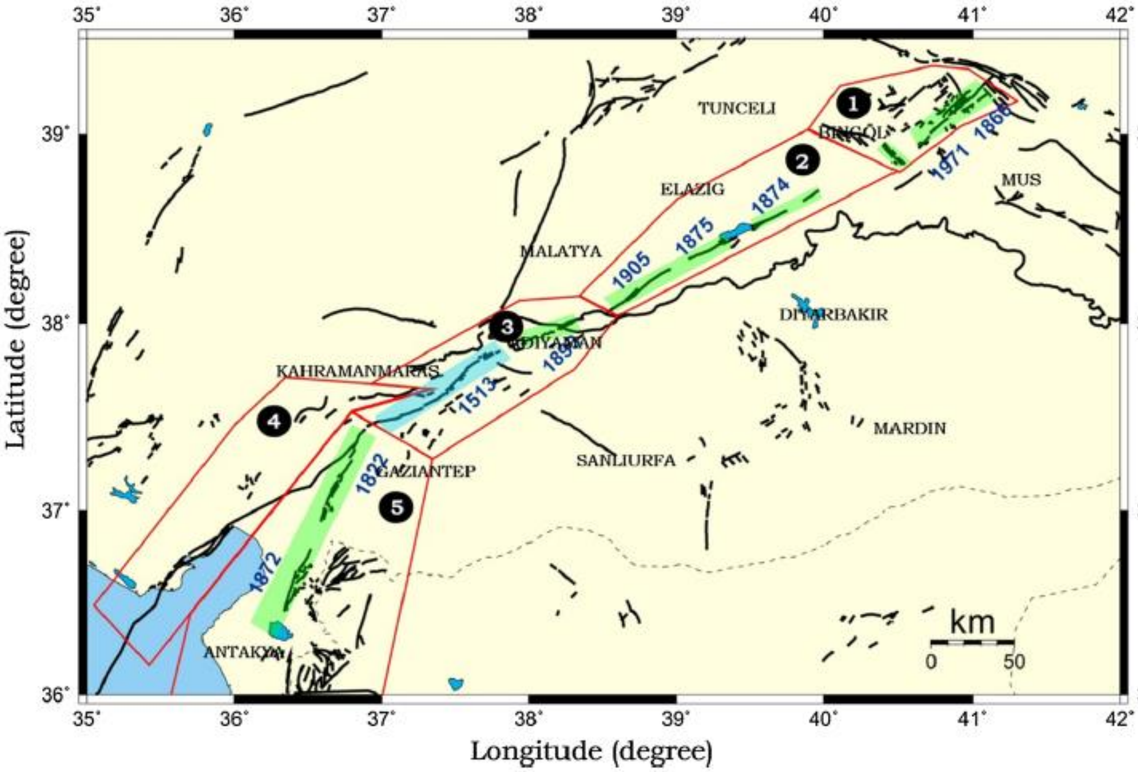

Figure 8: Map of the main five segments of the East Anatolian Fault Zone and major earthquakes (M≥7) that occurred in 1822–1971, showcasing "seismic gap" in the segment that ruptured in the mainshock of February 6, 2015. Source: Bayrak et al. (2015).

Furthermore, prior to the earthquake sequence starting on February 6, only three earthquakes of magnitude 6 or larger had occurred within 250 km since 1970. The largest of these, Mw 6.7, occurred to the northeast on January 24, 2020, southeast of the city of Elazig, causing the loss of 45 lives mainly due to the collapse of four apartment buildings in the city. This earthquake was the result of strike-slip faulting and was located on or close to the EAFZ that in this segment had no documented large rupture since an earthquake in 1875 (estimated magnitude 6.7). Prior to the January 2020 earthquake, there was also the March 8, 2010, Elazig earthquake (Mw 6.1) that occurred in the rural area between Elazig and Bingöl and caused the loss of around 45 lives. The EAFZ segment in the Elazig area had also ruptured with an estimated magnitude 7.0 or 7.2 in 1789 causing extensive loss of life. Only five strong earthquakes occurred within a 250 km radius of the first (Mw 7.8) February 6 event since 1900 (see Table 6).

Table 6: A selection of (not comprehensive) important earthquakes between Adana and Elazig around the East Anatolian Fault System since 1900

Date / UTC Time	Nearest Place	Location	Magnitude	Source
1905-12-04 07:05:30	Malatya	38.15°N 38.65°E	6.8	USGS
1945-03-20 07:58:52	Adana	37.24°N 35.86°E	6.1	USGS
1986-05-05 03:35:38	Adıyaman	37.99°N 37.81°E	6.1	USGS
1998-06-27 13:55:52	Adana	36.88°N 35.31°E	6.3	USGS
2020-01-24 17:55:14	Elazığ	38.43°N 39.06°E	6.7	USGS

Prior to 1900, the region had been hit by several strong earthquakes over its history. Several major earthquakes occurred in the 19th century near Afrin (1822, Mw7.5), Malatya (1893, Mw7.1) and Elazığ (1874, Mw7.1).

Since the 12th century, several very large earthquakes have been recorded as well in the region. Due to the uncertainty of historic earthquake data, their magnitudes are only estimates but point to a return period of at least 100 years of earthquakes larger than magnitude 7. At least six earthquakes are assumed to have had magnitudes larger than 7.5, similar to the events of February 6, 2023.

Table 7: Large historic earthquakes around the East Anatolian Fault System 1800-1900.

Date / Local Time	Nearest Place	Location	Magnitude	Source
1822-08-13 20:40	Afrin	36.7°N 36.9°E	7.4	GHEA
1872-04-03 07:40	Hatay	36.4°N 36.5°E	7.2	GHEA
1874-05-03 07:00	Elazığ	38.5°N 39.5°E	7.1	GHEA
1893-03-02 22:51	Malatya	38°N 38.3°E	7.1	GHEA

Table 8: Large historic earthquakes around the East Anatolian and Dead Sea Fault Systems before 1800.

Date / Local Time	Nearest Place	Location	Magnitude	Source
1114-11-29	Maraş	37.6°N 37.2°E	7.4 - 7.8	GHEA, Megraoui (2015), Naji, et al. (2020)
1157-08-12	El-Ghab	35.4°N 36.6°E	7.2 - 7.8	GHEA, Megraoui (2015)
1170-06-29	Missyaf / Homs	34.8°N 36.4°E	7.3 - 7.7	GHEA
1202-05-20	Syria	34.1°N 36.1°E	7.2 - 7.6	GHEA
1344-01-02	Aleppo / Gaziantep	36.7°N 37.4°E	6.8 - 7.6	GHEA
1408-12-29	Latakia	35.8°N 36.1°E	7.4	GHEA
1513	Maraş	37.8°N 37.5°E	7.4	GHEA, Naji et al. (2020)
1626-01-21	Aleppo	36.5°N 37.1°E	7.3	GHEA
1759	Damascus	33.7°N 35.9°E	7.4 - 7.5	GHEA

A1.2 Aftershocks

For large earthquakes, as occurred on February 6, 2023, major aftershock sequences are a common occurrence. According to KOERI data, far more than 200 aftershocks with magnitudes larger than 4 have been observed along the whole rupture line from Antakya to Malatya, but also some smaller triggered events in the vicinity of the larger fault system near Elazig, and also in Lebanon and Palestine.

