Brilliant Engineering 3 (2020) 22-26

Brilliant Engineering

www.acapublishing.com

RESEARCH ARTICLE

The Ground-Motion Attenuation Comparison: A case study for the 2017/05/11 Askale earthquake (Mw4.7)

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Abstract

Turkey is located on the Mediterranean-Himalayan seismic belt, which is the second largest earthquake zone in the world. Due to the fact that Erzurum basin is located in the Eastern Anatolia Region, it has a very complex structure in terms of its geological, tectonic and morphological features. Erzurum has been affected by destructive earthquakes throughout history. Some of these are Erzincan earthquake (26 December 1939), Horasan-Narman earthquake (30 October 1983), Spitak-Armenia earthquake (7 December 1988). In this study, the acceleration data of Erzurum-Aşkale (Mw=4.7) was used in order to estimate the peak ground acceleration using attenuation relationships. Attenuation relationships are important to determine how the peak ground acceleration decreases with distance. The data was recorded at twenty accelerometers in and around Erzurum. Peak ground accelerations were estimated according to Sadigh et al. (1997), Ambraseys et al. (1996), Kalkan and Gülkan (2004) attenuation relationships. As a result of calculations and comparisons, attenuation relationship of Sadigh et al. (1997) has found to be appropriate to the acceleration values recorded in the stations and has given the best results for the different soil types.

Keywords: The peak ground acceleration, attenuation relationship, intensity, earthquake, seismic hazard

1.Introduction

Turkey is located in the Alpine-Himalayan seismic belt generally under the influence of Arabian and Eurasian plates. As a result of the movement of these plates, many tectonic structures with different mechanisms have been formed and it still continues to develop in and around Turkey. The most important zones of these tectonic structures are the North Anatolian Fault Zone(NAFZ), East Anatolian Fault (EAF), Bitlis Thrust Zone (BTZ), and Northeast Anatolian Fault Zone (NEAFZ). Destructive earthquakes have occurred on these faults.

Erzurum is located on the Eastern Anatolian Tectonic Block [1-2]. Destructive earthquakes occurred in and around Erzurum in both historical and instrumental periods. Some of these are Erzincan earthquake (26 December 1939), Caldiran earthquake (24 November 1976) Horasan-Narman earthquake (30 October 1983), Spitak-Armenia earthquake (7 December 1988) and Tabanlı (Van) earthquake (23 October 2011)[3]. Furthermore, the shallow-depth earthquake (Mw = 5.6, h=10 km) occurred in the town of Askale, Erzurum on March 25, 2004[4].

In this study, the acceleration records of the earthquake (Mw=4.7, 11.05.2017) were examined with this motivation. Acceleration records were obtained from the website of the Ministry of Interior Disaster and Emergency Management Presidency (AFAD). Earthquake records of a region are important data used to evaluate the seismic activity and to determine the design standards of the structures in the related region. The peak ground acceleration (PGA) of an earthquake is one of the most important parameters which defines the earthquake [5]. To determine the impact of an earthquake, peak ground acceleration measures have been widely used. These measures are mostly associated with the significant properties of the strong ground motion amplitudes [6]. The reliability of such studies is possible with the increase in the number of quality earthquake data. Due to the increase in the number of data and the development of analysis techniques, the proposed equations will also be revised and updated. However, by reducing some important uncertainties, more sensitive results can be obtained for future updates [7].The most common use of relationships between measured ground motion parameters and magnitudes is to prepare numerical earthquake maps. These maps indicate the area affected by an earthquake and indirectly provide guidance for rapid assessment of structural damage. ShakeMap is a software used to prepare numerical intensity maps, which is effectively used in many parts of the world for disaster management and rapid response purposes. Such programs use attenuation relationships to create the map. As a result, different acceleration values will be observed according to the soil characteristics in the areas affected by the earthquake. Therefore, such relationships need to be selected in accordance with regional datasets.

In this study, the peak ground accelerations recorded at the stations were obtained and the PGA map of this earthquake was prepared. Also, the estimated acceleration values were obtained using attenuation relationships and compared with the acceleration values recorded at the stations. Above all, suitable attenuation relationship was determined for Erzurum province.