Both large earthquakes triggered their own aftershock sequence, which overlapped. More than 20 aftershocks were stronger than magnitude 5, making them a significant threat, especially to any pre-damaged structures. The strongest aftershock occurred just 10 minutes after the first Mw7.8 earthquake and had a magnitude of Mw6.7. This is in line with the usually expected largest aftershock being about 1 magnitude smaller than its respective mainshock. **However, the occurrence of similarly large aftershocks during the next weeks and months cannot be ruled out. The aftershock sequence is expected to go on for the next couple of months with a decreasing frequency.** The magnitude 6.3 earthquake on February 20, 2023, in the area of Hatay is a reminder of this risk.

A1.3 Surface Displacement and Fault Ruptures

The earthquake sequence in Türkiye caused widespread destruction in Türkiye and Syria with large surface displacements. As news of the earthquake events began to spread, scientists around the world began processing, analyzing and interpreting satellite data in order to support the assessment of the impact of the twin earthquakes. Scientists from the U.K. Centre for Observation and Modelling of Earthquakes, Volcanoes & Tectonics (COMET) analyzed satellite images before and after the two devastating earthquakes and discovered two large faults in the earth's crust. Figure 9 shows (1) the east-west displacement and (2) the north-south displacement derived from pixel tracking on Sentinel-2 imagery.

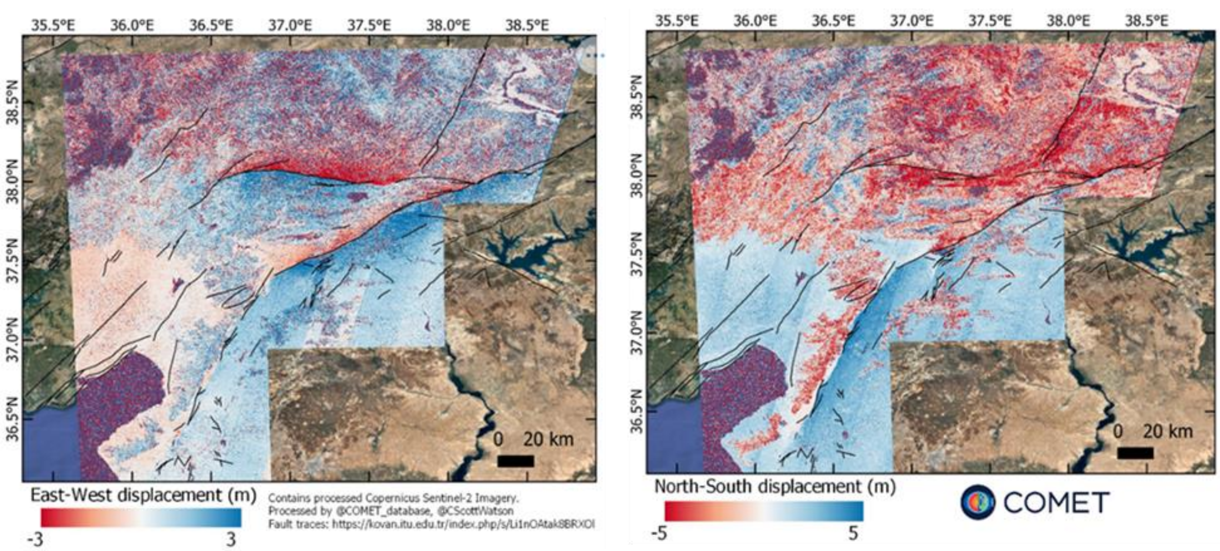

Figure 9: Surface displacement in (1) east-west and (2) north-south direction derived from pixel tracking using Sentinel-2 pre- and post-event imagery. Source: Watson (2023).

Maps that were produced using pixel offset or tracking are useful to measure surface slip, localize earthquake surface ruptures and to estimate the distribution of damages to better understand earthquake disasters. In Figure 9, two large surface displacements can be observed. The longer surface displacement rupture along the East Anatolian Fault in northeastern direction from the tip of the Mediterranean Sea was caused by the first of the two major earthquakes. It is about 300 km long. The second smaller surface displacement rupture is about 125 km long and was created by the second earthquake that occurred about nine hours later. According to Prof. Tim Wright, COMET team lead, the length of these two cracks indicates the large amount of energy that was released during the twin earthquake events; stronger earthquakes form larger and longer faults. The analysis of the COMET researchers shows horizontal displacements of up to 5 m (Pultarova, 2023).

The earthquakes caused movement of tectonic plates such that the fault ruptures were clearly visible on the surface. They passed through cities, streets and in some cases through buildings and houses. The General Directorate of the Mineral Research & Exploration of Türkiye (Turkish: Maden Tetkik ve Arama Genel Müdürlüğü, commonly known as MTA) carried out field investigations in several locations of Gaziantep and Hatay provinces in the southeastern region of Türkiye. Several slips and displacements caused by fault ruptures on roads, agricultural fields, garden walls and railways were detected (see Figure10).

Figure 10: Examples of visible surface ruptures along roads and railways captured during field investigations in southeastern *Türkiye*. Source: MTA (2023).

According to the examinations and findings of the MTA team, several displacements and fault ruptures expanding up to 4.5 m were visible on roads, railways, fields and in stone walls.

A1.4 Additional Methodology Undertaken for the Earthquake Assessment

For this analysis, hazard footprint datasets and shaking intensity maps were developed based on recorded ground shaking and remote sensing damage assessments. These estimates were checked against ground truthing of the shaking and modified where needed. It was found that, due to the nature and uncertainty of the fault rupture, a pure Shakemap-style methodology could not be used, and thus other felt reports, response spectra from TADAS via AFAD, and damage observations were used to develop bespoke maps for this assessment. Modified seismic intensity maps were produced based on response spectra-based intensity.

In addition, the fact that two major earthquakes hit part of the affected region, meant that modelling of the additional damage was required via hybrid vulnerability and fragility functions. Both ground-based and satellite images and social media feeds were used to derive a composite spatial damage distribution analysis. Technical aspects of the modelling are included in the annex.

A1.5 Building Damage Assessment Summary

Building damage assessments following earthquake disasters are a crucial post-disaster recovery action, especially during the acute phase, as they provide the necessary degree of confidence among citizens as to the state/safety of the buildings they occupy and give the authorities the information needed for the following stages of recovery. These visual damage assessments are carried out quickly to determine how much the building stock has been affected and are not meant to determine how resistant a building is to earthquake shaking. Visual inspection from outside and, if necessary, inside the building are being carried out. Damages and defects in the building that may have occurred before the earthquake are not evaluated (if prior damage can be discerned from damage caused by this event).

Damage surveys conducted by more than 7,328 Turkish engineers and experts, including 400 professors and associate professors from more than 20 universities, began soon after the event and focused first on the worst affected cities in the 11 affected provinces declared as “disaster zones”. Local technical universities and technical chambers are also involved in the process, including structural/civil engineering students. Many volunteer civil engineers from different institutions and organizations who wanted to take part in the building damage assessment studies were evaluated and, after training, were sent to regions determined according to the needs. This tremendous effort is coordinated by the General Directorate of Construction of the Ministry of Environment, Urbanization and Climate Change.

The inspected buildings are classified in four safety levels:
a) “Heavily damaged or destroyed, need to be demolished urgently” (*Acil-Yikilacak Agir Hasarli*)
b) “Moderately Damaged” (*Orta Hasarli*)
c) “Slightly Damaged” (*Az Hasarli*) and
d) “Undamaged” (*Hasarsiz*)

Buildings that have been damaged beyond repair and cannot be reused are rated as **“Heavily damaged or destroyed, need to be demolished urgently”**. This category includes buildings in which the structural elements are permanently displaced and partially or completely destroyed, as well as buildings in which there are wide and widespread shear cracks/separations in the load-bearing elements of the structure and are considered to have sustained irreparable loss of load bearing capacity and irreversible (in terms of strength and economy) damage. These buildings will be demolished soon after the damage assessment process is completed. Removal of contents is also not permitted. It will be possible to construct new housing for the owners/tenants of heavily damaged buildings within the scope and conditions of Law No. 7269.

"Moderately damaged" buildings are those that have been damaged to such an extent that they will require repair and strengthening, exhibiting cracks in the walls of the building and thin cracks in the load-bearing elements. It is not allowed to use such buildings without strengthening. It is also possible that a second level, more detailed damage assessment will follow for some "Moderately Damaged" buildings for the final decision on whether to demolish or repair/strengthen. The decrease in the bearing capacity must be eliminated or the structure cannot be used before it is strengthened. Therefore, entry to these buildings is not permitted until this process has been finalized.

Buildings that have no damage to their structural system but have damage such as cracks on their non-bearing walls, plaster cracks, and paint/coating spills are rated as **"Slightly damaged"**. Those who wish can return to the buildings that are determined as undamaged and slightly damaged.

Following the completion of the damage assessment, citizens can enter their address and ID numbers, see the damage assessment of their house via e-Government, and access information on the subject. It can thus be determined whether the building is classified as heavily damaged, moderately damaged, slightly damaged, or undamaged, by making an address query with its identification number from the "hasartespit.csb.gov.tr" web address. On the damage assessment screen, the citizens are asked for the city, district, neighbourhood, street and building numbers. The results of the damage evaluation reports are available for inspection for 30 days in the mukhtars and/or district governorships.

Detailed data giving the building damage statistics by damage level and district and Mahalle have been assembled for the situation, as of February 15. At that point, around 387,000 buildings with 1.86 million individual properties had been processed. Note there are also comments in the archive file such as "unable to access" etc. Although incomplete as a % of buildings in a lot of the Mahalles/Districts, this data gave a first pass check of the model results. These data were extracted in order to inform the study summarizing the building damage assessment data for damage-safety level "Heavily damaged or destroyed, need to be demolished urgently" and for the "Slightly damaged" and "Undamaged" buildings combined in each of the 11 provinces and by both the number of buildings inspected and the number of properties they contain. It was not possible to include the safety level "Moderately damaged" in this analysis due to data inconsistencies.

The number of buildings inspected by February 18 was 830,806, containing around 3.273 million individual properties. A detailed breakdown was not released beyond province data, but the number of buildings "to be demolished" was 105,000 containing around 385,000 individual properties/sections/dwellings. Damage surveys are expected to continue for weeks to come to also include locations outside the 11 provinces and possibly to re-visit some of the cases that require more detailed investigation before it is decided if a building will be demolished or not. Therefore, the data presented here are preliminary as the numbers will continue to rise until the damage assessments are completed.

Around 73 percent of buildings of those checked so far can be inhabited with only minor damage (205,086; 24 percent) or no damage (407,786; 49 percent). There are buildings that were unable to be examined for reasons such as no access which make up around 12 - 13 percent of buildings surveyed.

The building damage assessment surveys until late on February 18, 2023, highlight the following key issues:

- So far, according to these inspections, **105,000 buildings containing 385,000 individual properties will have to be demolished and then rebuilt**. It is expected that around two-thirds of the buildings are in the three worst affected provinces of Gaziantep, Hatay and Kahramanmaraş, while another quarter are in Malatya and Adiyaman provinces. In the remaining six provinces there are less than one in ten of the “to be demolished” buildings.
- In terms of damage distribution, **just over 14 percent and 13 percent of the inspected buildings and individual properties are in the “Severely damaged or destroyed, need to be demolished urgently” category.**
- The number of people who will be waiting for the reconstruction of their homes is in excess of 1.2 million, while those waiting for the repair/strengthening of the buildings they resided in (buildings in the “moderately damaged” level) is more than 0.3 million.
- So far, **most of the inspected buildings were in Gaziantep province, followed by Kahramanmaraş and Hatay provinces,** while most of the corresponding individual properties are in Gaziantep province followed by Diyarbakir province.
- **Around five properties correspond to each inspected building** in these two categories, but in provinces like Adana, Diyarbakir and Elazig, this rises to above 10, as damage surveys have so far focused on bigger multi-family apartment buildings. A similar trend is observed for the case of the buildings by the two showcased damage categories.
- The province level building damages have been released sporadically with only total numbers and some individual districts being reported.

Table 9: Building damage inspection statistics in the 11 provinces declared as "disaster areas" (as of a.m. February 19, 2023).

	Total Buildings					Total Independent Sections				
	Heavily Damaged	Moderately Damaged	Slightly Damaged	Undamaged	Total	Heavily Damaged	Moderately Damaged	Slightly Damaged	Undamaged	Total
ADANA	97	462	2,568	9,396	13,141	1,715	10,667	53,986	113,890	**183,448**
ADIYAMAN	13,730	4,338	19,410	18,598	63,452	44,817	17,489	63,737	40,037	**190,693**
DİYARBAKIR	1,110	1,044	10,977	27,334	45,149	8,284	12,106	109,784	226,953	**373,947**
ELAZIĞ	1,036	174	2,176	1,266	4,810	5,193	1,027	21,911	15,401	**44,536**
GAZİANTEP	15,088	5,662	42,945	135,809	228,272	36,620	22,829	252,089	461,926	**842,811**
HATAY	30,112	7,281	36,112	77,107	158,112	123,349	33,351	117,588	169,711	**465,813**
MALATYA	16,870	1,694	17,745	17,333	64,883	62,547	12,098	88,763	54,180	**257,762**
KAHRAMANMARAŞ	22,113	2,208	33,664	45,395	117,801	84,059	12,975	139,406	98,242	**374,218**
ŞANLIURFA	663	829	22,913	30,964	63,428	3,535	5,932	165,453	123,916	**327,130**
KİLİS	1,261	307	4,746	7,918	15,387	1,921	1,629	24,044	25,301	**55,290**
OSMANİYE	3,794	465	11,830	36,666	56,371	12,505	3,472	54,959	80,097	**158,241**
TOTAL	**105,794**	**24,464**	**205,086**	**407,786**	**830,783**	**384,545**	**133,575**	**1,091,720**	**1,409,654**	**3,273,605**

A1.6 Building Code Evolution in Türkiye

Two codes influence the design and construction of reinforced concrete buildings in Türkiye: "TS-500, Building Code Requirements for Reinforced Concrete" (in Turkish, 1985), termed the "building code" in this report, and "Specification for Structures To Be Built in Disaster Areas" (Ministry of Public Works and Settlement 1975, 1997), termed the "seismic code."

The seismic zonation map published in 1996 was underlined by PGA levels estimated through probabilistic seismic hazard analysis (PSHA) for 475 years of the mean return period. This map offered five seismic regions with the corresponding effective peak accelerations. In 1997, the seismic code was modified with the same name of the previous seismic provision. Two years after this revision, a densely populated region of Türkiye was shattered by two disastrous earthquakes: 17th August Kocaeli (Mw7.4) and 12th November Düzce (Mw7.2).

After these earthquakes, the rehabilitation needs of existing buildings led to the review of the 1997 seismic code. In 2007, a new code was released entitled "Specifications for Buildings to be Built in Earthquake Areas" (Soyluk and Harmankaya, 2012). With the advent of earthquake engineering, the studies of the currently used Turkish Building Seismic Code (TBDY 2018) were published in 2018 and made effective in 2019.