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Received 03 Feb 2020 Revised 10 March 2020 Accepted 11 March 2020
Brilliant Engineering 2 (2020) 22-26
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https://doi.org/10.36937/ben.2020.003.004

2. Seismicity of the study area

The epicenter of the earthquake that occurred on 11.05.2017 was near Askale Fault (Figure 1). The magnitude of the earthquake was reported as M_W= 4.7 by AFAD (40.705^{0}D-40.0566^{0}K). The focal depth of the earthquake was around 6 km and it was a shallow earthquake. Also, the earthquake was felt in Erzurum and its districts. Erzurum is located on the second seismic zone according to the Turkey Earthquake Regions Map (Figure 2a). "Turkish Building Earthquake Code [4]" entered into force on 01.01.2019 and the earthquake hazard maps have been updated. The earthquake hazard for Erzurum has significantly increased after this update (Figure 2b). Although the acceleration value for Erzurum was 0.30 g according to the 1996 map, it now varies between 0.40-0.50 g according to the new hazard map (Figure 2b). For this reason, local soil conditions should be determined in detail during the construction studies for Erzurum. A moderate earthquake with the magnitude of Mw 5.6 occurred on March 25, 2004 at approximately 17 km east of the Askale town in Erzurum. Three days after this earthquake, a medium-sized (Mw = 5.5) and shallow-depth (h = 5 km) earthquake occurred on March 28, 2004, at 06.51 (local time). Both earthquakes were felt in an area covering the center of the city, Aşkale, Ilıca, Çat, Kandilli districts and a number of villages in the same region. As a result of these earthquakes, especially in the villages around Askale, nine people lost their lives, and 1300 buildings were severely damaged [4].

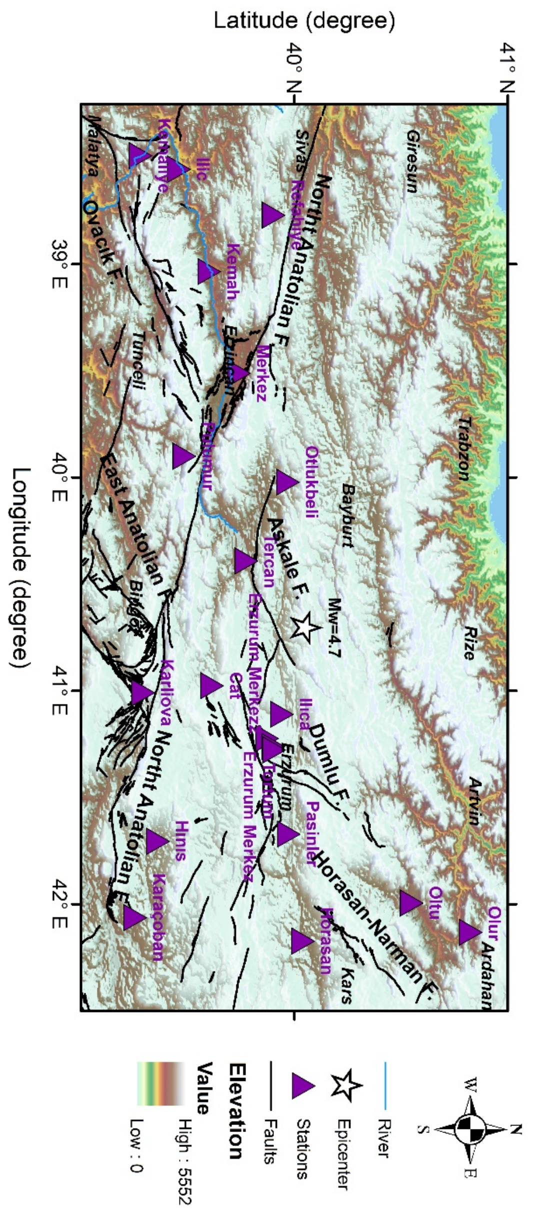

Figure 1. The active faults, epicenter and strong ground motion stations in the study area (Active faults data was taken from MTA [9])