When compared to the previous code, one of the major amendments made was in the definition of earthquake design loads. Rather than a seismic zonation map, a georeferenced based contour map was presented and gives PGA, PGV and spectral accelerations for different earthquake ground motion levels. To construct the design spectrum, firstly, spectral accelerations for the periods of 0.2s and 1.0s are identified for a specific coordinate for referenced stiff soil sites from interactive Turkish earthquake hazard maps (Sucuoğlu et al., 2020).[34]

A1.7 Response Spectra

The figures in this section of the report compare the elastic design spectra for construction on local soil classes ZC (Very Dense Sand / Hard Clay) and ZD (Medium sand / Stiff clay) according to the seismic design code in Türkiye (2019) against spectral acceleration recordings from various stations in Antakya, Hassa, Nurdagi and Kahramanmaraş[35]. The comparisons are made using AFAD station data for the following earthquake events:

1. Magnitude 7.7 ***mainshock*** occurring on 06/02/23 at 01:17 UTC.
2. Magnitude 5.6 ***aftershock*** occurring on 06/02/23 at 01:26 UTC.
3. Magnitude 6.6 ***aftershock*** occurring on 06/02/23 at 01:28 UTC.
4. Magnitude 5.7 ***aftershock*** occurring on 06/02/23 at 01:36 UTC.
5. Magnitude 5.6 ***aftershock*** occurring on 06/02/23 at 02:03 UTC.
6. Magnitude 7.6 ***aftershock*** occurring on 06/02/23 at 10:24 UTC.

It is noted that during the mainshock, the recorded ground motion exceeded the design level at all locations except in the case of Nurdağı, where data was only available from one station. Therefore, buildings designed to behave elastically according to this code would not have performed well. Spectral accelerations from the aftershock earthquakes are smaller than those from the mainshock earthquake.

The below figures are derived by the World Bank GPDRA team and compare the accelerations to which code-compliant buildings will have been built (shown by the elastic response spectra), with the accelerations they actually experienced. Where accelerations have exceeded the elastic response spectrum, we expect that buildings will behave plastically, exhibiting cracking and residual deformations. Whether the building will collapse depends on a number of factors such as the duration and frequency content of shaking, and the level of ductility capacity that has been designed/built into the structure. Of course, where buildings have not been designed/built to code, then damage may be expected to occur even where accelerations are within the design levels.

[34] EEFIT Mission Report: Aegean 30 October 2020, https://www.istructe.org/resources/report/eefit-mission-report-aegean-30-october-2020/

[35] It should be noted that at the time of producing this report, access to the https://tdth.afad.gov.tr/ website was not obtainable. Ss and S1 coefficients required to produce the design spectra at the various station locations were taken from tabulated values provided at a 0.1-degree latitude and longitude grid. Values for the coefficients were taken from the closest coordinate to the AFAD stations.

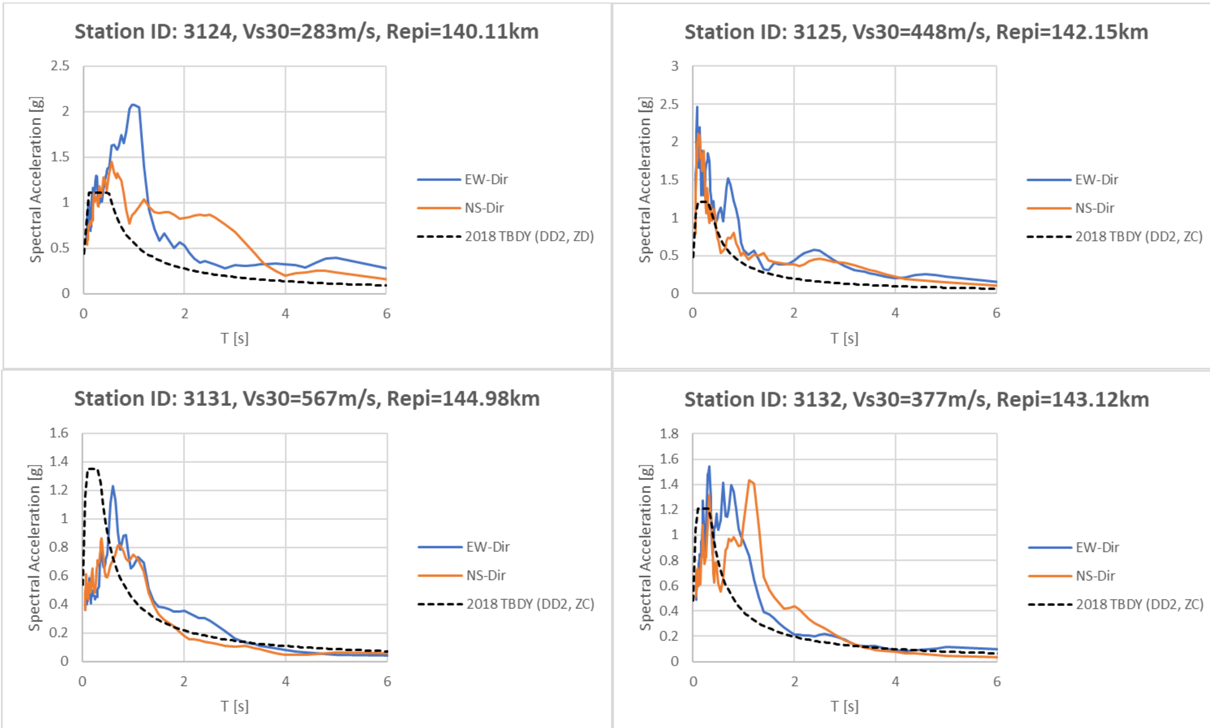

Figure 2: Plots comparing the EW and NS components of spectral acceleration at various stations in Antakya to the horizontal elastic response spectrum according to the seismic design code in Türkiye (2019). Recordings relate to the magnitude 7.7 earthquake occurring on 06/02/23 at 01:17 UTC.

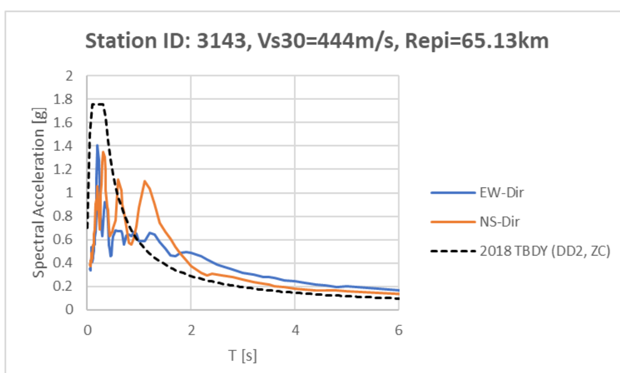

Figure 3: Plot comparing the EW and NS components of spectral acceleration at a station in Hassa to the horizontal elastic response spectrum according to the seismic design code in Türkiye (2019). Recordings relate to the magnitude 7.7 earthquake occurring on 06/02/23 at 01:17 UTC.