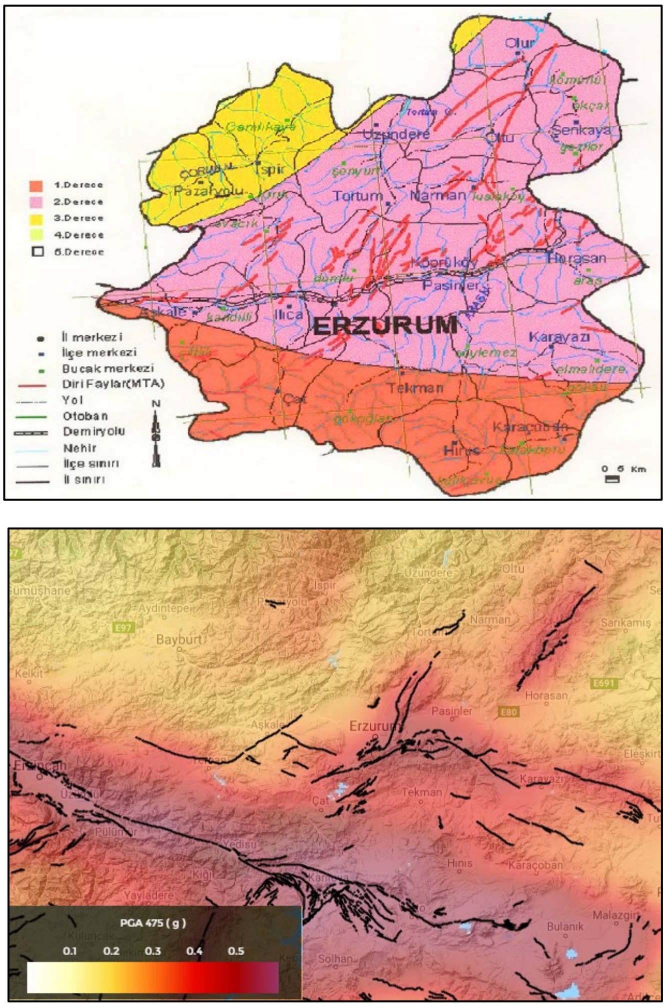

Figure 2. a) Seismic Hazard Situation, based on 1996 Earthquake Zones Map (Turkey Ministry of Public Works and Settlement, 1996) b) Seismic Hazard Situation according to the 2018 Turkey Earthquake Hazard Map [4]

3. Acceleration data used in the study

Twenty acceleration data of the earthquake occurred on 11.05.2017, were used in this study. The location of the stations, their codes, the calculated acceleration values and their distance to the earthquake epicenter have been given in Table 1 [4].

The greatest acceleration value after the earthquake was calculated as 14.21 gal at the station located in Tercan (Erzincan-2407). The distance interval between the stations and epicenter was 41-209 km. The observed peak ground acceleration map has been shown in Figure 3. The maximum acceleration values show their effect in a narrow area around the epicenter location.

Table 1. Information about the stations [4]

No	Station location	Long.	Lat.	PGA (gal)	R_{rup} (km)
1	Cat	40.97	39.62	7.76	54
2	Tercan	40.39	39.78	14.21	41
3	Pulumur	39.89	39.48	1.02	94
4	Karliova	41.01	39.29	1.03	89
5	Ilica	41.11	39.94	9.12	37
6	Erzurum	41.22	39.87	2.69	49
7	Oltu	41.99	40.55	0.29	122
8	Pasinler	41.67	39.97	1.09	83
9	Erzurum	41.26	39.90	5.82	50
10	Tortum	41.27	39.90	1.10	76
11	Horasan	42.17	40.04	0.61	125
12	Karacoban	42.06	39.25	0.36	147
13	Hinis	41.71	39.36	0.76	116
14	Olur	42.13	40.82	0.28	148
15	Kemah	39.03	39.60	0.60	152
16	Refahiye	38.77	39.90	0.31	166
17	Kemaliye	38.49	39.28	0.12	209
18	Ilic	38.55	39.46	0.22	196
19	Erzincan	39.51	39.74	0.45	108
20	Otlukbeli	40.02	39.97	5.70	59

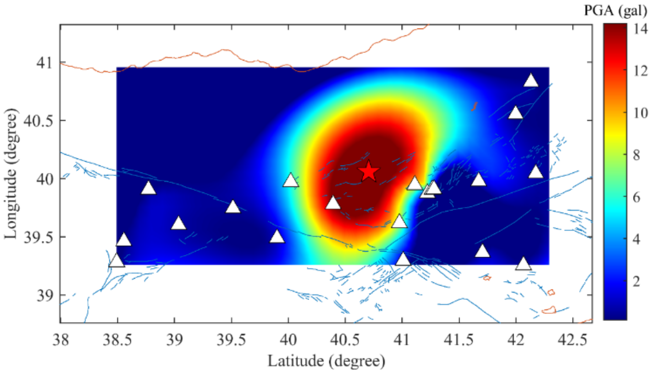

Figure 3. Map of the observed PGA values (The white triangles and red star show the earthquake station and earthquake epicenter; respectively. PGA values and information about stations were obtained from AFAD [4]. The faults (blue thin line) were taken from MTA [9]