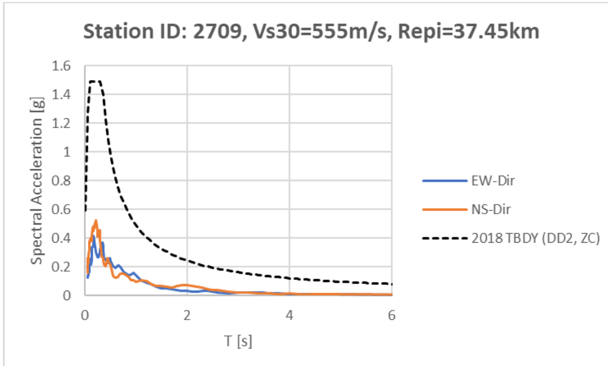

Figure 4: Plot comparing the EW and NS components of spectral acceleration at a station in Nurdagi to the horizontal elastic response spectrum according to the seismic design code in Türkiye (2019). Recordings relate to the magnitude 7.7 earthquake occurring on 06/02/23 at 01:17 UTC.

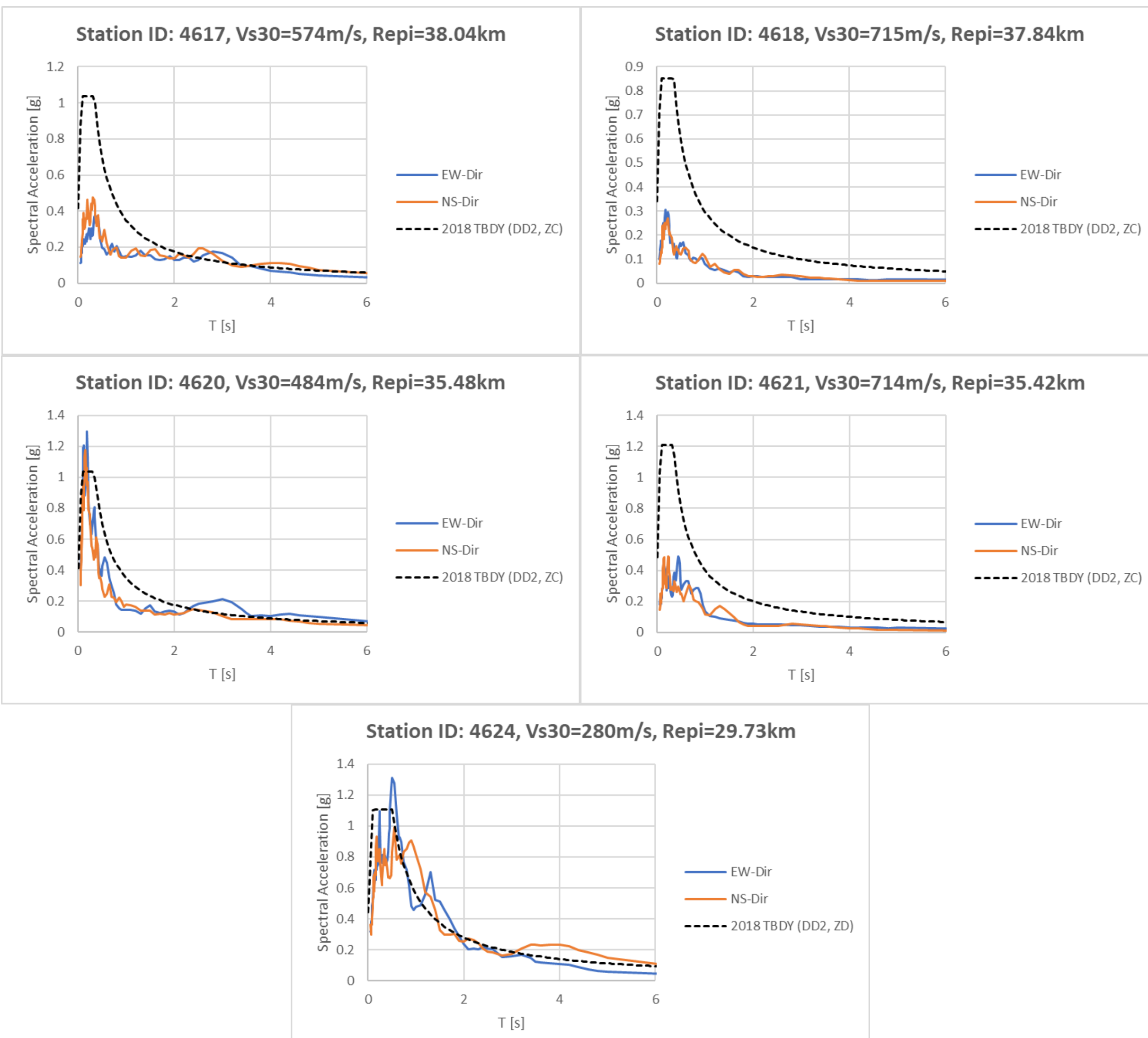

Figure 5: Plots comparing the EW and NS components of spectral acceleration at various stations in Kahramanmaras to the horizontal elastic response spectrum according to the seismic design code in Türkiye (2019). Recordings relate to the magnitude 7.7 earthquake occurring on 06/02/23 at 01:17 UTC.

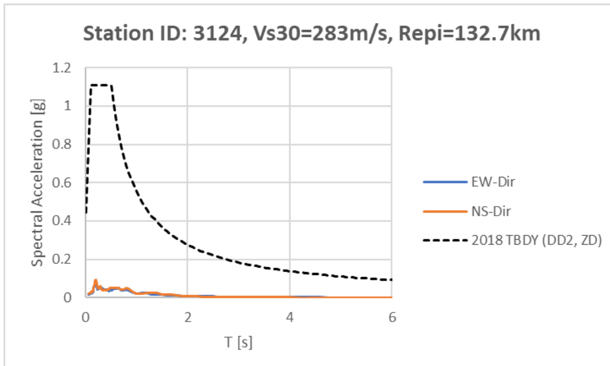

Figure 6: Plot comparing the EW and NS components of spectral acceleration at a station in Antakya to the horizontal elastic response spectrum according to the seismic design code in Türkiye (2019). Recordings relate to the magnitude 5.6 earthquake occurring on 06/02/23 at 01:26 UTC.

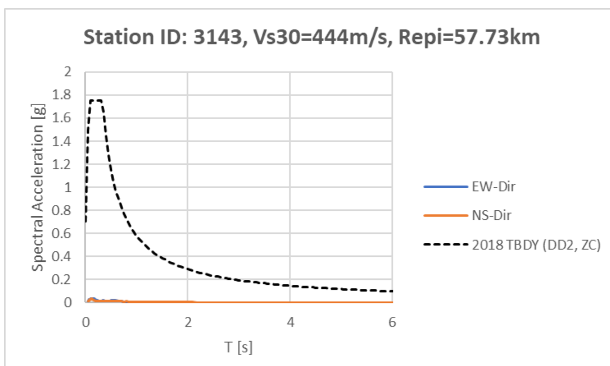

Figure 7: Plot comparing the EW and NS components of spectral acceleration at a station in Hassa to the horizontal elastic response spectrum according to the seismic design code in Türkiye (2019). Recordings relate to the magnitude 5.6 earthquake occurring on 06/02/23 at 01:26 UTC.