4. Attenuation relationship used in the study

Peak ground acceleration (PGA) is an important parameter for earthquake hazard assessments. Therefore, attenuation relationships have been developed for the calculation of PGA. In general, attenuation relationships are expressed as a function of earthquake magnitude and hypocentral distance. In addition, different researchers developed different attenuation relationships using other parameters (soil classification, seismic velocity, etc.).

In this study, peak ground acceleration was obtained by using the attenuation relationships of Kalkan and Gülkan (2004), Sadigh et al. (1997) and Ambraseys et al. (1996) [10-12].

4.1.Kalkan and Gülkan (2004)

Kalkan and Gülkan [10] developed the attenuation relationship in equation 1 using 112 strong ground motion records of 57 earthquakes that occurred between the years 1976 and 2003 in Turkey.

Limitation of boundary values of the database not only constraints but also defines the limits of applicability of any relations. Reliable usage margins of this attenuation relations are as follows: 4.0≤MW≤7.4; the maximum epicentral distance is 250 km.

$$lnY = b_1 + b_2(M-6) + b_3(M-6)^2 + b_5 lnr_{hypo} + b_v \ln(\frac{V_S}{V_A}) \quad (1)$$

where, M: magnitude, b_1=0.393, b_2=0.576, b_3=-0.107, b_4=-0.899, b_v=-0.2, V_A=1112, V_S=the shear wave velocity, and r_{hypo} is hypocentral distance $((r^2+h^2)^{1/2})$.

4.2. Sadigh et al. (1997)

Sadigh [11] developed the attenuation relationship in equations 2 and 3 by using the acceleration recordings of earthquakes in California. This relationship is limited to a minimum of 4 magnitude and a maximum distance of 200 km. For the rock sites, equation 2 is proposed:

$$lny = C_1 + C_2M + C_3(8.5-M)^{2.5} + C_4\ln\big(r_{rup} + \exp(C_5 + C_6M)\big) + C_7\ln(r_{rup}+2) \quad (2)$$

where, C_1=-1.92, C_2=1.11, C_3=0, C_4=-2.1, C_5=-0.4845, C_6=0.524, C_7=0.

For the weak ground sites, equation 3 is proposed:

$$lny = C_1 + C_2M - C_3\ln\big(r_{rup} + C_4e^{C_5M}\big) + C_6 + C_7(8.5-M)^{2.5} \quad (3)$$

where, M=magnitude, r_{rup} is hypocentral distance $((r^2+h^2)^{1/2})$, C_1=-2.17, C_2=1, C_3=-1.7, C_4=0.3825, C_5=0.5882, C_6=0, C_7=0.

4.3. Ambraseys et al. (1996)

Ambraseys [12] developed the attenuation relationship by using the earthquakes occurred in and around Europe. The boundary of the developed relationship is 4.0<M_S<7.5 and the maximum distance is 200 km. The relationship;

$$logy = C_1 + C_2M + C_4logr_{rup} + C_AS_A + C_SS_S \quad (4)$$

where, M=magnitude, r_{rup} is hypocentral distance $((r^2+h^2)^{1/2})$, C_1=-1.48, C_2=0.266, C_4=-0.922, C_A=0.117, C_S=0.124.

SA and SS are coefficients according to the type of soil,
for V_S>750 m/s, SA=0, SS=0,
for 360<V_S≤750 m/s, SA=1, SS=0,
for 180<V_S≤360 m/s, SA=0, SS=1,
for Vs≤180 m/s, SA=0, SS=1.

5.Results and Discussions

Generally, PGA values were obtained from the attenuation relationship for rock conditions. However, researchers have obtained different attenuation relationships by adding some parameters, for example; local soil conditions, fault mechanisms, etc.

In this study Kalkan and Gülkan (2004), Sadigh et al. (1997) and Ambraseys et al. (1996) [10-12] attenuation relationships were used. The soil conditions were discussed in four different groups and the parameters in the related equations were changed.

Using these relationships, four different soil conditions and acceleration values at different distances were calculated for the earthquake with magnitude Mw = 4.7 occurred on 11.05.2017 (Figure 4-7). In addition, stations have been presented on these graphs to determine which relationship fits better with the observed PGA values for this earthquake.

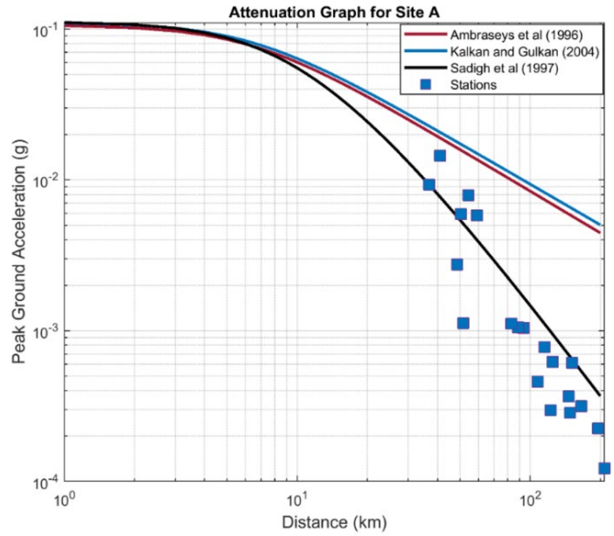

Figure 4. Calculated attenuation relationship for soil type A (Blue squares indicate stations)

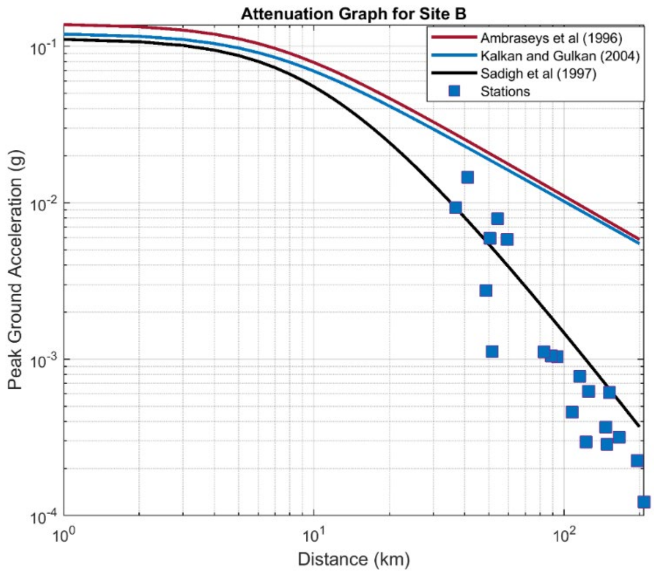

Figure 5. Calculated attenuation relationship for soil type B (Blue squares indicate stations)

The A and B type soil graphs were examined a the maximum acceleration values were obtained in accordance with the Kalkan and Gülkan [10] relation. Moreover, very close values were calculated with Ambraseys [12] equation. The calculated PGA values obtained by using the equation Sadigh [11] are better fit to the observed values in the stations and give the best results according to these types of soil (Figures 4-5).

According to the calculated acceleration values obtained by using Sadigh [11] relation, up to 110 km distance PGA values are higher. But after this distance, the values obtained with the other two equations are higher values for C and D soil type. For these two soil types, Kalkan and Gülkan [10] and Ambraseys [12] show a very similar pattern. In general, the values, calculated according to the equation of Sadigh [11], are close to the acceleration values recorded in the stations and give the best results for these soil types (Figures 6-7).