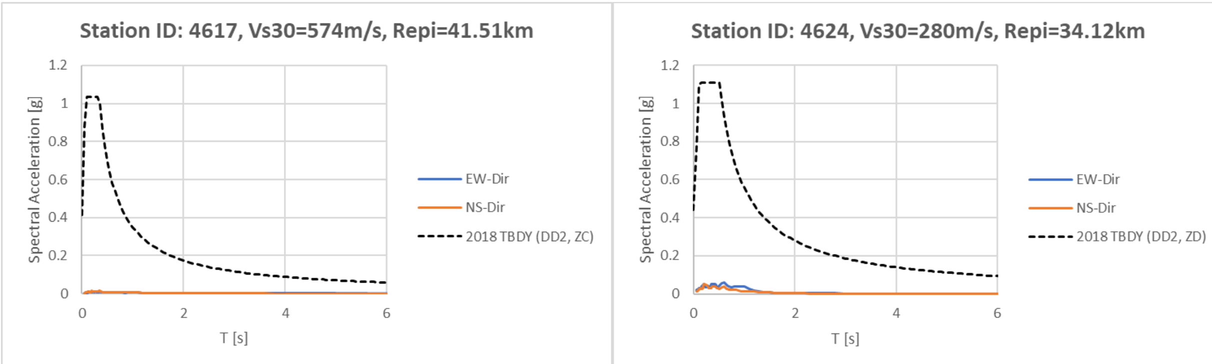

Figure 8: Plots comparing the EW and NS components of spectral acceleration at various stations in Kahramanmaras to the horizontal elastic response spectrum according to the seismic design code in Türkiye (2019). Recordings relate to the magnitude 5.6 earthquake occurring on 06/02/23 at 01:26 UTC.

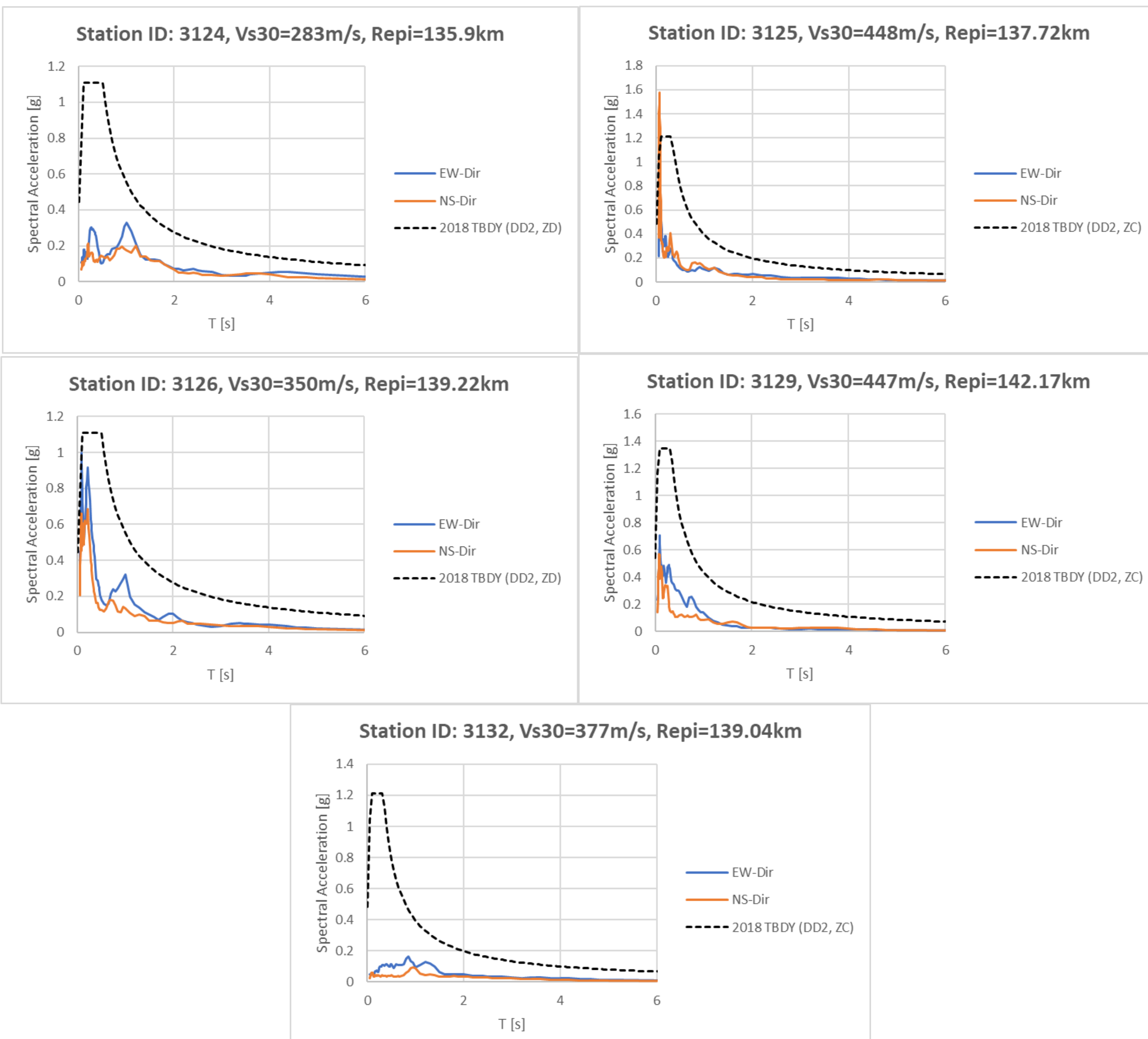

Figure 9: Plots comparing the EW and NS components of spectral acceleration at various stations in Antakya to the horizontal elastic response spectrum according to the seismic design code in Türkiye (2019). Recordings relate to the magnitude 6.6 earthquake occurring on 06/02/23 at 01:28 UTC.

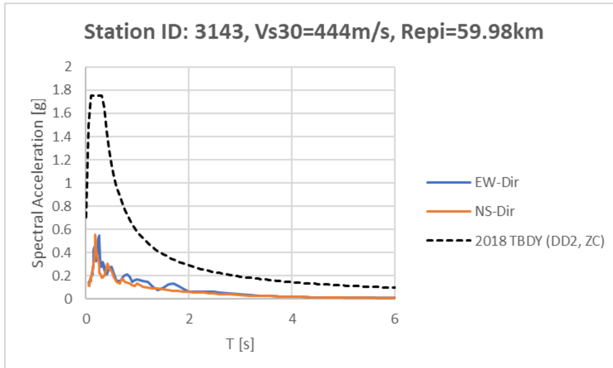

Figure 10: Plot comparing the EW and NS components of spectral acceleration at a station in Hassa to the horizontal elastic response spectrum according to the seismic design code in Türkiye (2019). Recordings relate to the magnitude 6.6 earthquake occurring on 06/02/23 at 01:28 UTC.

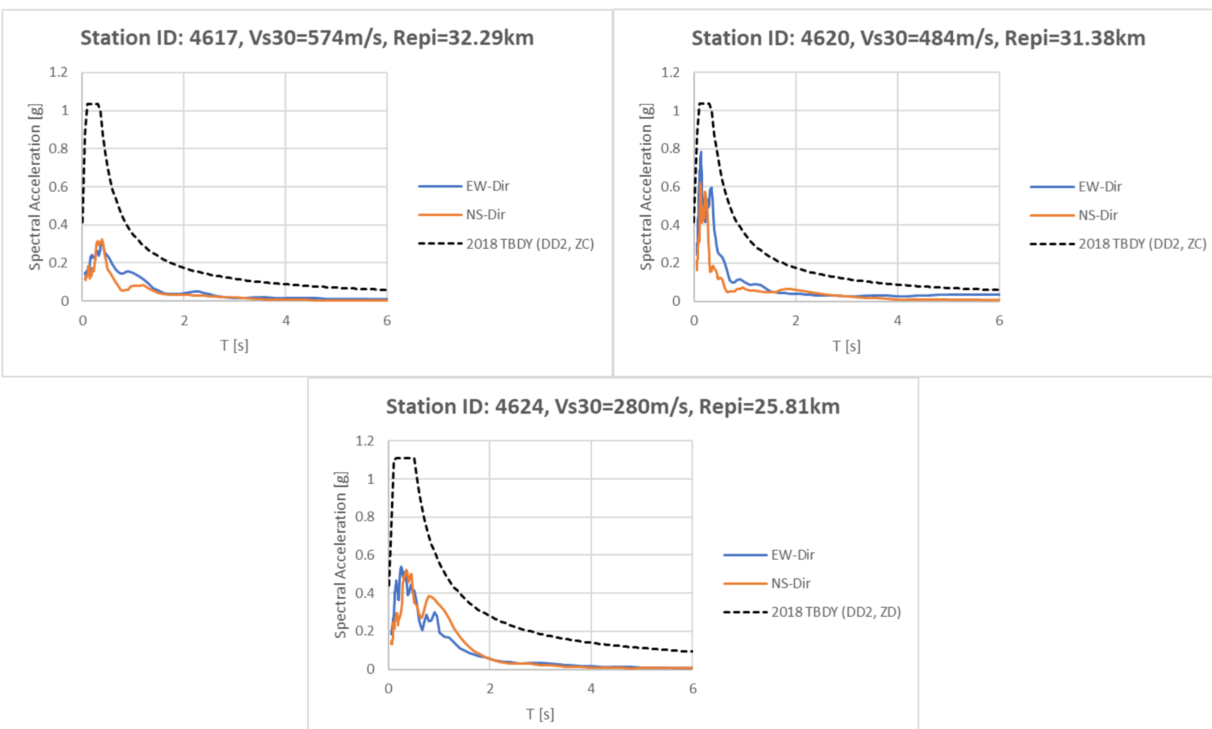

Figure 11: Plots comparing the EW and NS components of spectral acceleration at various stations in Kahramanmaras to the horizontal elastic response spectrum according to the seismic design code in Türkiye (2019). Recordings relate to the magnitude 6.6 earthquake occurring on 06/02/23 at 01:28 UTC.

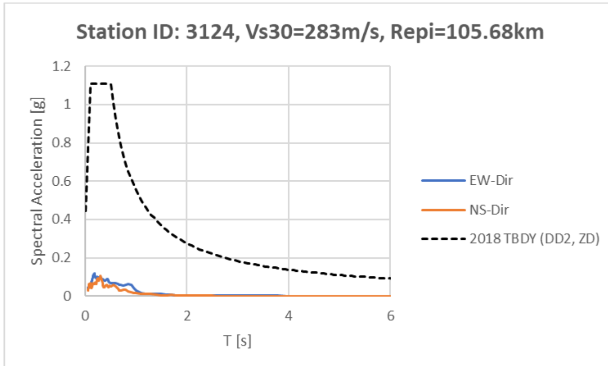

Figure 12: Plot comparing the EW and NS components of spectral acceleration at a station in Antakya to the horizontal elastic response spectrum according to the seismic design code in Türkiye (2019). Recordings relate to the magnitude 5.7 earthquake occurring on 06/02/23 at 01:36 UTC.

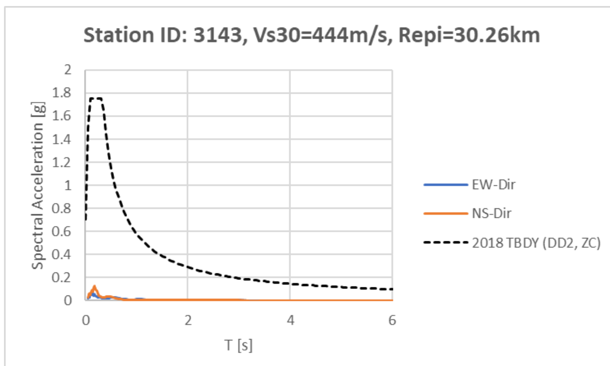

Figure 13: Plot comparing the EW and NS components of spectral acceleration at a station in Hassa to the horizontal elastic response spectrum according to the seismic design code in Türkiye (2019). Recordings relate to the magnitude 5.7 earthquake occurring on 06/02/23 at 01:36 UTC.

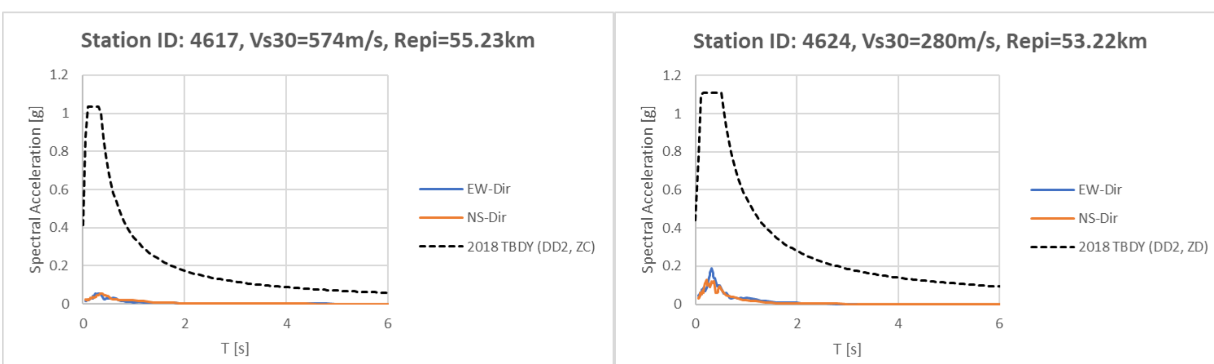

Figure 14: Plots comparing the EW and NS components of spectral acceleration at various stations in Kahmaranmaras to the horizontal elastic response spectrum according to the seismic design code in Türkiye (2019). Recordings relate to the magnitude 5.7 earthquake occurring on 06/02/23 at 01:36 UTC.

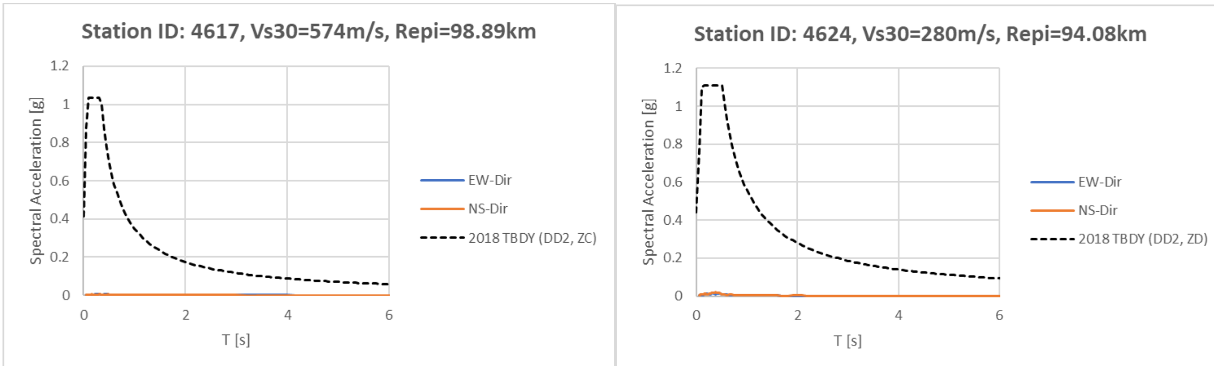

Figure 15: Plots comparing the EW and NS components of spectral acceleration at various stations in Kahmaranmaras to the horizontal elastic response spectrum according to the seismic design code in Türkiye (2019). Recordings relate to the magnitude 5.6 earthquake occurring on 06/02/23 at 02:03 UTC.