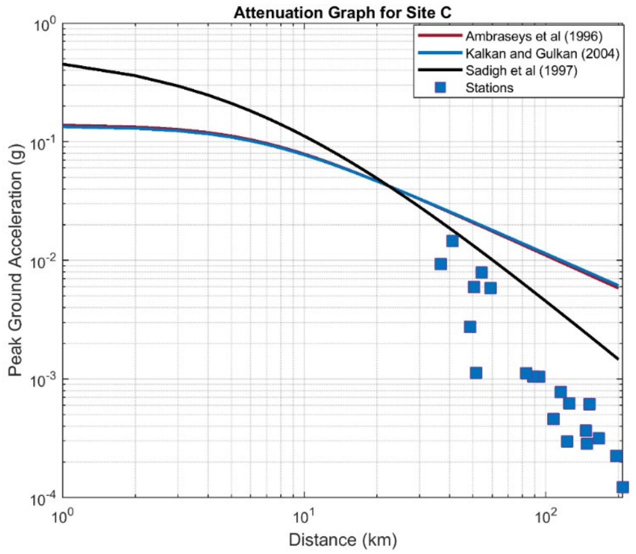

Figure 6. Calculated attenuation relationship for ground type C (Blue squares indicate stations)

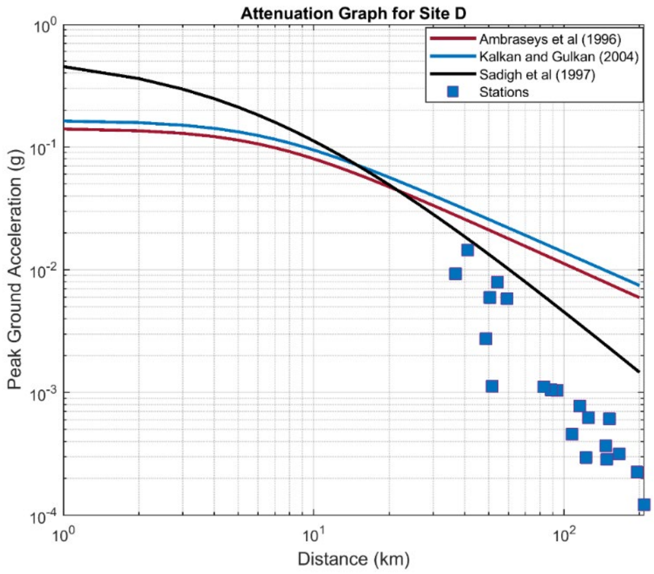

Figure 7. Calculated attenuation relationship for ground type D (Blue squares indicate stations)

6. Conclusions

Turkey is located on a very active seismic region. Therefore, very strong destructive earthquakes have occurred in Turkey and around, and caused loss of lives and properties. In order to respond quickly after these catastrophic events, it is necessary to estimate the damage of the earthquake on the earth. These estimates are usually conduct using the peak ground acceleration or intensity of the earthquake. PGA, one of the strong ground motion parameters, is an instrumental parameter that shows ideally the effect of an earthquake on the earth. Attenuation relations (a function of magnitude, distance, local soil conditions, etc.) were used in order to determine the peak ground acceleration for any region. Kalkan and Gülkan [10], Sadigh [11] and Ambraseys [12] equations were used in this study to understand the feature of the region.

Attenuation relationships are often used in earthquake hazard and risk studies for the rapid detection of earthquake damages. However, since each region has its own unique seismicity characteristics, it is necessary to determine the attenuation relationship which is compatible with that region. Within the scope of this study, the observed and calculated acceleration values for the earthquake that occurred in Aşkale in 2017 were compared using both different soil conditions and different attenuation relationships. This study was the first to compare acceleration values for the 2017 Aşkale earthquake using these attenuation relationships. As a result, Sadigh [11] attenuation relationship is more compatible with the observed PGA values.

Earthquake hazard studies are now carried out with logic tree method using many attenuation relationships and different aggravations. It is clear that the Sadigh [11] relationship can also be used successfully in earthquake hazard and other seismicity studies for this region and it is appropriate to include this relationship in the logic tree.

Acknowledgments

We would like to thank the Ministry of Interior Disaster and Emergency Management Presidency for sharing the data of strong ground motion stations from the website. In addition, the fault data used in the study were compiled from Mineral Research and Exploration General Directorate drawing editor. The authors would like to thank Atatürk University Earthquake Research Center, whose computer infrastructure was used in this study.

Nomenclature

NAFZ: The North Anatolian Fault Zone

NEAFZ: Northeast Anatolian Fault Zone

EAF: The East Anatolian Fault

BTZ: Bitlis Thrust Zone

AFAD: The Ministry of Interior Disaster and Emergency Management Presidency

PGA: The peak ground acceleration

MTA: Mineral Research and Exploration General Directorate

Declaration of Conflict of Interests

The authors declare that there is no conflict of interest.

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