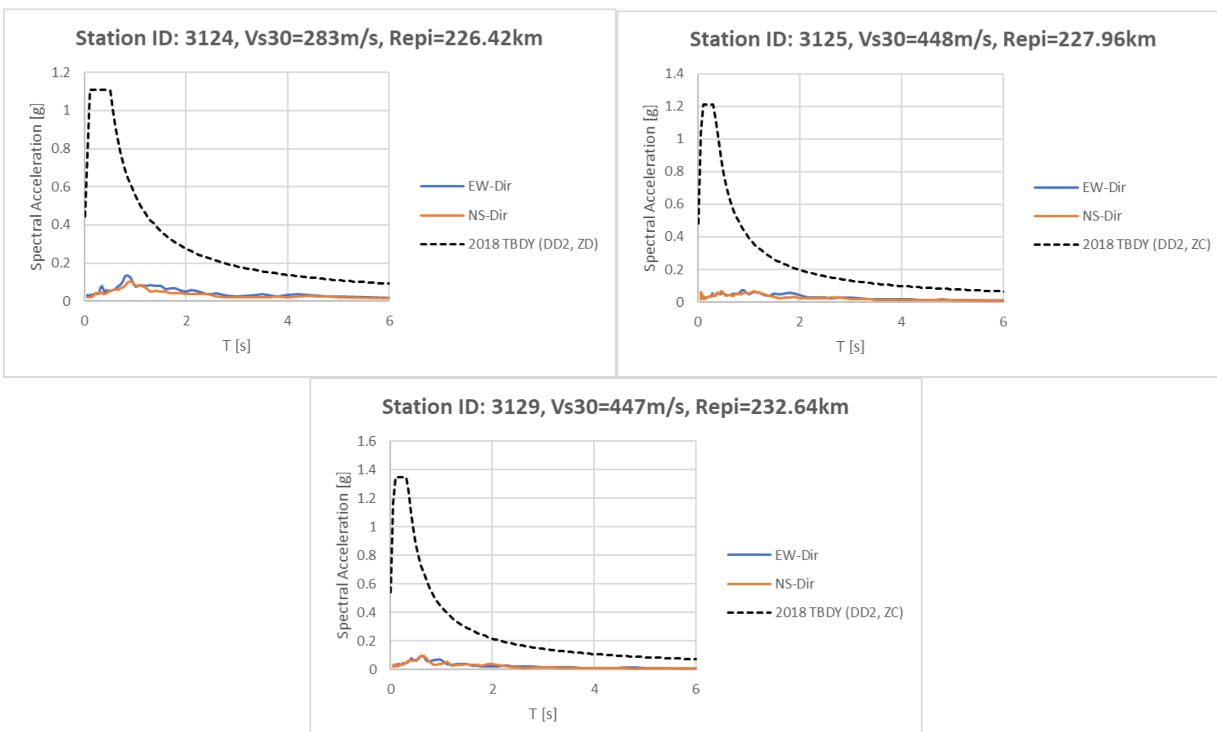

Figure 16: Plots comparing the EW and NS components of spectral acceleration at various stations in Antakya to the horizontal elastic response spectrum according to the seismic design code in Türkiye (2019). Recordings relate to the magnitude 7.6 earthquake occurring on 06/02/23 at 10:24 UTC.

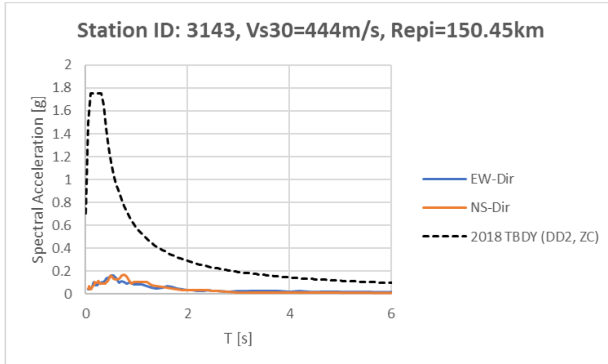

Figure 17: Plot comparing the EW and NS components of spectral acceleration at a station in Hassa to the horizontal elastic response spectrum according to the seismic design code in Türkiye (2019). Recordings relate to the magnitude 7.6 earthquake occurring on 06/02/23 at 10:24 UTC.

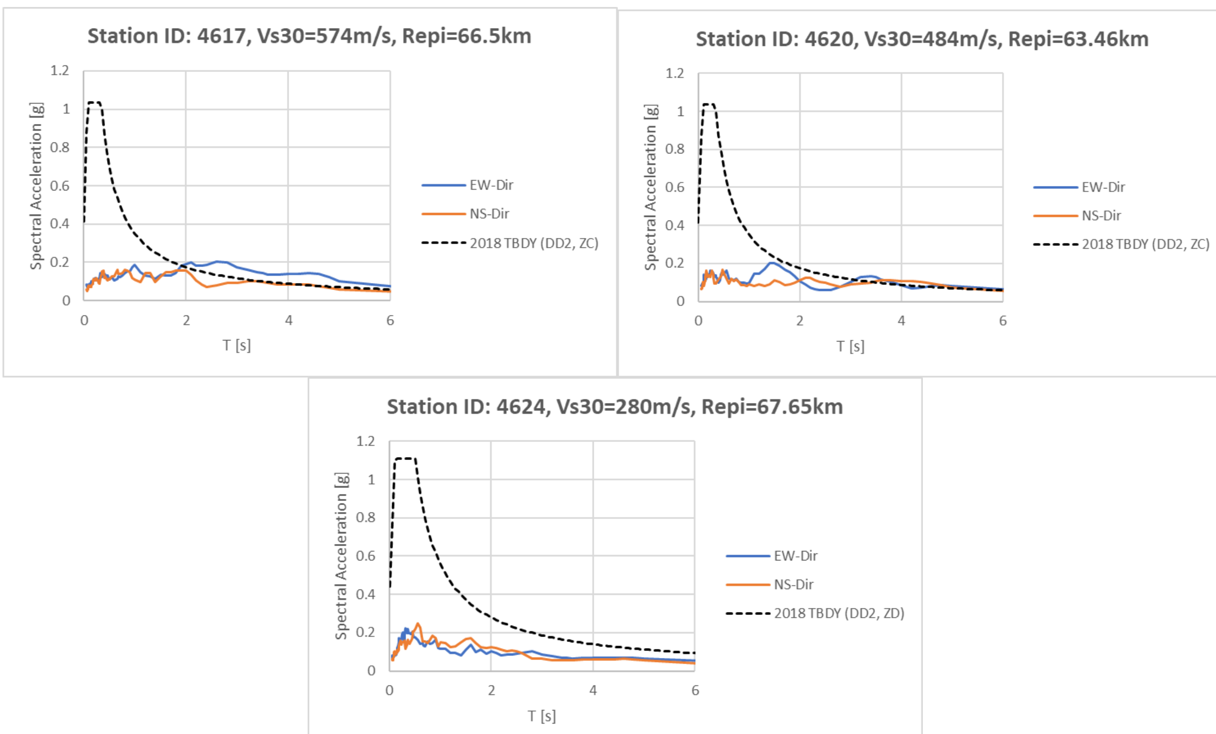

Figure 18: Plots comparing the EW and NS components of spectral acceleration at various stations in Kahmaranmaras to the horizontal elastic response spectrum according to the seismic design code in Türkiye (2019). Recordings relate to the magnitude 7.6 earthquake occurring on 06/02/23 at 10:24 UTC.